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Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines

EPA

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Office of Air and Radiation
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CHAPTER 1: INTRODUCTION

EPA is setting significantly more stringent standards for emissions of oxides of nitrogen, hydrocarbons, and particulate matter from diesel-cycle engines used in land-based nonroad equipment and in some marine applications.[a] This Final Regulatory Impact Analysis (Final RIA) provides technical, economic, and environmental analyses of the new emission standards for the affected engines. The anticipated emission reductions will translate into significant, long-term improvements in air quality in many areas of the U.S. For engines in this large category of pollution sources, NOx and PM standards are reduced by up to two-thirds compared with current standards. Overall, these requirements provide much needed assistance to states and regions facing ozone and particulate air quality problems that are causing a range of adverse health effects, especially in terms of respiratory impairment and related illnesses.

Chapter 2 contains an overview of the manufacturers, including some description of their engines and equipment, that may be affected by the new requirements. Chapter 3 provides a description of the range of technologies being considered for improving emission controls from these engines, including detailed projections of a possible set of compliance technologies. Chapter 4 applies cost estimates to the projected technologies for several different power categories and contains the Final Regulatory Flexibility Analysis. Chapter 5 presents the calculated reduction in emission levels resulting from the new standards; Chapter 6 compares the costs and the emission reductions for an estimation of the cost-effectiveness of the rulemaking.

Table 1-1 lists the new standards and the affected model years. References in the text of the document to the engine power ratings listed in Table 1-1 identify only the kilowatt rating. The reader may refer to the table for horsepower equivalent ratings. Other values are listed with English units in parentheses.

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[a] Diesel-cycle engines, referred to simply as “diesel engines” in this analysis, may also be referred to as compression-ignition (or CI) engines. These engines typically operate on diesel fuel, but other fuels may be also be used. This contrasts with otto-cycle engines (also called spark-ignition or SI engines), which typically operate on gasoline.

Table 1-1
Emission Standards in g/kW-hr (g/hp-hr)

Engine Power	Tier	Model Year	NMHC+ NOx	CO	PM
kW<8 (hp<11)	Tier 1	2000	10.5 (7.8)	8.0 (6.0)	1.0 (0.75)
	Tier 2	2005	7.5 (5.6)	8.0 (6.0)	0.80 (0.60)
8≤kW<19 (11≤hp<25)	Tier 1	2000	9.5 (7.1)	6.6 (4.9)	0.80 (0.60)
	Tier 2	2005	7.5 (5.6)	6.6 (4.9)	0.80 (0.60)
19≤kW<37 (25≤hp<50)	Tier 1	1999	9.5 (7.1)	5.5 (4.1)	0.80 (0.60)
	Tier 2	2004	7.5 (5.6)	5.5 (4.1)	0.60 (0.45)
37≤kW<75 (50≤hp<100)	Tier 2	2004	7.5 (5.6)	5.0 (3.7)	0.40 (0.30)
	Tier 3	2008	4.7 (3.5)	5.0 (3.7)	
75≤kW<130 (100≤hp<175)	Tier 2	2003	6.6 (4.9)	5.0 (3.7)	0.30 (0.22)
	Tier 3	2007	4.0 (3.0)	5.0 (3.7)	
130≤kW<225 (175≤hp<300)	Tier 2	2003	6.6 (4.9)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	4.0 (3.0)	3.5 (2.6)	
225≤kW<450 (300≤hp<600)	Tier 2	2001	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	4.0 (3.0)	3.5 (2.6)	
450≤kW≤560 (600≤hp≤750)	Tier 2	2002	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	4.0 (3.0)	3.5 (2.6)	
kW>560 (hp>750)	Tier 2	2006	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)

CHAPTER 2: INDUSTRY CHARACTERIZATION

In understanding the impact of emissions standards on regulated industries, the nature of the regulated and otherwise affected industries must be accurately assessed. This chapter characterizes the nonroad engine and equipment industry based on the different manufacturers and their products, the size and degree of vertical integration of the companies, and the diversity of the manufacturer pool for the various types of equipment.

Nonroad engines are generally distinguished from highway engines in one of four ways: (1) the engine is used in a piece of motive equipment that propels itself in addition to performing an auxiliary function (such as a bulldozer grading a construction site); (2) the engine is used in a piece of equipment that is intended to be propelled as it performs its function (such as a lawnmower); (3) the engine is used in a piece of equipment that is stationary but portable, such as a generator or compressor; or (4) the engine is used in a piece of motive equipment that propels itself, but is primarily used for off-road functions.

This category is also different from other mobile source categories because: (1) it applies to a wider range of engine sizes and power ratings; (2) the pieces of equipment in which the engines are used are extremely diverse; and (3) the same engine can be used in widely varying equipment applications (e.g., the same engine used in a backhoe can also be used in a drill rig or in an air compressor).

Nonroad equipment can be grouped into several categories. This Final RIA considers the following seven categories: agriculture and logging, construction, general industrial, lawn and garden, utility, material handling, and small marine. Engines used in locomotives, large marine applications (rated over 37 kW), aircraft, underground mining equipment, and all spark-ignition engines within the above categories are not included in this rulemaking. Table 2-1 contains examples of the types of nonroad equipment regulated by this rulemaking, arranged by category. A more detailed list would include many more entries.

A major challenge in regulating nonroad engines is the lack of vertical integration in this field. Although some nonroad engine manufacturers also produce equipment that rely on their own engines, most engines are sold to various equipment manufacturers over which the original engine manufacturer has no control. A characterization of the industry affected by this rulemaking must therefore include equipment manufacturers as well as engine manufacturers.

Table 2-1
Sampling of Nonroad Equipment Applications

Segment	Applications		
Agriculture	Ag Tractor Baler Combine	Sprayer Swather Other Ag Equipment	Skidder
Construction	Backhoe Bore/drill Rig Cement Mixer Crawler Tractor Excavator Grader	Off-highway Truck Paver Paving Equipment Plate Compactor Roller Rubber-Tired Dozer	Rubber-Tired Loader Scraper Signal Board Skid-Steer Loader Trencher Feller/buncher
General Industrial	Concrete/Ind. Saw Crushing Equipment	Oil Field Equipment Refrigeration/AC	Scrubber/sweeper Rail Maintenance
Lawn and Garden	Garden Tractor	Rear Engine Mower	Chippers/Grinder
Utility	Air Compressor Hydro Power Unit Pressure Washer	Pump Generator Set Aircraft Support	Irrigation Set Welder
Material Handling	Aerial Lift Crane	Forklift Terminal Tractor	Rough-Terrain Forklift
Marine <37 kW	Propulsion	Auxiliary	

I. Characterization of Engine Manufacturers

For purposes of discussion, the characterization of nonroad engine manufacturers is arranged by the power categories used to define the new emission standards. The information detailed in this section was derived from the Power Systems Research database and trade journals.[1] EPA recognizes that the PSR database is not comprehensive, but EPA has not identified a better source to provide consistent data for identifying additional companies.

A. Engines Rated Under 37 kW

In 1995, sales of engines in this category comprised approximately 35% (approximately 182,000 units) of the nonroad market. Emission standards for this category are further separated into three power ranges to provide more appropriate phase-in and standard levels. These ranges are under 8 kW, between 8 and 19 kW, and between 19 and 37 kW.

The largest manufacturers of engines in this category are Yanmar and Kubota. Yanmar Diesel America Corporation markets diesel engines with ratings ranging from 4 to 3700 kW (5 to 5000 hp). Most of their engines are four-cycle, water-cooled direct injection models. Kubota makes diesel engines with ratings ranging from 3 to 70 kW (4 to 90 hp.) Most of their engines are liquid-cooled indirect injection models. Kubota also markets a 16 kW (21 hp) gaseous fueled engine which is designed to meet the new standards.

1. Under 8 kW

In 1995, total sales were 21,000 engines, which is approximately 12% of the market for engines rated under 37 kW. Of these engines, direct injection (DI) diesel engines comprise 90% (approximately 18,900 units) of the market and indirect injection (IDI) diesel engines make up the remaining 10% (approximately 2,000 units). Yanmar has the largest share of the DI market at approximately 41%, followed by Robin America (22%), Lombardini (13%), Lister Petter (10%) and Hatz (7.5%). Other DI manufacturers are Acme, Onan, Farymann, Deutz, Honda, and Ruggerini. The largest selling direct injection engines in this range are used in pumps, generator sets and refrigeration units. Kubota has the largest share of the IDI market with 87%, the remaining 13% being sold by Yanmar. Commercial turf mowers and general industrial engines are the largest selling applications for IDI engines.

2. 8-19 kW

This is the largest category of engines rated under 37 kW, with approximately 101,000 units sold in 1995. IDI engines dominate this category with 81% of the market (82,000 units). Yanmar is the leading manufacturer with 55% of IDI sales and 51% of DI sales. Kubota is ranked second with 36% of the IDI market. Other manufacturers in this category include Mitsubishi, IHI-Shibaura, Perkins, Lombardini, Lister Petter, Deutz, Onan, Acme, Hatz and Teledyne-Wisconsin. The largest selling engines in this category are primarily used in refrigeration units, commercial turf mowers, welders, and generator sets.

3. 19-37 kW

This category comprises the remaining 32% of engines rated under 37 kW, with approximately 58,600 units sold in 1995. There is a fairly even split between IDI and DI engines, with IDI capturing 55% of the market with 32,000 units. Kubota dominates the IDI market with 84 percent of sales, followed by Perkins (7%), Isuzu (3%) and Yanmar (2%). Deutz and Yanmar each have approximately 32% of the DI market, followed by Perkins (10%), Lister-Petter (8%), Hatz (8%), Isuzu (3%) and Onan (3%). As with the smaller power ranges, commercial turf mowers and refrigeration units are the largest selling engines, but skid-steer loader sales are also growing rapidly in this power range.

B. Engines Rated Between 37 and 75 kW

In 1995, approximately 130,000 engines in this power range were sold. This represents the second largest category of nonroad engines with 22% of the total market. Approximately 90% of these engines are DI. Engines used in construction equipment comprise the largest segment in this range. Of the construction segment, the largest selling piece of equipment is the skid-steer loader. The single largest selling engine, however, is that used in refrigeration/air conditioning units.

There are three manufacturers which represent approximately two-thirds of total DI sales: John Deere with 27% of the DI market, followed by Isuzu with 20% and Cummins with 17%. Kubota, Deutz, and Perkins each have approximately 10% of the market. John Deere sells engines with ratings ranging from 16 to 370 kW (21 to 500 hp). John Deere's Power Systems Group has developed engines in Deere's Power Tech Series. Key features of the Power Tech Series engines are a Lucas electronically controlled unit injection system, a cam-in-head engine design, high pressure injection (1500 to 1800 bar (23,000 - 27,000 psi)) and a two-piece articulated steel piston. An option on some engines is an electronic control unit that monitors engine functions through remote-mounted engine sensors, resulting in added performance through improved low-end torque, fuel efficiency and application flexibility due to programmable power curves.

Isuzu makes engines with ratings ranging from 8 to 230 kW (11 to 314 hp). Key features of Isuzu's L series IDI engines are Bosch unit injection pumps, swirl-type combustion chambers, and a single cam-driven overhead valve system to actuate the unit injection pumps and intake and exhaust valves. Isuzu has also expended considerable effort to reduce the overall noise level of these engines.

Cummins manufacturers diesel engines with ratings ranging from 54 to 4500 kW (72 to 6000 hp).[b] Most of Cummins' sales are in midrange engines, which were redesigned for the 1996 model year to achieve greater power density as well as lower noise and exhaust emissions. The new design features include a new Bosch "A" in-line fuel pump that provides injection pressures to 1100 bar (16,000 psi), new three-ring pistons and a new Holset turbocharger for improved performance. More recently, Cummins completed additional design changes for its 6-liter engine to introduce full-authority electronic controls with four valves per cylinder.[2]

In the IDI market, Wis-Con and Isuzu each have approximately a 20% share, followed by PSA (15%), Mitsubishi (15%), and Mazda (10%). Wis-Con sells diesel engines with ratings ranging from 19 to 60 kW (26 to 80 hp).

C. Engines Rated Between 75 and 130 kW

Engines in this power range rank fourth in total nonroad diesel engines sales with approximately 68,000 units sold in 1995. Direct injection engines comprise 94% of this category. The top three manufacturers are Cummins (36%), John Deere (25%), and Caterpillar (17%). Other manufacturers include Perkins, Deutz, New Holland, Detroit Diesel, Hino, Mazda, Volvo, Komatsu, Hercules, Isuzu, and Mitsubishi. The engines in this power range are used mostly in construction equipment such as backhoes, rubber-tired loaders, and forest equipment. The second largest use for these engines is in utility equipment such as air compressors and generator sets.

In this power range, it is expected that engine manufacturers will transfer the technological

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[b] Engine sales by Consolidated Diesel, a subsidiary company that manufactures Cummins engines, are included in the total engine sales for Cummins.

advancements from highway engines to their nonroad counterparts. In fact, Caterpillar, which makes diesel engines with ratings ranging from 60 to 6000 kW (80 to 8000 hp), is already using the Hydraulically actuated, Electronically controlled Unit Injection (HEUI) fuel system with Advanced Diesel Engine Management on some nonroad Tier 1 engines.

D. Engines Rated Between 130 and 450 kW

This is the third largest nonroad category with 1995 sales approaching 107,000 units. Most of the engines in this category are used in agricultural equipment, followed by construction and utility equipment. There are two separate standards in this category: one for ratings between 130 and 225 kW and one for ratings between 225 and 450 kW. As with the previous category, it is expected that manufacturers will utilize highway technology to meet the new standards.

1. 130-225 kW

This market includes about 8 percent IDI engines, but DI engines are dominant. The two largest manufacturers are Cummins (38%) and John Deere (31%). Other major manufacturers include Caterpillar (14%), Navistar (6%), New Holland (4%), and Detroit Diesel (4%). The engines used in agricultural tractors comprise the largest category of equipment, followed by construction equipment such as excavators, crawlers, and rubber-tired loaders.

2. 225-450 kW

The three largest manufacturers in this range are Caterpillar (34%), Cummins (33%), and Detroit Diesel (25%). Other manufacturers include John Deere and Deutz. Engines used in construction equipment (scrapers, crawlers, off-highway trucks) comprise the largest category in this range.

E. Engines Rated Over 450 kW

This is the smallest nonroad category with approximately 3% of the total nonroad market. There are two separate standards for engines rated above and below 560 kW. Caterpillar is the largest manufacturer (46%), followed by Detroit Diesel (27%) and Cummins (26%). Generator sets are the principal application in this range, followed by off-highway trucks and other types of construction equipment.

II. Characterization of Equipment Manufacturers

For purposes of discussion, nonroad equipment is grouped into five power ranges similar to those used for characterizing engine manufacturers. This section explores the characteristics of nonroad equipment applications and the companies involved in manufacturing that equipment. This analysis includes several numerical summaries of different categories. A more detailed treatment is contained in a memorandum to the docket.[3]

In the range of ratings under 37 kW, engines and equipment are manufactured for all the major market segments: agricultural, construction, general industrial, lawn and garden, material handling, utility, and marine. The applications with the most manufacturers in this power range are pumps, generator sets, commercial turf equipment, pressure washers, rollers, skid-steer loaders, and light plants/signal boards. About 14% of the equipment in this power range is manufactured by a single original equipment manufacturer (OEM). There are 58 total applications with engines rated under 37 kW. All market segments are also represented in the 37 to 75 kW range. There are 59 total applications and about 12 % of these are made by a single OEM. The applications with the most manufacturers, in descending order, are generator sets, pumps, rough terrain forklifts, standard forklifts, other general industrial, rubber-tired loaders, drill rigs, rollers, and pavers. The major market segments are also represented in the 75 to 130 kW range. With 54 total applications, less than 8% are manufactured by a single OEM. The equipment pieces with the largest manufacturing diversity (largest number of OEMs) are generator sets, pumps, other general industrial equipment, forest equipment, other agricultural equipment, drill rigs, cranes, rough terrain forklifts, and rubber-tired loaders. The 130 to 560 kW market has the largest number of OEMs producing generator sets, forest equipment, cranes, chippers/grinders, pumps, and excavators. The applications with the fewest number of OEMs (two-wheeled tractors, cement mixers, tillers, gas compressors, and welders) include only a single manufacturer in the database. All of the major nonroad market segments are represented in this power range. The largest engines, those rated over 560 kW, are only produced for the nonroad market segments of construction, general industrial, material handling, and utility equipment. Of the equipment in this power range, those pieces with the largest number of OEMs are generator sets, chippers/grinders, off-highway trucks, and rubber-tired loaders. About 36% of the equipment in this power range is manufactured by a single OEM.

Most equipment manufacturers must buy engines from another company. For most power categories, the PSR OELink database estimates that between 5 and 25 percent of equipment sales are from equipment manufacturers that also produce engines.[4] Equipment with engines rated between 130 and 450 kW have the greatest degree of vertical integration, with over 40 percent of sales coming from these companies. Since vertically integrated manufacturers are typically very large companies, such as John Deere and Caterpillar, the companies that make up this fraction of the market are in a distinct minority.

A. Equipment Using Engines Rated Under 37 kW

Engines rated under 37 kW are predominantly indirect injection (63% of the market) engines that are water-cooled (77% of the market). About 20% and 4% of equipment in this power range uses engines that are air-cooled and oil-cooled, respectively. The six leading manufacturers produce 45% of the equipment in this category. Their collective sales volume over five years (1991 to 1995) was approximately 350,000 pieces of equipment in a market which has a five year total sales volume of 770,000. These manufacturers are shown in Table 2-2.

Of these top six OEMs, their sales are typified by welders, generators, excavators, tractors, commercial turf, and refrigeration/air conditioning units. The uses of the equipment are listed in Table 2-3. These top six manufacturers have engines that are typical of the market. Sixty-three

OEMs produce 90% of the equipment in this horsepower range.

Table 2-2

Characterization of the Top 6 Manufacturers under 37 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Percentage of Market	1991 to 1995 Equipment Sales	Engine Characterization*	Average Annual Sales
Deere & Co.	Commercial Turf, Lawn/Garden Tractors	21%	165,062	W,NA, D/I	33,012
ThermoKing Corporation	Refrigeration, A/C	8%	65,099	W,NA,I	13,020
Carrier Transicold	Refrigeration, A/C	7%	50,138	W,NA,D/I	10,028
Melroe Company	Skid-Steer Loaders and Trenchers	4%	30,405	W,NA,I	6,081
Gillette Mfg., Inc.	Generator Sets	3%	19,884	W/A,NA,I/D	3,977
Lincoln Electric	Welders	2%	19,081	W,NA,D	3,816

*W = water-cooled, A= air cooled, O = oil cooled; NA = naturally aspirated, T=turbocharged; I = indirect injection, D = direct injection.

Table 2-3
Equipment Sales Distribution under 37 kW

Application Description	Five-Year Sales Volume (1991-1995)	Average Annual Sales	Percentage of Total Sales
Commercial Turf	200,698	40,140	30%
Refrigeration / AC	111,742	22,348	16%
Generator Sets	62,505	12,501	9%
Skid-Steer Loaders	60,875	12,175	9%
Pumps	41,229	8,246	6%
Welders	36,173	7,235	5%
Lawn and Garden Tractors	33,452	6,690	5%
Agricultural Tractors	25,082	5,016	4%
Light Plant/Signal Boards	19,695	3,939	3%
Trenchers	14,680	2,936	2%
Other General Industrial	9,645	1,929	1.4%
Scrubber/Sweeper	8,635	1,727	1.3%
Rollers	5,584	1,117	0.8%
Air Compressors	5,170	1,034	0.8%
Plate Compactors	4,376	875	0.7%
Pressure Washers	4,329	866	0.6%
Aerial Lifts	3,165	633	0.5%
Excavators	2,998	600	0.4%
Hydraulic Power Units	2,946	589	0.4%
Paving Equipment	2,833	567	0.4%
Listed Total	**657,803**	**131,163**	**96.8%**
Grand Total	**679,549**	**135,910**	**100%**

B. Equipment Using Engines Rated between 37 and 75 kW

For the 37 to 75 kW range, almost all equipment uses direct injection engines that are water-cooled and naturally aspirated. The six leading manufacturers produce 55% of the equipment in this category. These manufacturers are listed in Table 2-4.

Table 2-4
Characterization of the Top 6 Manufacturers between 37 and 75 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Percentage of Market	1991 to 1995 Equipment Sales	Engine Characterization*	Average Annual Sales
Thermo King Corporation	Refrigeration, A/C	13%	74,256	W,NA,D	14,851
Melroe Company	Skid-Steer Loader, Sprayers	11%	60,715	W,NA/T,D	12,171
Deere & Co.	Ag Tractors, Crawlers, Backhoe-loaders	11%	59,830	W,NA,D	11,966
J.I. Case	Crawlers, Backhoe-loaders	10%	56,009	W,NA,D	11,202
Lincoln Electric	Welders	6%	33,404	W/O,NA,D/I	6,681
Ingersoll-Rand Co.	Air Compressors, Rollers	4%	21,904	W/A/O, NA,D	4,381

*W = water-cooled, A= air cooled, O = oil cooled; NA = naturally aspirated, T=turbocharged; I = indirect injection, D = direct injection.

The 37 to 75 kW range of engines has the following typical applications: skid-steer loaders, refrigeration/AC, tractors, loaders, backhoes, generator sets, welders, agricultural tractors, pumps, and forklifts. These top selling applications represent about 66% of the market as seen in Table 2-5. The top 90% of the market is supplied by 73 different companies.

Table 2-5
Equipment Sales Distribution Across Application between 37 and 75 kW

Application Description	Five-Year Sales Volume (1991-1995)	Average Annual Sales	Percentage of Total Sales
Skid-Steer Loader	87,180	17,436	16%
Refrigeration, A/C	74,256	14,851	14%
Tractor/Loader/Backhoe	51,448	10,290	10%
Generator Set	44,043	8,809	8%
Welder	33,854	6,771	6%
Ag Tractor	26,951	5,390	5%
Pump	17,876	3,575	3%
Forklift	17,675	3,535	3%
Air Compressor	14,442	2,888	3%
Commercial Turf	14,260	2,852	3%
Crawlers	12,730	2,546	2%
Roller	12,693	2,539	2%
Rough Terrain Forklift	12,620	2,524	2%
Trencher	12,601	2,520	2%
Chippers/grinder	12,176	2,435	2%
Unknown	9,298	1,860	2%
Scrubber/sweeper	9,187	1,837	2%
Irrigation Set	9,121	1,824	2%
Swather	7,251	1,450	1.4%
Other General Industrial	5,423	1,085	1.0%
Listed Total	**487,076**	**97,017**	**91%**
Grand Total	**532,825**	**106,565**	**100%**

C. Equipment Using 75 to 130 kW Engines

For equipment using 75 to 130 kW engines, the OEMs use predominantly direct injection (82%), water cooled (95%), turbocharged (58%) engines. The six leading manufacturers produce 48% of the equipment in this category. These manufacturers are shown in Table 2-6. The market as a whole has a very similar sales distribution as that of the top six manufacturers.

Table 2-6
Characterization of the Top 6 Manufacturers between 75 and 130 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Percentage of Market	1991 to 1995 Equipment Sales	Engine Characterization*	Average Annual Sales
LTV Aerospace & Defense Company	Military	17%	56,303	W, NA/T, I/D	11,261
Caterpillar, Inc.	R/T Loader	10%	33,703	W, T/NA, D	6,741
Deere and Co.	Tractor/Loader/ Backhoe, Swathers	8%	27,303	W,T/NA,D	5,461
J.I. Case	Tractor/Loader/ Backhoe Rubber-Tired Loader	7%	23,156	W,T/NA,D	4,631
Ingersoll-Rand	Air Compressors, Rollers	3%	10,440	W/A,T/NA,D	2,088
Onan Corporation	Gen Sets, Marine Auxiliary	3%	9,997	W,T/NA,D	1,999

*W = water-cooled, A= air cooled, O = oil cooled; NA = naturally aspirated, T=turbocharged; I = indirect injection, D = direct injection.

The applications listed in Table 2-7 represent about 70% of the market. The top 90% of this market is supplied by 98 OEMs. The 75 to 130 kW range is characterized by a wide distribution of applications as shown in Table 2-7.

Table 2-7
Equipment Sales Distribution Across Application between 75 and 130 kW

Application Description	Five-Year Sales Volume (1991-1995)	Average Annual Sales	Percentage of Total Sales
Generator Set	26,353	5,271	13%
Tractor/Loader/Backhoe	25,569	5,114	12%
Rubber-Tired Loader	16,966	3,393	8%
Ag Tractor	9,878	1,976	5%
Grader	9,399	1,880	5%
Forklift	8,332	1,666	4%
Forest Equipment	8,053	1,611	4%
Air Compressor	7,637	1,527	4%
Irrigation Set	7,603	1,521	4%
Pump	7,265	1,453	3%
Roller	6,825	1,365	3%
Cranes	6,627	1,325	3%
Rough Terrain Forklift	6,429	1,286	3%
Swather	5,342	1,068	3%
Scrubber/Sweeper	5,059	1,012	2%
Crawler	4,882	976	2%
Sprayer	4,844	969	2%
Excavator	3,821	764	2%
Aircraft Support	3,677	735	2%
Chipper/Grinder	3,316	663	2%
Listed Total	**177,877**	**35,575**	**68%**
Grand Total	**208,801**	**41,760**	**100%**

D. Equipment Using 130 to 560 kW Engines

For 130 to 560 kW engines, the OEMs use almost exclusively direct injection, water-cooled, turbocharged engines. The six leading manufacturers produce 55% of the equipment in this category. These manufacturers are shown in Table 2-8. Typical applications include agricultural tractors, combines, crawlers, graders, and generator sets. About 45 OEMs produce 90% of the equipment in this power range. Table 2-9 lists the most common applications, led by farm tractors, generator sets, and combines.

Table 2-8
Characterization of the Top 6 Manufacturers between 130 and 560 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Percentage of Market	1991 to 1995 Equipment Sales	Engine Characterization*	Average Annual Sales
Deere & Co.	Ag Tractors, Combines	26%	130,906	W, T, D	26,181
Caterpillar, Inc.	Generator Sets, Graders	12%	60,151	W,T,D	12,030
Case IH	Ag Tractors, Combines	12%	59,812	W,T,D	11,962
New Holland	Ag Tractors, Combines	4%	19,719	W,T,D	3,944
Wayne Wheeled Vehicles	Tactical Military Equipment	3%	15,505	W,T, D	3,101
Kohler Company	Generator Sets	3%	13,050	W,NA/T,D	2,610

*W = water-cooled, A= air cooled, O = oil cooled; NA = naturally aspirated, T=turbocharged; I = indirect injection, D = direct injection.

Table 2-9
Equipment Sales Distribution Across Application between 130 and 560 kW

Application Description	Five-Year Sales Volume (1991-1995)	Average Annual Sales	Percentage of Total Sales
Agricultural Tractor	77,306	15,461	22%
Generator Sets	58,526	11,705	16%
Combines	39,025	7,805	11%
Rubber-Tired Loader	16,517	3,303	5%
Graders	16,008	3,202	5%
Crawlers	15,969	3,194	4%
Air Compressors	14,763	2,953	4%
Off-Highway Truck	13,085	2,617	4%
Forest Equipment	9,609	1,922	3%
Scrapers	8,932	1,786	3%
Excavators	8,322	1,664	2%
Cranes	8,162	1,632	2%
Terminal Tractors	8,140	1,628	2%
Special Vehicle/ Carts	7,217	1,443	2%
Chippers/Grinders	6,210	1,242	2%
Sprayers	5,419	1,084	2%
Pumps	4,564	913	1.3%
Other Agricultural Equipment	4,278	856	1.2%
Off-highway Tractors	3,983	797	1.1%
Surfacing Equipment	3,081	616	0.9%
Listed Total	**331,107**	**65,823**	**92.5%**
Grand Total	**355,590**	**71,118**	**100%**

E. Equipment Using Over 560 kW Engines

As in the previous category, equipment rated over 560 kW uses turbocharged, direct injection engines that are water-cooled. The leading six manufacturers produce 70% of the equipment in this power range. These manufacturers are shown in Table 2-10. Generator sets make up the majority of equipment in this range, while off-highway trucks and crawler tractors also have significant sales (see Table 2-11).

Table 2-10
Characterization of the Top 6 Manufacturers over 560 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Percentage of Market	1991 to 1995 Equipment Sales	Engine Characterization*	Avg. Annual Sales
Caterpillar, Inc.	Crawlers, Off Highway Truck	41%	6,816	W,T,D	1,363
Onan Corporation	Generator Sets	10%	1,677	W,T,D	335
Kohler Company	Generator Sets	8%	1,249	W,T,D	250
Detroit Diesel Distributors	Generator Sets	5%	824	W,T,D	165
Fermont Division	Generator Sets	3%	572	W,T,D	114
Komatsu-Dresser	Off Highway Truck, Rubber-Tired Loader	3%	494	W,T,D	99

*W = water-cooled, A= air cooled, O = oil cooled; NA = naturally aspirated, T=turbocharged; I = indirect injection, D = direct injection.

Table 2-11
Equipment Sales Distribution Across Application over 560 kW

Application Description	Five-Year Sales Volume (1991-1995)	Average Annual Sales	Percentage of Total Sales
Generator Sets	7,116	1,423	72%
Off-highway Trucks	1,257	251	13%
Crawlers	837	167	8%
Off-highway Tractors	218	44	2%
Oil Field Equipment	148	30	1.5%
Chippers/Grinders	118	24	1.2%
Bore/Drill Rigs	91	18	0.9%
Rubber-Tired Loaders	68	14	0.7%
Locomotives	37	7	0.4%
Excavators	28	6	0.3%
Cranes	9	2	0.1%
Listed Total	**11,918**	**1,986**	**100%**

Chapter 2 References

1. Information in the literature was taken principally from the July 1996 issue of *Diesel Progress.*

2. “Big Changes for Cummins’ B Series,” *Diesel Progress*, May 1997, page 14.

3. “Industry Characterization Support Data,” EPA memorandum from Cleophas Jackson to Docket A-96-40, August 5, 1997.

4. Power Systems Research, OELink Database, 1996.

CHAPTER 3: TECHNOLOGICAL FEASIBILITY

The nonroad emission source category encompasses a large and diverse population of engines and equipment, as described in Chapter 2. Setting emission standards that apply to all the participating manufacturers for all the applications is not straightforward. EPA has, however, attempted to take into account the needs and constraints of the affected industries to develop a set of emission standards that can be met in the specified time frame. The Agency believes there are several factors that will enable manufacturers to successfully meet the new standards. First, and perhaps most importantly, EPA believes that manufacturers will be able to draw from the experience in the development of advanced highway engine technology when determining their strategies to meet the new standards. Second, market demand is driving engine manufacturers to greater use of advanced technologies that also provide improved capability for controlling emissions. Manufacturers are expected to continue to improve engine performance by redesigning combustion chambers, increasing the use of turbocharging and aftercooling, modifying fuel injection hardware, and introducing electronic controls. Third, manufacturers have acknowledged that the majority of their research and development efforts will be focused on meeting the most stringent standards (Tier 2 for engines rated under 37 kW and Tier 3 for larger engines). Even though these stringent standards present significant challenges and will require a substantial effort on the part of industry, EPA believes that the long lead time, coupled with the experience gained with highway engines, will allow manufacturers to comply with the most stringent emission standards. Fourth, various provisions are included to ease the burden of complying with the new standards, including a phase-in schedule with considerable lead time, flexibility options for equipment manufacturers, and an enhanced program of averaging, banking, and trading. EPA therefore believes that manufacturers will be capable of achieving the new emission standards within the allotted lead time at a reasonable cost.

This chapter first briefly reviews the principles of diesel engine combustion and emission formation, then discusses in general terms the types of emission control strategies that may be utilized by manufacturers to meet the standards. The application of these strategies to each of the engine categories is considered next. The chapter concludes with an evaluation of the noise, energy, and safety impacts associated with the rulemaking. A discussion of the effects of the suggested engine modifications on equipment is discussed in the context of economic impacts in the next chapter.

I. Background on Diesel Technology and Emission Formation

In a diesel engine, the liquid fuel is injected into the combustion chamber after the air has been heated by compression. In the case of indirect injection engines, the fuel is injected into a prechamber, where combustion initiates before spreading to the rest of the combustion chamber. The fuel is injected in the form of a mist of fine droplets that mix with the air. Power output is controlled by regulating the amount of fuel injected into the combustion chamber, without throttling (limiting) the amount of air entering the engine. The compressed air heats the injected fuel droplets, causing the fuel to evaporate and mix with the available oxygen. At several sites where the fuel mixes with the oxygen, the fuel autoignites and the multiple flame fronts spread through the combustion chamber.

NOx and PM are the emission components of most concern from diesel engines. Incomplete evaporation and burning of the fine fuel droplets result in emissions of the very small particles of PM. Small amounts of lubricating oil that escape into the combustion chamber can also contribute to PM. The high temperatures and excess oxygen associated with diesel combustion can cause the nitrogen in the air to combine with available oxygen to form NOx. Because of the presence of excess oxygen, hydrocarbons evaporating in the combustion chamber tend to be completely burned and HC and CO are not emitted at high levels. Evaporative emissions from diesel engines are insignificant due to the low evaporation rate of diesel fuel.

Controlling both NOx and PM emissions requires different, sometimes opposing strategies. The key to controlling NOx emissions is reducing peak combustion temperatures. In contrast, higher temperatures in the combustion chamber or faster burning lower rates of PM emissions, either by decreasing the formation of particulates or by oxidizing those particulates that have formed. To control both NOx and PM, manufacturers need to combine approaches using the many different variables to achieve optimum performance.

II. General Description of Emission Control Strategies

In general, nonroad engine manufacturers are expected to apply similar emission control strategies to those utilized by the manufacturers of heavy-duty highway diesel engines, even though the application of these strategies could differ because of some unique aspect of the operating environment or performance needs of the nonroad engines. While both highway and nonroad engines experience frequent changes in load and speed caused by work fluctuations, nonroad operators typically do not change engine speeds as often as highway vehicles. Also, nonroad engines often power both nonmotive and motive functions. Another factor affecting the choice of emission control strategies is the fact that many nonroad engines are used in multiple equipment applications, many of which have low sales volumes. Nonroad engine manufacturers are, however, currently in the process of introducing models that have been certified to the Tier 1 standards and are successfully demonstrating their ability to meet the first level of emission standards. Based on a review of current emissions research, EPA believes that emission control improvements from engine design changes have not yet leveled off and that further emission reductions are possible.

The remainder of this section discusses in more detail potential engine control strategies, including combustion optimization, better fuel control, exhaust gas recirculation, improved charge air characteristics, and aftertreatment devices. A more detailed analysis of the application of these strategies to individual categories of nonroad engines is discussed in Section III. The costs associated with these systems are considered in the next chapter.

A. Combustion Optimization

Several parameters in the combustion chamber of a heavy-duty diesel engine affect its efficiency and emissions. These engine parameters include charge (or intake) air temperature and pressure, peak cylinder temperature and pressure, turbulence, valve and injection timing, injection pressure, fuel spray geometry and rate, combustion chamber geometry and compression ratio. Many technologies that are designed to control the engine parameters listed above have been investigated. As mentioned previously, however, a positive influence on one pollutant may have a negative influence on another. For example, charge air cooling reduces NOx emissions, but increases PM. Manufacturers will need to integrate all of these variables into optimized systems to meet the new standards.

1. Timing retard

The effect of injection timing on emissions and performance is well established.[1,2,3,4] Retarded timing is the strategy most likely to be used by manufacturers of engines rated under 37 kW to meet the new Tier 1 standards. NOx is reduced because the premixed burning phase is shortened and because cylinder temperature and pressure are lowered. Timing retard increases HC, CO, PM, and fuel consumption, however, because the end of injection comes later in the combustion stroke where the time for extracting energy from fuel combustion is shortened and the cylinder temperature and pressure are too low for more complete oxidation of PM. One technology that can offset this trend is higher injection pressure, which is discussed further below.

2. Combustion chamber geometry

While manufacturers are already achieving emission reductions through modifications to the combustion chamber, EPA believes there are additional changes that may provide further improvements in emission control. The parameters being investigated include (1) the shape of the chamber and the location of injection; (2) reduced crevice volumes; and (3) compression ratio. These parameters have been thoroughly explored for highway engines and should be readily adaptable to nonroad engines.

Efforts to redesign the shape of the combustion chamber and the location of the fuel injector for highway and nonroad engines have been primarily focused on optimizing the relative motion of air and injected fuel to simultaneously limit the formation of both NOx and PM. Piston crown design must be carefully matched with injector spray pattern and pressure for optimal emission behavior.[5] One strategy, reentrant piston bowl design, focuses on optimizing the radius of the combustion bowl, the angle of the reentrant lip, and the ratio of the bowl diameter to bowl depth to optimize air motion. An alternative is the use of higher pressure injection systems that decrease the need for turbulent in-cylinder charge air motion. While higher pressure systems raise concerns of durability, there has been a significant amount of progress in this area and it is expected that manufacturers will be able to develop a durable system.[6]

The second parameter being investigated is reducing crevice volumes by moving the location of the top piston ring relative to the top of the piston.[7] A reduced crevice volume can result in reduced HC emissions and, to a lesser extent, reduced PM emissions. Costs associated with the relocation of the top ring can be substantial because raising the top of the piston ring requires modified routing of the engine coolant through the engine block and lube oil routing under the piston to prevent the raised ring from overheating. It is also important to design a system that retains the durability and structural integrity of the piston and piston ring assembly, which requires very precise tolerances to avoid compromising engine lubrication.

Compression ratio is another engine design parameter that impacts emission control. In general, higher compression ratios cause a reduction of cold start PM and improved fuel economy, but can also increase NOx. Several methods can be employed to increase the compression ratio in an existing diesel engine. Redesign of the piston crown or increasing the length of the connecting rod or piston pin-to-crown length will raise the compression ratio by reducing the clearance volume.[8] There is a limit to the benefit of higher compression ratios because of increased engine weight (for durability) and frictional losses, which could somewhat limit fuel economy improvements.

3. Swirl

Increasing the turbulence of the intake air entering the combustion chamber (i.e., inducing swirl) can reduce PM by improving the mixing of air and fuel in the combustion chamber. Historically, swirl was induced by routing the intake air to achieve a circular motion in the cylinder. Manufacturers are, however, increasingly using "reentrant" piston designs in which the top surface of the piston is cut out to allow fuel injection and air motion in a smaller cavity in the piston to induce additional turbulence. Manufacturers are also changing to three or four valves per cylinder, which reduces pumping losses and can also allow for intake air charge motion. The effect of swirl is often engine-specific, but some general effects may be discussed.

At low loads, increased swirl reduces HC, PM, and smoke emissions and lowers fuel consumption due to enhanced mixing of air and fuel. NOx emissions might increase slightly at low loads as swirl increases. At high loads, swirl causes slight decreases in PM emissions and fuel consumption, but NOx may increase because of the higher temperatures associated with enhanced mixing and reduced wall impingement.[9] A higher pressure fuel system can be used to offset some of the negative effects of swirl, such as increased NOx, while enhancing the positive effects such as a reduction in PM.[10]

B. Advanced Fuel Injection Controls

Control of the many variables involved in fuel injection is central to any strategy to reduce diesel engine emissions. The principal variables being investigated are injection pressure, nozzle geometry (e.g., number of holes, hole size and shape, and fuel spray angle), the timing of the start of injection, and the rate of injection throughout the combustion process (e.g., rate shaping).

Manufacturers continue to investigate new injector configurations for nozzle geometry and higher injection pressure (in excess of 2300 bar (34,000 psi)).[11,12] Increasing injection pressure achieves better atomization of the fuel droplets and enhances mixing of the fuel with the intake air to achieve more complete combustion. Though HC and PM are reduced, higher cylinder pressures can lead to increased NOx formation.[13] Retarding the start of fuel injection in conjunction with higher fuel injection pressures can, however, lead to reduced NOx because of lower combustion temperatures. HC, PM, or fuel economy penalties from this strategy can be avoided because the termination of fuel injection need not be delayed. Nozzle geometry is used to optimize the fuel spray pattern for a given combustion chamber design in order to improve mixing with the intake air and to minimize fuel condensation on the combustion chamber surfaces.[14] Minimizing the leakage of fuel droplets is critical for reducing HC emissions. Valve-closed orifice (VCO) tips are more effective than sac-type nozzles, because they eliminate any droplets remaining after injection, which would increase HC emissions. Although VCO tips are subject to very high pressures, EPA believes progress will continue in developing a durable injector tip prior to implementation of the Tier 2 standards.

The most recent advances in fuel injection technology are the systems that use rate shaping or multiple injections to vary the delivery of fuel over the course of a single injection. Igniting a small quantity of fuel initially limits the characteristic rapid increase in pressure and temperature that leads to high levels of NOx formation. Injecting most of the fuel into an established flame then allows for a steady burn that limits NOx emissions without increasing PM emissions. Rate shaping may be done either mechanically or electronically. Rate shaping has been shown to reduce NOx emissions by up to 20 percent.[15]

For electronically controlled engines, multiple injections may be used to shape the rate of fuel injection into the combustion chamber. Recent advances in fuel system technology allow high-pressure multiple injections to be used to reduce NOx by 50 percent with no significant penalty in PM. Two or three bursts of fuel can come from a single injector during the injection event. The most important variables for achieving maximum emission reductions with optimal fuel economy using multiple injections are the delay preceding the final pulse and the duration of the final pulse.[16] This strategy is most effective in conjunction with retarded timing, which leads to reduced NOx emissions without the attendant increase in PM.

A promising fuel injection design is that developed by Caterpillar and Navistar, the Hydraulically Actuated Electronically Controlled Unit Injection (HEUI) system.[17] The HEUI system utilizes a common rail of pressurized oil to provide high injection pressures throughout an engine's operating range. The HEUI system provides full electronic control of injection timing and duration, along with the possibility for rate shaping. The most attractive aspect of this system is that it operates largely independent of engine speed. This could be an important strategy for nonroad engine manufacturers because of the use of a single engine in a wide range of applications. Some manufacturers are already utilizing this system on production engines. It is expected that manufacturers will be able to develop and produce a full-authority electronic fuel injection system for a reasonable cost in time for some engines meeting Tier 2 standards; many more models are expected to incorporate electronic controls in engines designed for Tier 3 standards.

C. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is the most recent development in diesel engine control technology for obtaining significant NOx reductions. EGR reduces peak combustion chamber temperatures by slowing reaction rates and absorbing some of the heat generated from combustion. While NOx emissions are reduced, PM and fuel consumption can be increased, especially at high loads, because of the reduced oxygen available during combustion.[18,19] One method of minimizing PM increases is to reduce the flow of recirculated gases during high load operation, which would also prevent a loss in total power output from the engine. Recent experimental work showed NOx reductions of about 50 percent, with little impact on PM emissions, using just 6 percent EGR in conjunction with a strategy of multiple injections.[20]

Another challenge facing manufacturers is the potential negative effects of soot from the recirculated exhaust being routed into the intake stream. Soot may form deposits in the intake system, which could cause wear on the turbocharger or decrease the efficiency of the aftercooler. As the amount of soot in the cylinder increases, so does the amount of soot that works its way past the piston rings into the lubricating oil, which can lead to increased engine wear. One thing that has been developed to reduce soot in the recirculated exhaust gas is a low-voltage soot removal device.[21] Engine wear was shown to be greatly reduced as a result of this device. Another strategy is to recirculate the exhaust gas after it has passed through a particulate trap or filter. Demonstrations have shown that some prototype traps can remove more than 90 percent of particulate matter.[22]

D. Improving Charge Air Characteristics

Charge air compression (turbocharging) is primarily used to increase power output and reduce fuel consumption from a given displacement engine. At rated power, a typical diesel engine loses about 30 percent of its energy through the exhaust. A turbocharger uses the waste energy in the exhaust gas to drive a turbine linked to a centrifugal compressor, which then boosts the intake air pressure. By forcing more air into the cylinder, more fuel can also be added at the same air-fuel ratio, resulting in higher power and better fuel consumption while controlling smoke and particulate formation. To prevent increased NOx emissions, an aftercooler is typically installed to reduce the temperature of the charge air after it has been heated during compression.

While aftercooling reduces NOx emissions, it was initially developed to improve the specific power output of an engine by increasing the density of air entering the combustion chamber. There are two kinds of aftercooling strategies—air-to-water or air-to-air. Air-to-water aftercoolers use engine coolant to lower the intake air temperature. This method, however, can only reduce the temperature of the compressed intake air to the operating temperature of the engine and significantly adds to the heat load on the cooling system. The temperature of the intake air after compression by the turbocharger is approximately 300°F. An air-to-water aftercooler can only cool the charge air to approximately 200°F.

Air-to-air aftercoolers use a stream of outside air flowing through a separate heat exchanger to cool the intake air. An air-to-air aftercooler can cool the compressed intake air to a temperature approaching that of the ambient. Air-to-air aftercoolers are widely used with highway engines, but nonroad engines complying with Tier 1 standards generally have not incorporated air-to-air aftercooling, due to limits on dust tolerance and space constraints. Ground-level dust is becoming less of an issue because recent developments have improved dust resistance, primarily through greater fin spacing on the heat exchanger. Over time, equipment manufacturers are expected to modify their designs to make space for air-to-air aftercooling technology. While introducing air-to-air aftercooling requires a greater degree of engine and equipment modification, the benefits for improved fuel efficiency, greater engine durability, and better control of NOx emissions make a compelling case for their widespread use in the long term.[23]

E. Exhaust Aftertreatment Strategies

Researchers in industry and academia have explored various technologies for treating engine-out exhaust emissions. In general, EPA does not expect that manufacturers will need to utilize exhaust aftertreatment to meet the new standards; however, further work on these technologies may lead to development of an approach that provides effective control at a lower cost than today's anticipated technologies. This may be especially true in certain niche markets. For example, some nonroad applications that involve operation in confined areas are currently using some form of exhaust aftertreatment. This analysis considers in detail only oxidation catalysts and particulate traps. Other technologies being pursued include selective and nonselective catalytic reduction, various plasma and electrochemical approaches, and fuel additives.

1. Oxidation catalysts

The flow-through oxidation catalyst provides relatively moderate PM reductions by oxidizing both gaseous hydrocarbons and the portion of PM known as the soluble organic fraction (SOF). The SOF consists of hydrocarbons adsorbed to the carbonaceous solid particles and may also include hydrocarbons that have condensed into droplets of liquid.[34] The carbon portion of the PM remains largely unaffected by the catalyst. Although recent combustion chamber modifications have reduced SOF emissions, the SOF still comprises between 30 and 60 percent of the total mass of PM. Catalyst efficiency for SOF varies with exhaust temperature, ranging from about 50 percent at 150°C to more than 90 percent above 350°C.[24] Because exhaust gas temperatures typically fluctuate between 100°C and 400°C during the Federal Test Procedure for highway diesel engines, the reduction in tested total particulate mass provided by the oxidation catalyst is relatively modest.

Another challenge facing catalyst manufacturers is the formation of sulfates in the exhaust. At higher exhaust temperatures, catalysts have a greater tendency to oxidize sulfur dioxide to form sulfates, which contribute to total PM emissions. In addition to the introduction of low-sulfur fuel by EPA, catalyst manufacturers have been successful in developing catalyst formulations that minimize sulfate formation.[25] Catalyst manufacturers have also adjusted the placement of the catalyst to a position where the needed SOF reduction is achieved, but sulfate formation is minimized.[26] Nonroad fuel with sulfur concentrations higher than 0.05 weight percent may prevent the use of more active oxidation catalysts with higher conversion efficiencies.

2. Particulate traps

Use of a particulate trap is a very effective way of reducing particulate emissions, including the carbon portion. Particulate traps have been extensively developed for highway applications, though very few engines have been sold equipped with traps, primarily because of the complexity of the systems needed to remove the collected particulate matter. Continued efforts in this area may lead to simpler, more durable designs that control emissions cost-effectively. Research in this area is focused on developing new filter materials and regeneration methods. Some designs rely on an additive acting as a catalyst to promote spontaneous oxidation for regeneration, while other designs aim to improve an active regeneration strategy with microwave or other burner technology.

III. Specific Description of Emission Control Strategies by Power Category

In developing the various numerical standards and implementation dates, EPA depended heavily on extending the analysis of technological feasibility for the earlier rulemaking to set emission standards for highway heavy-duty engines. While the 2004 standards for highway engines apply equally to all sizes of engines starting in the same year, the standards established in this rulemaking are a complex combination of numerical values and applicable model years. Varying numerical standards were considered necessary to account for the very wide range of engines represented in nonroad applications. Also, because of the range of engines offered by individual manufacturers, EPA believes that new standards can be implemented most expeditiously by phasing the standards in at different times for different power ranges. EPA applied a similar phase-in for the first tier of nonroad emission standards in 1994.

Because the new emission standards depend on the evaluation of technologies for complying with the standards for highway engines, the discussion of technological feasibility in that rulemaking is central to supporting the feasibility of complying with standards for nonroad engines. This analysis of diesel engine technologies is contained in Chapter 4 of the Final RIA for the highway rule.[27]

By setting multiple tiers of standards that extend well into the next decade, EPA is providing engine manufacturers with substantial lead time for developing, testing, and implementing emission control technologies. This lead time and the coordination of standards with those for highway engines allows time for a comprehensive R&D program to integrate the most effective emission control approaches into the manufacturers' overall design goals related to durability, reliability, and fuel consumption. The following sections describe a set of projections related to the technologies manufacturers may ultimately implement.

A. Engines Rated over 75 kW

Although this category of engines extends over a very large range, EPA expects manufacturers to use similar emission control strategies previously identified for highway diesel engines. In fact, some manufacturers currently use the same engine for both their highway and nonroad applications.

The difference between models lies primarily with charge air compression and cooling, and electronic control software where applicable. The expected increasing use of electronic controls allows manufacturers to tailor the engine to specific applications with minimal modification to the rest of the engine.

To meet Tier 2 standards, manufacturers will continue optimizing the combustion chamber and modifying injection timing. Manufacturers are expected to increase their use of electronic controls to improve both emission control and engine performance. Certification data for the 1996 model year indicates that some manufacturers have already upgraded their systems to incorporate advanced high-pressure electronic fuel injection systems.[28] There are even a few engines certified in 1996 with emission levels close to the Tier 2 standards.

The Tier 3 standards will likely lead to very widespread use of full authority electronic systems with very high-pressure unit injector or common rail fuel systems. The technology for electronic fuel injection is advancing at a rapid pace, driven by market demand for improved performance and increasingly stringent emission standards. Manufacturers may also utilize EGR to further reduce NOx emissions. EPA believes manufacturers can meet the Tier 3 standards for these engines by transferring and adapting these technologies developed for highway engines.

B. Engines Rated between 37 and 75 kW

This category is somewhat transitional in nature, because some current engines are naturally aspirated and resemble smaller engines, while others are turbocharged and resemble highway and larger nonroad engines. In discussions that led to the proposed Tier 2 and Tier 3 emission standards, manufacturers placed a high priority on being able to continue to produce naturally aspirated engines in this size range. Since that time, however, increased use of turbochargers for light-duty highway applications (in the U.S. and abroad), among other things, has advanced the technology and reduced costs enough that turbocharging has become a viable near-term option for engines in this size range.

Most of these engines have certified Tier 1 emission levels that are near or below the new Tier 2 levels. Compliance with Tier 2 standards will therefore require incremental change in injection or other combustion variables, though some bigger steps such as turbocharging and introducing a low level of EGR may be adopted for some engines, primarily in anticipation of Tier 3 standards.

Meeting Tier 3 standards will involve more extensive changes. Manufacturers are expected to make broad use of turbocharging (or supercharging) in conjunction with either aftercooling or EGR for controlling both NOx and PM emissions. Further fuel injection upgrades, perhaps including electronically controlled injection, will also be needed to meet emission standards. The Tier 3 standards are comparable to, but less stringent than, the highway standards that will become effective in model year 2004. EPA believes that implementation of the Tier 3 standards in 2008 for these engines gives manufacturers sufficient time to adapt highway technologies as appropriate and optimize the systems for controlling emissions at a relatively low cost.

C. Engines Rated under 37 kW

The design features of these small engines and their greater cost sensitivity constrain the targeted level of emission control. These engines are therefore subject to less stringent emission standards.

Engines using indirect injection (IDI) are already controlled to levels below the new Tier 1 standards and, in many cases, below even the Tier 2 standards. Certification data submitted to the California ARB for diesel engines rated under 19 kW show most IDI engines controlling NMHC + NOx emissions well below 7 g/kW-hr (5.2 g/hp-hr), with PM levels between 0.3 and 0.4 g/kW-hr (0.2 and 0.4 g/hp-hr).[29] Those engines that need additional control can use currently available, low-cost upgrades to fuel injection systems to meet the new emission standards. An additional advantage of IDI engine technology is the relatively quiet engine operation. Since fuel consumption in IDI engines is 10 to 15 percent higher than in their direct-injection counterparts, shifting to IDI technology to comply with emission standards is not an optimal solution.

For direct injection engines, EPA expects that manufacturers will be able to meet the Tier 1 standards by optimizing the combustion chamber and retarding the timing. These control technologies are well established for diesel engines and should be readily adaptable to the small engines. Additional certification data from the California ARB show emission rates for some DI engines rated under 19 kW to be between the Tier 1 and Tier 2 standards.[30] To meet the Tier 2 standards, some manufacturers could replace the existing rotary pump fuel injection systems with a more sophisticated rotary pump, some designs of which have already been developed, or perhaps an in-line pump system.[31] Current trends, though, indicate that consumers are requesting more sophisticated electronics on their machinery for improvements in performance.[32] For this reason, it is possible that by 2004 an electronically controlled engine will be available at a reasonable cost. Electronic controls enable the engine designer to more carefully control the engine, especially the fuel injection parameters, to optimize engine operation for the best combination of emission control, power, and fuel economy. At any rate, limited electronics should be available for governing and for some improvements in performance. Finally, some applications may employ EGR to ensure sufficiently low NOx emission levels.

Many of the air-cooled diesel engines rated under 8 kW face unique design challenges. The small size and low cost of these engines limit the flexibility of designing or adapting technologies to control emissions. For example, increasing injection pressure in very small cylinders involves tradeoffs resulting from the greater impingement of fuel spray on cylinder walls. Also, for some approaches, such as reducing injector hole diameters, scaling a technology down to the smallest engines may not be feasible due to machining or other production limitations. Tier 1 standards for these engines are therefore set at less stringent levels than those for larger engines. To reach these levels, manufacturers will need to rely on several of the strategies used for other engines. For example, increasing swirl and redesigning piston head geometries can be an effective way of improving fuel air mixing in small engines, with the additional benefit of allowing higher injection pressures without increasing fuel wetting on the cylinder walls. The position and design of piston rings can be improved to reduce the contribution of engine oil to particulate emissions. Incorporating fuel injectors that provide mechanically controlled rate shaping would allow substantial control of NOx emissions at a low cost. Using injectors with valve-closed-orifice nozzles would similarly control HC emissions. Engines that operate within a relatively narrow range of engine speeds can achieve a degree of charge-air compression with intake manifold designs that rely on pulse tuning. These types of strategies have been shown to reduce emission levels to that of the new Tier 2 standards; EPA believes that despite the more difficult characteristics of these engines, manufacturers will be able to incorporate such strategies to achieve compliance with Tier 2 standards.

IV. Impact on Noise, Energy, and Safety

The Clean Air Act requires EPA to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad diesel engines. One important source of noise in diesel combustion is the sound associated with the combustion event itself. When a premixed charge of fuel and air ignites, the very rapid combustion leads to a sharp increase in pressure, which is easily heard and recognized as the characteristic sound of a diesel engine. The conditions that lead to high noise levels also cause high levels of NOx formation. Fuel injection changes and other NOx control strategies therefore typically reduce engine noise. Combustion-related noise reductions may be as great as 8 or 10 decibels, which is much greater than that anticipated from increasing the size or speed of the cooling fan.[1]

Another principle source of noise is the cooling fan. Any engine changes that increase the heat load to the heat exchangers would increase the need for fan cooling, either with larger fans or with higher fan speeds, which quickly increases noise levels. Fans are typically positioned to provide cooling air for three heat exchanger applications: engine coolant, hydraulic working fluid, and air conditioning. Applying cooled EGR to an engine would likely require the engine coolant to absorb the heat from the recirculating exhaust gases. Heat rejection from the EGR system, however, would generally occur during lower-power operation. During periods of high-power operation, and therefore high heat rejection from combustion, there is little or no EGR flow. As a result, EGR cooling is expected to have a small effect on total cooling capacity. EPA believes that any increase in noise from a cooling fan resulting from increased heat rejection would be more than offset by a reduction in combustion noise related to controlling NOx emissions. The need and ability of manufacturers to maintain low noise levels from diesel engines is therefore not compromised by the new standards.

The impact of new emission standards on energy is measured by the effect on fuel consumption from complying engines. Manufacturers of engines rated under 37 kW are expected to retard injection timing, which increases fuel consumption somewhat. Most of the technology changes anticipated in response to the new standards, however, have the potential to reduce fuel consumption as well as emissions. Redesigning combustion chambers, incorporating improved fuel injection systems, and introducing electronic controls provide the engine designer with powerful tools for improving fuel efficiency while simultaneously controlling emission formation. To the extent that manufacturers shift from air-to-water aftercooling to air-to-air aftercooling, there will be a marked improvement in fuel efficiency. A moderate degree of cooled EGR can be incorporated with little or no increase in fuel consumption, especially with the anticipated use of EGR cooling. Manufacturers of highway diesel engines have been able to steadily improve fuel efficiency even as new emission standards required significantly reduced emissions.

There are no apparent safety issues associated with the new standards. Manufacturers will likely use only proven technology that is currently used in other engines, especially in diesel trucks.

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9.See reference 4--SAE 930592

10.See reference 1--SAE 920470

11.See reference 4--SAE 930592

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27.“Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines,” U.S. EPA, September 16, 1997.

28.“Certification Data for Nonroad Diesel Engines,” EPA memorandum from Phil Carlson to Docket A-96-40, August 8, 1997.

29.See reference 28

30.See reference 28

31.“Pump Evolution Meets Emissions Standards,” *OEM Off-Highway*, March 1996, Page 138.

32.“Build It and They Will Come,” *OEM Off-Highway*, November 1996, page 74.

CHAPTER 4: ECONOMIC IMPACT

The new emission standards are set in a far-reaching schedule extending well into the next decade. This will help manufacturers plan and conduct a comprehensive, efficient, and orderly R&D program. For engine models that have heavy-duty highway counterparts, much of the R&D focus will be on transferring emission control technology from highway engines to work in nonroad applications. Even engines that are smaller or bigger than the highway engines are expected to benefit from the technological development for highway engines, which face similar emission standards two to five years earlier than comparable standards for nonroad engines. Manufacturers that produce engines for both highway and nonroad markets will have an advantage in transferring technology development, but dedicated nonroad engine manufacturers are also expected to learn from highway technologies, either by accessing publicly available information, by working with consultants or contractors that have been involved in developing the highway technologies, or by inspection of manufactured engines. Basic research on highway engines will likely go a long way toward narrowing the list of design options, so that designers of nonroad engines can work more directly toward final solutions.

The time available for conducting R&D and the potential for transferring highway technology play significantly in the analysis of costs for complying with the new emission standards. Learning from this experience and applying additional R&D will enable manufacturers to optimize a combination of control strategies and techniques that control emissions at the lowest cost, with minimum effects on operating costs and engine durability. Also, the program review scheduled for 2001 provides manufacturers and EPA an opportunity to review the feasibility and cost of complying with the Tier 3 standards for engines rated over 37 kW, and Tier 2 standards for smaller engines.

This chapter lays out EPA's estimates of the cost of complying with the new standards, first for incremental engine prices, then incremental equipment prices. The estimated aggregate cost to society is also considered, followed by an analysis of the impact on small businesses.

I. Cost of Engine Technologies

A. Methodology

Using the technical information in Chapter 3, EPA identified packages of technologies that engine manufacturers could use to meet the new emission standards. To quantify the costs of these technologies, EPA relied extensively on the contracted study of the cost of highway engine technologies conducted by ICF, Incorporated and Arcadis Geraghty & Miller.[1] In addition, Arcadis developed cost estimates for utilizing electronic controls for nonroad engines.[2]

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

Costs of control include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). Variable costs are marked up at a rate of 29 percent to account for manufacturers' overhead and profit.[3] For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. The analysis also includes consideration of lifetime operating costs where applicable.

B. Technologies for Meeting the New Standards

The following discussion provides a description and estimated costs for those technologies EPA projects will be needed to comply with the new emission standards. For some technologies, it is difficult to make a distinction between the benefits related to reduced emissions and the benefits for improved fuel economy and engine performance. Modifications to fuel injection systems, for example, have the potential to improve engine performance in addition to the expected reductions in NOx, HC, and PM emissions.

The technology packages in the analysis include multiple sets of projections. EPA has information about technologies for those engines already complying with the Tier 1 standards finalized in 1994. For engines not yet subject to Tier 1 standards, some judgment is required to project the technology packages for complying with finalized Tier 1 standards; these Tier 1 projections serve as the baseline scenario for estimating the impact of the new emission standards. Specification of these technologies is based on an observation of the technologies used with certified engines and a set of technical judgments about the most likely control steps manufacturers will use to meet Tier 1 emission standards. Tier 1 standards do not apply to engines rated under 37 kW, so current designs provide the technology baseline for those engines.

Cost estimates based on these projected technology packages apply to engines starting in the first year of production under the new standards. Costs in subsequent years should be reduced as manufacturers pursue innovations to streamline production and simplify designs. EPA has attempted to quantify the cost savings associated with this ongoing development, which is well established in the literature, as described in Section I.E. below.

A variety of technological improvements are anticipated for complying with the multiple tiers of emission standards. The fact that manufacturers have nearly a full decade before implementation of the most challenging of the new standards ensures that technologies will develop significantly before reaching production. This ongoing development will lead to reduced costs in additional ways.

First, research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission control technologies than would be predicted given the current state of development. Similarly, the continuing effort to develop different technologies may ultimately provide a lower-cost alternative. Finally, manufacturers will focus research efforts on any potential drawbacks, such as increased fuel consumption or maintenance costs, attempting to minimize or overcome any negative effects. Because the analysis does not explicitly factor in any cost savings for these efforts, actual costs for some technologies ten years from now may be substantially lower than are estimated here.

A combination of technology upgrades are anticipated for complying with the new emission standards. Achieving very low NOx emissions will require basic research on reducing in-cylinder NOx, HC, and PM. Modifications to basic engine design features, such as piston bowl shape and engine block and head geometry, can improve intake air characteristics and distribution during combustion. For this analysis, EPA projects large R&D expenditures for these basic engine modifications to be spread over the applicable tiers of new emission standards. Manufacturers are expected to introduce electronic controls or exhaust gas recirculation on some engines. Advanced fuel-injection techniques and hardware will allow designers to modify various fuel injection parameters for higher pressure, further rate shaping, and some split injection. Most engines rated over 75 kW are expected to also incorporate air-to-air aftercooling, either for Tier 2 or Tier 3 standards.

Similar developments in highway diesel engines have shown that most of these technologies not only can reduce emissions, but also can greatly enhance engine performance. As a demonstration of this, truck drivers and trucking companies currently enjoy the benefits of using sophisticated, new, high-performance electronic engines that have much lower emissions than engines from fifteen years ago. Similarly, EPA has observed a clear increase in the deployment of electronic controls in nonroad engines independent of changes to emission standards, which results from a willingness for engine and equipment consumers to pay a premium for these more capable engines. A difficulty in assessing the impact of new emission standards then is establishing the appropriate technology baseline from which to make projections. Ideally, the analysis would establish the mix of technologies that manufacturers would have introduced absent the changes in emission standards, then make a projection for any additional changes in hardware or calibration required to comply with those standards. The costs of those projected technology and calibration changes would then most accurately quantify the impact of setting new emission standards.

While it is difficult to take into account the effect of ongoing technology development, EPA believes that assessing the full cost of the anticipated technologies as an impact of the new emission standards would inappropriately exclude from consideration the observed benefits for engine performance, fuel consumption, and durability. Short of having sufficient data to predict the future with a reasonable degree of confidence, EPA faces the need to devise an alternate approach to quantifying the true impact of the new emission standards. EPA believes the observed value of performance improvements in the field justifies the use of a discount based on equal weighting of emission and non-emission benefits of those technologies which clearly have substantial non-emission benefits, namely electronic controls, fuel injection changes, turbocharging, and engine modifications. For some or all of these technologies, a greater value for the non-emission benefits could likely be justified. The following analysis describes current engine technologies as the baseline scenario, from which are made technology projections and cost estimates. Appendix A explores the sensitivity of discounting the estimated costs to account for non-emission benefits.

1. Baseline technology packages

An important technology distinction in the baseline packages is the difference between direct and indirect injection, because of the inherently lower NOx emissions associated with indirect injection. About 70 percent of engines rated under 37 kW use indirect injection technology, according to the PSR OE Link database. Similarly, about 15 percent of engines rated between 37 and 75 kW employ indirect injection. Bigger engines use almost exclusively direct injection.

Fuel injection hardware is another important consideration, because these systems represent such a big portion of the total engine cost. Engines rated under 75 kW typically use rotary fuel pumps, which have a relatively lower cost, but have less potential for increasing injection pressure or maintaining sophisticated control of injection variables. Bigger engines typically use in-line or unit pumps, which cost more than rotary pumps, but offer the advantages of higher pressure and greater control.

Another engine parameter to consider relates to charge air compression and cooling. Almost all engines rated under 37 kW are naturally aspirated (i.e., no turbocharging or aftercooling). For engines rated over 37 kW, EPA's certification records for engines complying with Tier 1 emission standards provide information on these engines' aspiration parameters. As shown in Table 4-1, substantial numbers of engines rated under 130 kW are currently naturally aspirated. For turbocharged engines, most have either no aftercooling or air-to-water aftercooling, though 10 to 20 percent of engines rated over 130 kW are equipped with air-to-air aftercooolers.

The certification data shows that almost all engines under 450 kW have mechanical controls, even though bigger engines almost all have electronic controls. Apparently the additional cost of developing electronic controls for these large engines is justified with the higher total cost of the product.

Table 4-1
Distribution of Engine Technologies in 1998 EPA Certification Data*

Power Rating	Aspiration		Aftercooling			Electronic Controls
	natural	turbo-charged	none	air-to-water	air-to-air	
37≤kW<75	67%	33%	33%	0%	0%	0%
75≤kW<130	25%	75%	20%	55%	0%	0%
130≤kW<450	0%	100%	30%	50%	20%	4%
450≤kW≤560	0%	100%	0%	90%	10%	86%

*Distributions based on manufacturers' projected sales volumes.

2. Projected technologies for Tier 1

The new Tier 1 standards, which apply only to engines rated under 37 kW, follow the Tier 1 standards already adopted for larger engines. Direct injection engines will likely be able to meet the standards through retarded injection timing and other modifications to engine design, such as re-entrant piston bowls, increased swirl, reduced crevice volume, and better ring packs for reduced oil consumption.

Indirect injection engines are already performing at levels that comply with the new Tier 1 standards and are therefore not expected to change in this time frame. Certification data from the California ARB for indirect injection engines rated under 19 kW, subject to a standard of 16 g/kW-hr (12 g/hp-hr) NMHC + NOx, show that these engines are typically emitting between 5 and 9 g/kW-hr (4 and 7 g/hp-hr). Engines rated between 19 and 37 kW are expected to have comparable emission levels.[4]

3. Projected technologies for Tier 2

Compliance with the Tier 2 standards, which apply to all power categories, will require a combination of engine technologies and design strategies. First, engine manufacturers are expected as much as possible to make an extensive review of engine design to reduce emissions and to incorporate a variety of changes for improved performance, fuel consumption, durability, or serviceability. These modifications will result in engines designed for optimum air flow and fuel-air mixing. With sufficient lead time, introducing a redesigned engine model gives the manufacturer opportunity to integrate several changes not directly related to emission control.

Second, electronic controls will likely play a role in controlling emissions from some engines. EPA expects that there will be an increasing demand for electronic controls in some sectors of the nonroad market, especially for the larger engines. In addition, electronic controls provide the designer with a very important tool for managing fuel injection and combustion processes to achieve optimum performance while controlling emissions. To reflect this, EPA projects that all direct injection engines rated over 37 kW will adopt electronic controls, either for Tier 2 or Tier 3 standards.

Improved fuel injection systems account for the third major change expected in response to Tier 2 standards. To account for the better emission control performance from indirect injection models, EPA has projected neither a cost nor an emission benefit related to the Tier 2 standards. Direct injection engines rated under 75 kW will likely continue to use rotary fuel pumps, which can be upgraded to increase fuel injection pressures to about 1,000 bar (15,000 psi) and to incorporate rate shaping of the fuel charge (either mechanically or electronically). Such fuel pumps are already available. For engines rated between 75 and 560 kW, the analysis projects improved unit injection systems that similarly provide the capability for higher injection pressures and injection strategies such as rate shaping or split injection. Common rail fuel injection systems, with increased control of fuel injection pressure, timing, and rate shaping, provide an attractive technology option for engines rated over 560 kW.

All engines rated between 75 and 560 kW are projected to utilize air-to-air aftercooling to meet either Tier 2 or Tier 3 emission standards. Whether engines currently have no aftercooling or air-to-water aftercooling, deploying air-to-air aftercooling provides a very big advantage in limiting NOx formation. In addition, the upgraded aftercooling system carries substantial benefits for improved fuel consumption and improved engine durability.

Finally, manufacturers may take a different approach for engines rated between 37 and 75 kW because of the greater cost sensitivity of these engines. Some manufacturers have indicated a preference to rely on turbocharging for these engines, but to use uncooled EGR instead of aftercooling to reduce NOx emissions. Relative to aftercooling, the fuel economy penalty associated with uncooled EGR is thought to be outweighed by its lower initial cost.

The result of engine modifications, new electronic controls, improved fuel injection, turbocharging, and aftercooling will be engines with better performance in addition to enhanced emission control. To estimate the impact of the new emission standards, EPA has therefore discounted the cost of these technologies and design strategies by one-half. Halving the projected costs of technological changes is intended to provide a distinction between benefits related to emission controls and benefits related to other aspects of engine performance. This approach is described more completely in the Final RIA for the emission standards for 2004 model year heavy-duty highway engines.[5]

4. Projected technologies for Tier 3

The engine changes for complying with Tier 3 standards will in many cases follow directly from the developments needed to meet emission standards for 2004 model year highway engines. Accordingly, these projections rely extensively on the analysis developed for highway engines, adapting the information as needed to apply to nonroad models. The Tier 3 standards, scheduled to take effect between 2006 and 2008 for engines rated between 37 and 560 kW, will also require multiple technological improvements.

Engines rated between 75 and 560 kW are projected to complete the shift to electronic controls and air-to-air aftercooling, while introducing cooled EGR and common rail fuel injection. Engines rated between 37 and 75 kW are expected to use an increased degree of uncooled EGR with further emission control resulting from new electronically controlled fuel injection systems.

C. Cost of Engine Technologies

The analysis includes cost estimates for the six power categories listed in Table 4-2, which are based generally on the standards specified for various engine sizes. Grouping engines this way is necessary to make distinctions in the cost of compliance based on engine size. Each power category nevertheless encompasses a rather wide range of engines. The analysis develops a cost estimate for a single engine near the middle of the range represented. Costs for engines on the high end of the power range would generally be higher than the nominal value presented and vice versa. Costs for engine sizes near the boundaries of the ranges can best be approximated by interpolation.

Table 4-2
Power Categories for
Estimating Incremental Costs

Power Range	Nominal Engine Power
0-37 kW (0-50 hp)	20 kW (25 hp)
37-75 kW (50-100 hp)	50 kW (75 hp)
75-130 kW (100-175 hp)	100 kW (150 hp)
130-450 kW (175-600 hp)	250 kW (300 hp)
450- 560 kW (600-750 hp)	500 kW (650 hp)
560+ kW (750+ hp)	750 kW (1000 hp)

EPA believes it is appropriate to use cost estimates for highway engines as the starting point for estimating nonroad engine costs for two main reasons. First, manufacturers have generally confirmed EPA's understanding that emission controls from diesel engines will rely on similar technology development, regardless of the application. The analysis therefore projects the use of similar technologies for different sizes of engines, with some variations to reflect the different characteristics of the smaller and bigger engines. The analysis also adjusts the variable costs according to the size of the engine. Second, the timing to introduce the new standards is intended to maximize the potential for transferring technology from highway to nonroad engines. An additional important factor is EPA's belief that manufacturers will increasingly sell single engine models into both highway and nonroad markets. Using an engine for both highway and nonroad applications is a very appealing way to minimize costs by reducing technology development efforts. Especially with the advent of electronic controls, the differences between highway and nonroad engines can be limited to the software driving the electronic controls and perhaps the specifications for bolt-on components such as turbochargers and aftercoolers.

R&D expenditures for emission-control development for engines with highway counterparts are therefore typically estimated at 10 percent of the total previously estimated for highway engines. A greater effort is anticipated to transfer and adapt technology development to smaller and bigger engines. Retooling costs are somewhat harder to predict, but are generally projected to be 10 to 20 percent of the total R&D expenditure for the same engines. Since tooling costs are consistently smaller than R&D, the retooling estimates are not a sensitive component of the total cost projections.

To adapt the highway cost estimates to nonroad engines, the analysis anticipates light heavy-duty vehicle technology to transfer most directly to 100 kW engines, while medium heavy-duty vehicle technology will transfer most directly to 250 kW engines. With somewhat greater adaptation, the heavy heavy-duty vehicle estimates can be applied to 500 kW engines. Cost estimates for 20, 50, and 750 kW engines were in most cases developed by using engineering judgment to extrapolate the previously developed cost estimates.

1. Engine modifications

All engines are projected to go through a significant upgrade over the course of the implementation of the new emission standards. Manufacturers are expected in some cases to conduct a major redesign either for the first or second tier of new standards, depending on the need for near-term reductions and the opportunities for improvements unrelated to emission controls (among other things). Furthermore, some manufacturers may make engine modifications to a smaller degree for both tiers of new standards. To reflect this distribution of effort between the tiers of standards, costs for engine modifications are divided between tiers.

Engine modifications, including retarded injection timing, involve substantial fixed costs for R&D and retooling and may add to the operating cost through higher fuel consumption, but EPA estimates no variable cost associated with these changes. Estimated costs for highway engines were $5 million for R&D and $350,000 for retooling per engine family. Projected R&D costs for nonroad engines range from $500,000 for engines rated between 75 and 450 kW to $3,300,000 for engines rated over 560 kW. Additional R&D expenditures are allocated for individual technologies, as described below.

Fixed costs are calculated on a unit basis by amortizing the total outlays over several years of production. A five-year amortization was selected as representative for most engines. Manufacturers are expected to amortize fixed costs for Tier 3 engines rated between 450 and 560 kW and for Tier 2 engines rated over 560 kW over 10 years to spread the costs over a greater number of engines. Annual domestic sales volumes are derived from the PSR OE Link database by adding up average annual sales over a five-year period for current engine models (Table 4-3). Under a scenario of harmonized emission standards, manufacturers can mitigate the impact of incurred fixed costs by distributing those costs over international sales volumes. Engine manufacturers provided data showing that on average they sell about 20 percent of their product in the U.S., with the rest going to foreign markets.[6] Table 4-3 shows the effect of increasing average sales volumes per model to reflect global markets.

Manufacturers would minimize the per-engine cost impact by distributing fixed costs over total worldwide sales, even though globally harmonized emission standards are not expected in the foreseeable future. This may nevertheless be appropriate if manufacturers choose to simplify production by offering a single low-emitting engine even in countries that have either no emission standards or less stringent emission standards. On the other hand, quantifying the fraction of engine sales going to those countries anticipated to have harmonized emission standards (Canada, Japan, and European Union members) would be very difficult. To test the sensitivity of different amortization calculations, Appendix A shows the effect of distributing fixed costs over only half of engine sales outside the U.S.

Table 4-3
Analytical Assumptions for Domestic and Global
Average Sales Volumes per Engine Model

Power Range	Domestic Sales Volume	Global Sales Volume
0-37 kW	1286	5787
37-75 kW	2237	10,067
75-130 kW	2409	10,841
130-450 kW	1322	5949
450- 560 kW	99	446
560+ kW	154	693

The widely varying cost estimates and sales volumes for different size engines cause very wide disparities in the per-engine costs of making the expected engine modifications (see Table 4-4). The low values of under $100 for a complete redesign for engines rated at or below 250 kW reflects the effect of technology transfer and relatively high sales volume. The higher values for engines rated over 450 kW show that high per-engine costs result from amortizing large fixed costs over very small sales volumes. Table 4-4 shows that amortizing costs over a longer period allows manufacturers to soften the sharp effect of low sales volumes.

The anticipated increase in operating costs for engines rated under 37 kW is focused on the minority of engines that need design improvements, as described above, totaling about $130 in net present value (npv) over the lifetime of those engines. The calculated sales-weighted composite increase in operating costs for all engines rated under 37 kW is about $30 in the Tier 1 time frame, with an additional $30 projected for the tier 2 time frame.

Table 4-4
Cost Calculation for Engine Modifications

	20 kW	50 kW	100 kW	250 kW	500 kW	750 kW
R&D	$2,000,000	$2,000,000	$500,000	$500,000	$2,000,000	$3,300,000
tooling	$200,000	$200,000	$100,000	$100,000	$200,000	$330,000
Unit fixed cost (5-yr)	$93	$53	$13	$25	$1204	—
Unit fixed cost (10-yr)	—	—	—	—	$703	$746
Tier 1 percentage	33%	—	—	—	—	—
Composite engine cost	**$31**	—	—	—	—	—
Operating cost	**$44**	**—**	**—**	**—**	**—**	**—**
Tier 2 percentage	33%	15%	50%	50%	50%	100%
Composite engine cost	**$31**	**$8**	**$7**	**$12**	**$602**	**$746**
Operating cost	**$44**	**—**	**—**	**—**	**—**	**—**
Tier 3 percentage	**—**	85%	50%	50%	50%	—
Composite engine cost	**—**	**$45**	**$7**	**$12**	**$352**	**—**

2. Electronic controls

Electronic controls have revolutionized engine design for light-duty and, more recently, heavy-duty highway engines. The experience with these engines has shown that electronic controls provide the engine designer with a tool that greatly enhances the emission control, engine performance, and fuel consumption characteristics of the engine. As electronic controls have seen increasing application, the cost of introducing electronics has decreased dramatically. The growing base of experience has reduced the development time to prepare the software to integrate the information from multiple sensors in managing the combustion process for an additional application. Also, the cost of designing and manufacturing the electronic control modules (ECMs), sensors, and other pieces of hardware has decreased as the engineering and production developments transfer to component development and manufacture for new applications. For example, for one recent engine conversion to electronic controls, an estimated 80 to 85 percent of the software was copied from other engine models.[7]

Arcadis has prepared a memorandum to characterize the variable and fixed costs of adopting electronic controls for the various sizes of nonroad engines.[8] Hardware costs include consideration of several components. Sensors are anticipated for measuring fuel pressure, crank angle, ambient temperature, intake air temperature (for turbocharged engines), and coolant temperature. Engines rated between 37 and 75 kW are expected to incorporate solenoids directly into the existing rotary fuel pumps, while bigger engines are expected to use electronically controlled fuel injectors. Finally, wiring harnesses and ECMs are needed to tie everything together. Based on information received during the comment period, EPA has reduced the estimated cost of adopting electronic controls for engines rated between 37 and 75 kW; the simpler design and operation of these engines allows a greater than anticipated cost savings relative to the bigger engines.

All direct injection engines are projected to adopt electronic controls, though several engine models with higher power ratings already utilize electronics (see Table 4-1). Engines rated between 37 and 75 kW are already certified at or below Tier 2 emission levels and would therefore be expected to have electronic controls starting in the Tier 3 time frame. Larger engines are expected to shift deployment of electronic controls more into the Tier 2 time frame, largely because of the greater potential for transferring technology from similar engine models already equipped with electronic controls.

Hardware costs for incorporating electronic controls depend on the number of cylinders or fuel injectors. Engines rated between 37 and 75 kW typically have four cylinders. For 100 kW and 250 kW models, almost all engines have six cylinders, while bigger engines are highly varied. The PSR OE Link database shows that engines rated between 450 and 560 kW have about 12 cylinders on average. Hardware costs are increased by 10 percent to account for a potential increase in warranty claims resulting from introduction of these substantially new systems.

Estimated R&D expenditures are based on development of multiple ratings for each engine model to reflect the multiple applications served by nonroad engines. The number of ratings was estimated by assigning one rating for each separate application for an engine model. EPA understands that the number of ratings for an engine model varies greatly from one model to another and from one manufacturer to another. The high costs contemplated for R&D reinforce EPA's belief that manufacturers will make a great effort to streamline their engine offerings to reduce the number of ratings offered for each engine. Reducing the number of ratings will lead to large savings in development costs.

Combining variable and fixed costs results in cost estimates that again vary widely according to engine size, as shown in Table 4-5. Total estimated costs for introducing electronic controls range from $400 for 50 kW engines to $2,200 for 500 kW engines.

Table 4-5
Cost Calculation for Electronic Controls

	50 kW	100 kW	250 kW	500 kW
ECM	$100	$150	$175	$250
modified fuel injectors		$180	$180	$420
electronic fuel pump	$115			
sensors	$43	$104	$114	$120
wiring harness	$5	$20	$20	$25
assembly	$13	$16	$16	$20
markup @ 29%	$80	$136	$146	$242
warranty @ 10%	$28	$47	$51	$84
Total hardware RPE	$383	$653	$702	$1,161
R&D	$1,250,000	$2,400,000	$2,250,000	$1,800,000
tooling	$220,000	$150,000	$155,000	$105,000
Fixed cost (per engine)	$36	$57	$99	$1043
Total engine cost	$419	$711	$801	$2204
Percentage applied—Tier 2	—	75%	75%	15%
Composite cost—Tier 2	**—**	**$533**	**$600**	**$331**
Percentage applied—Tier 3	85%	25%	20%	—
Composite cost—Tier 3	**$356**	**$178**	**$160**	**—**

3. Improved fuel injection hardware

Fuel injection is central to any analysis of diesel engine emission control. Engines of different sizes will experience very different improvements in fuel injection hardware. Three types of improvements are considered below.

a. rotary fuel pumps

For direct injection engines rated under 75 kW, EPA expects manufacturers to use rotary pumps designed with larger plungers or with modified cam profiles to achieve higher injection pressures. Other parts and assemblies will need to be stronger to accommodate the higher pressures. A multiple-spring assembly in the injector can be added to provide rate-shaping capability.

EPA estimated R&D costs for rotary pumps by allotting $3 million for a fuel pump supplier to design each of two pumps, one for engines rated under 37 kW and the other for engines rated between 37 and 75 kW. Fixed costs are amortized assuming that two companies supply injectors to all these engines. Hardware costs are marked up for both the suppliers' and the manufacturers' overhead and profit. Engine retail prices are estimated to increase by about $120 as a result of these upgraded fuel pumps (see Table 4-6). For engines rated under 37 kW, improved fuel pump costs are applied to all direct injection models and half of indirect injection models. Incremental fuel pump costs for engines rated between 37 and 75 kW are included as one of the cost elements for incorporating electronic controls.

Table 4-6
Cost Calculation for Improved Rotary Fuel Pumps

	20 kW	50 kW
incremental material markup @29%	$60 $17	$60 $17
Supplier's variable cost	$77	$77
R&D	$3,000,000	$3,000,000
tooling	$500,000	$500,000
engines per year	95,000	75,000
Fixed cost (per engine)	$13	$11
Total cost from supplier	$91	$89
Mfr. markup @ 29%	$26	$26
Total engine cost	$117	$115
Percentage applied—Tier 2	67%	—
Composite cost	**$78**	**—**

b. unit injection

Engines rated between 75 and 450 kW are projected to need upgraded unit injection systems. Previously developed costs were based on electronically controlled engines, but mechanically controlled engines will likely need a comparable degree of modification; the same cost estimates are therefore applied to both types of engines. The increased cost for stronger materials and additional components adds about $20 per injector to the price of these engines. Total incremental engine costs related to these improvements range from $100 to $630 (see Table 4-7).

Table 4-7
Cost Calculation for Improved Unit Injectors

	100 kW	250 kW	500 kW
incremental material improved solenoid markup @ 29%	$18 $45 $21	$24 $51 $25	$40 $80 $39
Total hardware RPE	$95	$113	$174
R&D	$150,000	$150,000	$600,000
tooling	$56,000	$35,000	$230,000
cylinders per engine	6	6	8
Fixed cost (per engine)	$5	$8	$454
Total engine cost	**$99**	**$120**	**$629**

c. common rail

Several highway engines have clearly demonstrated the benefits and the feasibility of using common rail injection systems. Common rail systems provide a constant supply of pressurized fuel at the injectors, which greatly increases control of the injection process. Available injection pressure does not decrease at low engine speeds, though the designer can in some cases vary the injection pressure based on the particular characteristics of different engine operating modes.

Engines converting to common rail need a high-pressure pump to maintain a consistent pressure of a fuel or oil reservoir. Injectors would have to be reconfigured to handle different actuation and pressures and solenoid control valves would be needed to control the timing and degree of fuel delivery to the combustion chamber. Cost estimates are developed for an engine that has been equipped with electronic controls. Engines rated between 450 and 560 kW are projected to adopt common rail technology on an earlier schedule, rather than continuing to modify unit injection systems. Resulting engine cost increases range from $120 to $600 (see Table 4-8).

Table 4-8
Cost Calculation for Improved Common Rail Fuel Systems

	100 kW	250 kW	500 kW	750 kW
solenoid control valves	$30	$36	$56	$108
higher pressure oil pump	$60	$65	$75	$85
markup @ 29%	$26	$29	$38	$56
Total hardware RPE	$116	$130	$169	$249
R&D	$150,000	$150,000	$600,000	$1,000,000
tooling	$64,000	$40,000	$160,000	$270,000
cylinders per engine	6	6	8	12
Fixed cost (per engine)	$5	$8	$416	$261
Total cost	**$121**	**$138**	**$585**	**$510**
Percentage applied—Tier 2	—	—	50%	100%
Composite engine cost	**—**	**—**	**$293**	**$510**
Percentage applied—Tier 3	100%	100%	50%	—
Composite engine cost	**$121**	**$138**	**$293**	**—**

4. Exhaust gas recirculation

The biggest technology change anticipated in response to the new standards is adoption of cooled EGR systems for engines in the Tier 3 time frame. Extensive R&D effort will be required to develop EGR technologies that control emissions without compromising engine performance or durability. The timing of the Tier 3 standards, however, is based on the expectation that manufacturers will be able to adapt well-developed EGR systems from highway engines to work in nonroad engines. The analysis therefore leaves out the costs of basic research, but includes considerable R&D costs for tailoring these basic EGR system designs to nonroad engines. EGR designs are expected to include a valve and sufficient tubing to route exhaust gases into the engine's air intake. A heat exchanger will likely be installed to cool the recirculated exhaust with engine coolant. Total EGR-related price increases, detailed in Table 4-9, range from $90 to $800.

As described earlier, engines rated between 37 and 75 kW are expected to take a somewhat different approach to EGR, introducing the technology sooner, but omitting EGR cooling. This has the effect of reducing the impact on initial purchase price, but will likely correspond with an increase in fuel consumption. EPA expects manufacturers to use a relatively light degree of EGR to comply with Tier 2 standards with direct-injection engines, then increase the extent of exhaust recirculation to comply with Tier 3 standards. The analysis incorporates this effect by assessing a one-half percent penalty in fuel consumption for Tier 2 and an additional one-half percent penalty for Tier 3. The estimated effect of the combined tiers of standards is an increase of $120 in lifetime fuel costs (net present value).

Table 4-9
Cost Calculation for Exhaust Gas Recirculation

	Tier 3			
	50 kW	100 kW	250 kW	500 kW
electronic EGR valve	$30	$35	$35	$50
EGR tubing	$7	$9	$14	$30
EGR cooler		$48	$53	$75
assembly	$7	$7	$7	$7
markup @ 29%	$13	$29	$31	$47
warranty @ 10%	$4	$10	$11	$16
Total hardware RPE	$60	$137	$151	$224
R&D	$1,000,000	$1,000,000	$1,000,000	$1,000,000
tooling	$40,000	$40,000	$40,000	$40,000
Fixed cost (per engine)	$25	$23	$43	$569
Total engine cost	**$86**	**$160**	**$193**	**$794**
rebuild cost impact	$44	$48	$56	$121
improved oil impact	$4	$6	$9	$15
fuel economy impact	$62	—	—	—
Total Operating Cost (npv)	**$110**	**$55**	**$65**	**$135**
Percentage applied—Tier 2	45%	—	—	—
Composite engine cost	$39	—	—	—
Composite operating cost	$50	—	—	—
Percentage applied—Tier 3	40%	100%	100%	100%
Composite engine cost	$34	$160	$193	$794
Composite operating cost	$44	$55	$65	$135

The EGR cooler goes a long way toward resolving the potential deleterious effects of EGR on fuel consumption and engine durability for the bigger engines. Recirculating particulate matter through the engine remains an issue. As described in the highway analysis, EPA believes that the great concern for these potential negative effects will drive manufacturers to make additional R&D investments in the intervening years to overcome these concerns. EPA anticipates that the effort to design acceptable EGR technology for highway engines will resolve these concerns for fuel consumption and durability effects. As in the analysis for highway engines, an estimated 2 percent increase in the cost of engine oil is included to reflect the outcome of the R&D effort. The increased cost of oil changes are calculated over the lifetime of the engines; the net present value of increased operating costs range from $4 to $15 per engine.

Engines rated between 37 and 75 kW

EPA anticipates that EGR systems will be serviced at the point of rebuild, including replacement of the EGR valve and solvent cleaning of the EGR tubing. The aftermarket cost of an EGR valve is estimated at three times the manufacturer's long-term cost. Cleaning time for a mechanic is estimated at 30 minutes. For this analysis, rebuilding for engines equipped with EGR is expected to occur after 10 years of operation. Median lifetimes developed from PSR's PartsLink database lead EPA to conclude that 40 percent of engines rated at or below 250 kW will be rebuilt, while 60 percent of larger engines are expected to continue operation until the point of rebuild. The resulting net present value of the increased rebuild burden is estimated as an average for all engines between $40 and $120 per engine.

5. Turbocharging and Aftercooling

Manufacturers are expected to rely on new or improved turbochargers and aftercoolers to reduce both NOx and PM emissions. Turbochargers increase the amount of air entering the cylinder by compressing the charge air. To offset the heating of the charge air coming out of the turbocharger, aftercoolers extract heat from the compressed charge air, further increasing its density. Air-to-water aftercoolers use the engine's main cooling system to cool the air approximately to the engine operating temperature. Air-to-air aftercoolers use fan-driven ambient air to more effectively cool the charge air.

Used together, turbochargers and aftercoolers allow manufacturers to produce more power with greater thermal efficiency, while suppressing NOx and PM emission formation. These performance advantages have led to common use of these technologies in relatively large nonroad diesel engines. Most of these engines, however, typically use turbocharging either with no aftercooling or with air-to-water aftercooling. Almost all highway diesel engines, which are subject to more stringent emission standards and have the added benefit of naturally high air speeds, have long relied on turbocharging and air-to-air aftercooling to achieve the maximum benefit from these systems.

The added cost and complexity of charge air compression and cooling have so far prevented most nonroad engines rated less than 100 or 150 kW from using turbocharging and aftercooling. The growth in the market for light-duty automotive diesel engines has contributed to the development of low-cost turbochargers sized for nonroad engines of comparable power ratings. Manufacturers have expressed an interest or intent to adopt turbocharging for engines currently rated as low as 40 or 60 kW. EPA has therefore incorporated into the cost analysis a projection that all direct injection engines rated over 37 kW will use turbochargers. For engines rated between 37 and 75 kW it may be more appropriate to consider supercharging, which would provide better low-speed and transient performance at the expense of some fuel economy improvement. The emission control potential and cost impact would be somewhat different for turbocharging and supercharging, but such distinctions are relatively minor and are not quantified in this analysis. Also, as described above, these engines are expected to rely on EGR instead of aftercooling to control emissions

Engines rated over 75 kW are all projected to adopt air-to-air aftercooling. Considering the reluctance of some equipment manufacturers to accept such a major change in engine system configuration, some engine manufacturers may attempt to meet Tier 2 and Tier 3 standards with air-to-water aftercooling systems. Aside from such redesign considerations, engine manufacturers are expected to add or convert to air-to-air aftercooling as broadly as possible for the emission control and performance benefits described above. Table 4-1 characterizes the deployment of turbocharging and aftercooling variations for current engines and provides a basis for calculating the percentage of engines in each power range that will make specific technology changes.

Table 4-10 lays out the cost components involved for adding a turbocharger to an engine, including the turbocharger itself, a waste gate, additional material, R&D, and a markup. The resulting incremental cost per engine is $300 and $550 for 50 and 100 kW engines, respectively.

The calculation of aftercooling is more complex, both because of the complexity of the systems and because of the potential for conversion from one type of aftercooling to another. Table 4-11 details the cost of adding an air-to-air aftercooler to an engine that previously had no aftercooling. The principal cost component is a new heat exchanger dedicated to the aftercooling system. The dramatically higher price estimated for the largest engines reflects the effect on costs from producing large units with very low sales volumes. Including the cost of other components, assembly, R&D, and markup leads to total engine costs for adding air-to-air aftercooling that range from $350 for a 100 kW engine to $4,000 for a 500 kW engine.

To determine an estimated cost for converting from air-to-water to air-to-air aftercooling, the analysis develops a cost for adding air-to-water aftercooling to an engine that previously had no aftercooling. Those costs, when subtracted from the air-to-air aftercooling costs in Table 4-11, yield a net cost to upgrade aftercooling systems. Estimated costs for upgraded aftercooling range from $120 for a 100 kW engine to $1300 for a 500 kW engine. These much lower costs for upgrading aftercooling systems result from the savings involved in decreasing the size of the main heat exchanger, which can then be dedicated to engine cooling.

As described earlier, turbocharging and aftercooling offer compelling performance benefits independent of the better control of emissions. EPA attempted to incorporate these benefits into the analysis, though much differently for turbocharging and aftercooling. For turbocharging, performance benefits are difficult to quantify in monetary terms; the analysis therefore discounts the total cost of turbocharging by 50 percent, as for fuel injection improvements and general engine modifications. EPA believes this discounted cost is the best way of isolating the effects of emission controls for an estimate of the impact of the new standards.

For aftercooling, it is possible to estimate an improvement in fuel economy, which can be calculated directly as a cost credit. The hardware costs for aftercooling are therefore included in the analysis with no discount. Manufacturers have expressed an expectation that upgrading from air-to-water aftercoolers to air-to-air aftercoolers at Tier 1 emission levels would allow them to improve fuel economy by 6 to 8 percent. That benefit would decrease at lower NOx emission levels. EPA's best estimate of the fuel economy improvement is therefore 3 percent for upgraded aftercooling systems and 6 percent for those engines that currently have no aftercooling. The resulting cost savings is in all cases greater than the incremental cost of adopting the technology, which is consistent with engine manufacturers' eagerness to move toward air-to-air aftercooling.

Table 4-10
Cost Calculation for Turbocharging

	50 kW	100 kW
turbocharger hardware waste gate additional materials markup @ 29%	$150 $55 $30 $68	$300 $75 $50 $123
Total hardware RPE	$303	$548
Engine R&D	$250,000	$250,000
engines per year	$50,000	$30,000
Fixed cost (per engine)	$1	$2
Total engine cost	**$304**	**$550**
Percentage deployment—Tier 2	50%	50%
Composite cost	**$152**	**$138**

Table 4-11
Cost Calculation for Air-to-Air Aftercooling

	100 kW	250 kW	500 kW
heat exchanger	$210	$700	$2800
plumbing	$18	$23	$29
hardware	$5	$6	$7
assembly	$10	$10	$10
markup @29 %	$70	$214	$825
warranty @ 10 %	$24	$74	$285
Total hardware RPE	$338	$1027	$3956
R&D	$300,000	$300,000	$300,000
tooling	$30,000	$30,000	$30,000
Fixed cost (per engine)	$7	$14	$181
Total engine cost (AA)	**$345**	**$1041**	**$4137**
Total operating cost (npv)	**($1177)**	**($2097)**	**($5988)**
Percentage applied—Tier 3	45%	30%	—
Composite cost—Tier 3	**$155**	**$312**	**—**

Table 4-12
Cost Calculation for Converting from
Air-to-Water to Air-to-Air Aftercooling

	100 kW	250 kW	500 kW
Air-to-Water Aftercooling:			
incremental radiator	$120	$400	$1600
supplier's markup @ 29 %	$35	$116	$464
plumbing	$9	$12	$15
hardware	$2	$3	$4
assembly	$3	$3	$3
markup @29 %	$49	$155	$605
Total hardware RPE	$218	$688	$2690
R&D	$200,000	$200,000	$200,000
tooling	$30,000	$30,000	$30,000
Fixed cost (per engine)	$5	$9	$126
Total engine cost (AW)	$223	$698	$2816
Total engine cost (AA)	$345	$1041	$4137
Net engine cost	**$122**	**$343**	**$1320**
Net operating cost (npv)	**($588)**	**($1048)**	**($2994)**
Percentage applied—Tier 2	25%	25%	40%
Composite cost—Tier 2	**$31**	**$86**	**$594**
Percentage applied—Tier 3	30%	25%	45%
Composite cost—Tier 3	**$37**	**$86**	**$594**

6. Closed crankcase

Naturally aspirated engines will be required to have closed crankcases. The necessary hardware, a simple tube with a PCV valve to route the crankcase vapors into the engine's air intake, can be readily adapted from highway engine models. The estimated cost for these components is $10, with no additional amount allocated for R&D (see Table 4-13). Due to the small number of naturally aspirated engines with high power ratings, costs are estimated only for 20 and 50 kW engines. As described above, several of these engines will be turbocharged in the future, thereby eliminating the need for a closed crankcase.

Table 4-13
Cost Calculation for Closed Crankcases

	20 kW	50 kW
PCV valve tubing assembly markup @29%	$5 $2 $1 $2	$5 $2 $1 $2
Total hardware RPE	$10	$10
Total engine cost	**$10**	**$10**

D. Projected Cost of Technology Packages

Added to the cost of incorporating the new engine technologies is the cost of certifying engine families. To factor in certification costs, the analysis uses a figure of $60,000 per engine family, allowing for two emission tests, two months of engineering time, and miscellaneous fees and expenses. Distributing those costs across the different engine categories, amortizing the costs over five years, and dividing by the number of projected sales results in per-engine costs of less than $15 for engines rated below 450 kW. Dividing the same costs over the larger engines with lower sales volumes leads to calculated costs of up to $150 per engine, as shown in Table 4-14.

The cost of combining the above technology elements to comply with the new standards is shown in Table 4-14. Where costs are discounted to reflect benefits unrelated to emission control requirements, this is factored into the individual technology costs shown. Tier 1 standards for engines rated under 37 kW have estimated incremental costs below $50 per engine for both retail price and increased operating expenses.

Tier 2 standards involve generally higher cost impacts than are expected from Tier 1 standards. The incremental cost to engines rated 250 kW or less is expected to be $70 to $460, while bigger engines may face incremental costs of $700 to $1400. The cost of complying with Tier 3 standards is similar to that for Tier 2, though the Tier 3 standards apply only to engines rated between 37 and 560 kW. The effect of improved fuel economy resulting from air-to-air aftercooling is shown by the projected reduction in operating costs, which for several engines completely offsets the projected incremental cost of incorporating new technologies.

Table 4-14
Incremental Unit Cost of Complying
with New Emission Standards—Engines

Em. Std.	Engine Technology	Percent Attributed to Em. Standards	Weighted Unit Cost					
			20 kW	50 kW	100 kW	250 kW	500 kW	750 kW
Tier 1	Engine modifications operating cost (NPV)	75%	$23 $44	—	—	—	—	—
	Certification	100%	$11	—	—	—	—	—
	Total first-year costs operating cost (NPV)	—	$34 $44	—	—	—	—	—
Tier 2	Engine modifications operating cost (NPV)	50%	$15 $44	$4 $9	$3 $0	$6 $0	$301 $0	$373 $0
	Electronic controls	50%	—	—	$267	$300	$165	—
	Improved injection	50%	$39	—	$50	$60	$146	$255
	EGR operating cost (NPV)	100%	—	$39 $50	—	—	—	—
	Turbocharger	50%	—	$76	$69	—	—	—
	AA Aftercooler upgrade operating cost (NPV)	100%	—	—	$31 ($147)	$86 ($262)	$594 ($1347)	—
	Closed crankcase	100%	$10	—	—	—	—	—
	Certification	100%	$8	$6	$6	$12	$148	$55
	Total first-year costs operating cost (NPV)	—	$72 $44	$124 $59	$425 ($147)	$463 ($262)	$1355 ($1347)	$683 $0
Tier 3	Engine modifications operating cost (NPV)	50%	—	$23 $53	$3 $0	$6 $0	$176 $0	—
	Electronic controls	50%	—	$178	$89	$80	—	—
	Common rail systems	50%	—	—	$60	$69	$146	—
	EGR operating cost (NPV)	100%	—	$34 $44	$160 $55	$193 $65	$794 $135	—
	AA Aftercooler upgrade operating cost (NPV)	100%	—	—	$37 ($177)	$86 ($262)	$594 ($1347)	—
	New AA Aftercooler operating cost (NPV)	100%	—	—	$155 ($530)	$312 ($629)	—	—
	Certification	100%	—	$6	$6	$12	$148	—
	Total first-year costs purchase price operating cost (NPV)	—	—	$240 $97	$511 ($652)	$758 ($826)	$1858 ($1212)	—

Characterizing these estimated costs in the context of their fraction of the total purchase price is helpful in gauging the economic impact of the new standards. ICF conducted a study to characterize the range of current prices for nonroad engines by collecting quoted list prices on a variety of engines.[9] Taking a straight average of these prices, and allowing a 40 percent discount off of list price results in a best estimate of actual prices for the various sizes of nonroad diesel engines, as shown in Table 4-15. The incremental costs estimated in this analysis for engines over 450 kW seem particularly high, but in fact represent a comparable price change relative to the total price of the engine. The estimated cost increases for all engines are between 1 and 13 percent of actual sales prices. Moreover, the cost savings described below further reduce the anticipated impact of the emission standards; long-term cost increases are expected to be less than 8 percent of total engine price.

Table 4-15
Estimated Prices for New Nonroad Diesel Engines

Power Range	List Price	Estimated Sale Price
0-37 kW (0-50 hp)	$4,000	$2,400
37-75 kW (50-100 hp)	$5,900	$3,500
75-130 kW (100-175 hp)	$6,700	$4,000
130-450 kW (175-600 hp)	$12,600	$7,500
560+ kW (750+ hp)	$79,800	$47,900

E. Summary of Engine Costs

The per-engine cost figures presented above are used in Chapter 6 to calculate the cost-effectiveness of the program by comparing the costs to lifetime emission reductions. Included in that calculation are the costs developed for first-year engines above, with the following modifications for later model year production.

First, the analysis anticipates that manufacturers recover their initial fixed costs for tooling, R&D, and certification over a five-year period. Fixed costs are therefore applied only to the first five model years of production.

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

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[10,11] As shown in Figure 4-1, of the 108 progress ratios observed, 8 were less than 70 percent, 39 were in the range of 71 to 80 percent, 54 were in the range of 81 to 90 percent, and 7 were above 90 percent. The average progress ratio for the whole data set falls between 81 and 82 percent. The lowest progress ratio of 55 percent shows the biggest improvement, representing a remarkable 45 percent reduction in costs with every doubling of production volume. At the other extreme, except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least 5 percent for every doubling of production volume. This data supports the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent. As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable level, beyond which increased production does not necessarily lead to markedly decreased costs.

EPA applied a p value of 20 percent in this analysis. That is, the variable costs were reduced by 20 percent for each doubling of cumulative production. To avoid overly optimistic projections, however, EPA included several additional constraints. Using one year as the base unit of production, the first doubling occurs at the start of the third model year and the second doubling at the start of the fifth model year. To be conservative, EPA incorporated the second doubling at the start of the sixth model year. Recognizing that the learning curve effect may not continue indefinitely with ongoing production, EPA used only two p cycles.

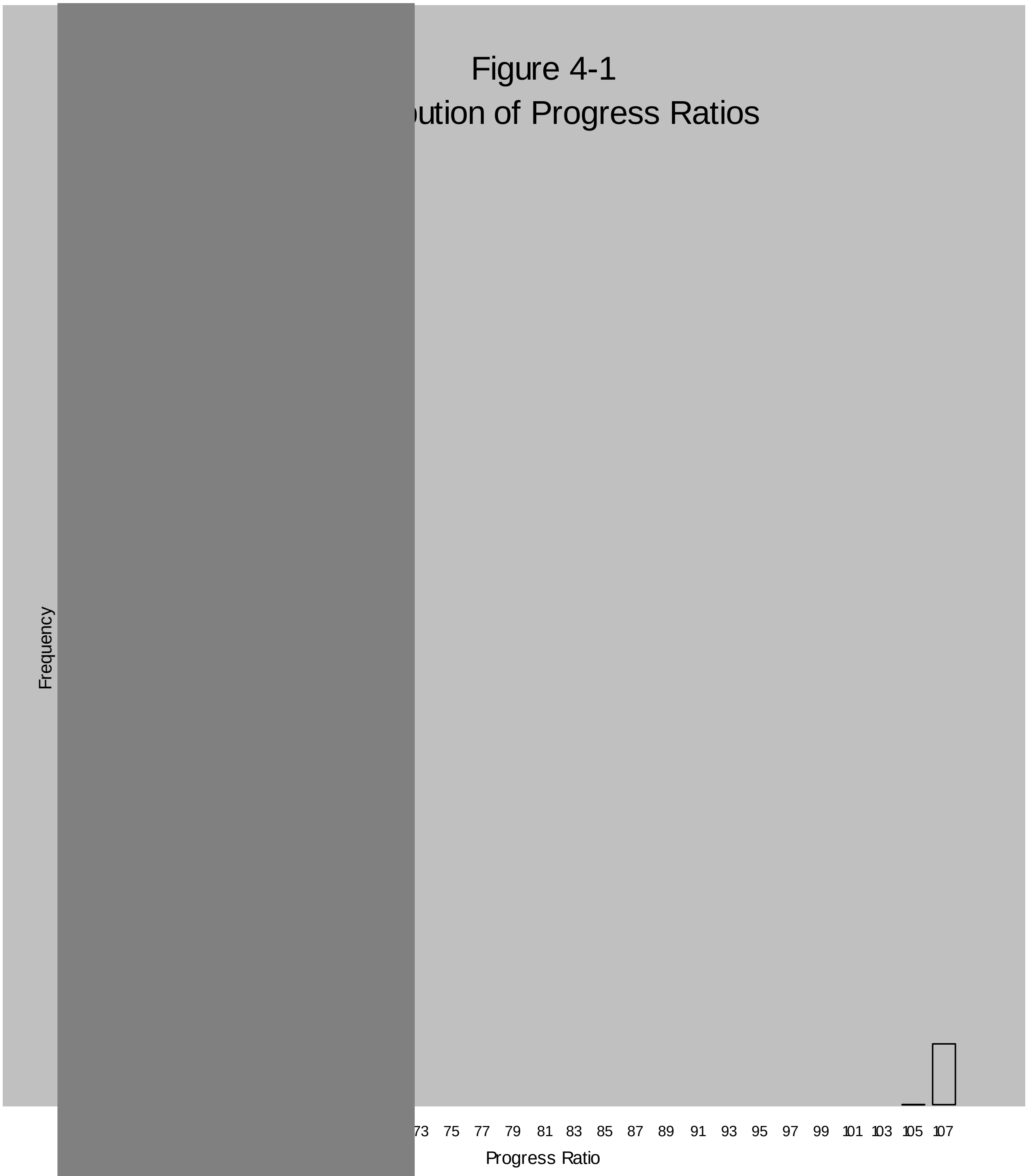


Figure 4-1

bution of Progress Ratios

From 22 field studies (n = 108).

EPA believes the use of the learning curve is appropriate to consider in assessing the cost impact of diesel engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. While all the technologies projected in this analysis specify either upgraded existing designs or transferred highway developments, the changes envisioned nevertheless require manufacture of new components and assemblies, involving new manufacturing operations. As manufacturers gain experience with these new systems, comparable learning is expected to occur with respect to unit labor and material costs.

Table 4-16 lists the projected schedule of costs over time for each power category. The estimated long-term cost savings are most pronounced for those engines whose costs are attributed mostly to R&D and other fixed costs. In particular, the initial estimated costs of $800 to $1900 for the biggest engines are reduced to levels $500 or less by the sixth year of production. The estimated impact on operating costs does not change over time and is therefore not shown in Table 4-16.

Table 4-16
Projected Long-Term Increase in Prices
Due to Tier 3 Standards—Engines

Years of Production*	Power (kW)			
	50	100	250	500
1-2	$240	$511	$758	$1858
3-5	$203	$418	$623	$1691
6+	$120	$297	$435	$535

*Year 3 costs are adjusted by reducing variable costs by 20 percent (fixed costs remain unchanged). Year 6 costs are adjusted by reducing variable costs an additional 20 percent and eliminating fixed costs.

II. Cost of Redesigning Equipment

As discussed earlier in this chapter for engine costs, the final rule sets a long-term schedule of emission standards extending well into the next decade, helping both engine and equipment manufacturers to plan and execute a comprehensive R&D program. The following section presents EPA’s analysis of the costs that equipment manufacturers will incur as a result of the new emission standards.

A. Methodology

Using the engine technology and cost information provided in the preceding section, EPA was able to develop estimates for the costs expected for equipment manufacturers to accommodate the newly redesigned engines. According to the PSR OE Link database and discussions with equipment and engine manufacturers, there are about 1,000 nonroad equipment manufacturers using diesel engines in many thousands of different applications. EPA realizes that the time needed for equipment manufacturers to make these changes will vary significantly from manufacturer to manufacturer and from application to application. As with the analysis of engine costs, EPA assessed the cost of equipment changes by evaluating a relatively uniform emission control strategy. Actual strategies may differ from those presented here, but EPA believes that the estimated costs in this analysis are representative of a wide range of equipment redesign scenarios. The provisions granting compliance flexibility to equipment manufacturers are intended to reduce the potential for anomalously high costs for individual equipment models.

As described earlier in this chapter, costs of control to equipment manufacturers include fixed costs (for R&D and tooling) and variable costs (for incremental hardware costs, assembly costs, and associated markups). Also, as for the engine costs, variable costs for equipment are marked up at a rate of 29 percent to account for equipment manufacturers' overhead and profit. Cost estimates for redesigning equipment are presented as the first-year production costs for the new emission standards. Costs in subsequent years will decrease based on an expected learning curve for equipment manufacturers and the eventual recovery of fixed costs.

B. Equipment Changes

The modifications to equipment due to the new standards relate to packaging (installing engines in equipment engine compartments), power train (torque curve), and heat rejection effects of the newly complying engines. The anticipated changes to nonroad equipment are drawn from the preceding analysis of projected changes to engine technology. EPA's emphasis on ongoing technological development is doubly important in the context of equipment impacts. Absent new emission standards, both engine and equipment manufacturers would be expected to pursue technological developments for improving product lines. To the extent that manufacturers have time to coordinate changes, the burden of redesigning equipment for emission standards can be minimized by including those changes as part of a comprehensive effort to develop and produce an improved product.

All engines rated under 560 kW face two tiers of new emission standards. Equipment manufacturers are expected to redesign their equipment models for the first tier of standards to minimize further changes for the next tier of engines to the greatest extent possible. To analyze costs for equipment, EPA projected one comprehensive redesign for each model. To reflect the possibility of splitting costs between the tiers or deferring significant redesign until the second tier of new engines, EPA divided costs between the two tiers of new emission standards. To divide costs, EPA allocated three-fourths of total costs (fixed plus variable costs) to Tier 2 standards and one-fourth of total costs to Tier 3 standards. In making this assumption for the analysis, EPA is not in any way stating an expectation that the standards will, in fact, produce this particular redesign schedule.

The projections of effort needed to make equipment changes were generally developed by considering the manufacturer's past experience in accommodating redesigned engines, applying engineering judgment as needed to quantify the projected changes. The following section details

EPA’s assessment of costs to equipment manufacturers.

C. Cost of Equipment Changes

The analysis includes cost projections for nonroad equipment in the six power categories described in Table 4-2. The equipment is grouped this way to make distinctions in compliance cost based on the size of the equipment and their engines. Even with these groupings by power category, each category includes a wide array of equipment and engine combinations for the various applications. The analysis presents costs at several points to represent, as much as possible, the whole range of equipment.

The R&D and tooling costs are estimated for modifying equipment based on those changes needed to accommodate the anticipated engine technology modifications for each power category. The principal cost to equipment manufacturers resulting from the new standards will be related to a general redesign of engine compartments and engine-related auxiliary devices. In some cases, the overall function of an equipment model will have to be reviewed to ensure satisfactory performance. Equipment design challenges will be greatest if engines are adopting air-to-air aftercooling. The effort to make space for the additional hardware and to account for the changes in heat rejection and other engine parameters will require a broad effort to maintain an effective product.

Variable costs are also considered. Many nonroad equipment models are expected to require some additional steel for new or reinforced brackets, modified location and shape of sheet metal, and other similar changes. An additional cost is assessed for various other materials required to accommodate new engines.

1. Fixed costs

a. methodology for estimating level of effort for fixed costs

For all the power categories, EPA generally matched the estimated fixed cost of compliance (a measure of the R&D and tooling effort required to accommodate new engines) with the equipment application. Thus, certain applications of equipment were considered to be more difficult than others for the purpose of accommodating complying engines. This estimation of difficulty was based a combination of engine packaging constraints and anticipated technology changes. The space available for engine changes and the degree of air-to-air aftercooling were thus used as indicators of the difficulty in redesigning an equipment model.

To calculate fixed costs for equipment applications, the following steps were taken. First, the applications were generally separated into the following two categories within the parameters of EPA's definition of nonroad engine (see 40 CFR 89.2): *motive* (e.g., agricultural tractors, excavators, forklifts, etc.) and *portable* (e.g., pumps, generators, air compressors, etc.). Second, within these two categories the applications were generally differentiated into "extensive" and "moderate" categories to indicate the level of effort needed to accommodate complying engines. EPA’s assessment of the level of effort for the different groups is developed in a separate memorandum and summarized in Table 4-17.[12] For example, some equipment without challenging constraints for engine packaging may need little or no modification to accommodate a new engine. Third, a fixed cost per equipment product line (model) was determined for each of these two distinctions within motive and portable categories for a total of four separate fixed costs per product line. Fourth, these fixed costs per product line were amortized over ten years at a 7 percent discount rate. The longer period for amortization reflects the smaller sales volumes and the longer product development cycles for nonroad equipment. Fifth, using the annual sales per equipment product line, the fixed cost in the first year was determined for both motive and portable applications for a total of four separate fixed costs per unit. Finally, these four fixed costs per unit were weighted based on the number of units in each of the four different categories for a weighted average fixed cost per unit for that power category.

Motive equipment is generally expected to require more effort in accommodating complying engines compared with portable equipment, because motive equipment on the whole has more engine compartment packaging constraints and is therefore more sensitive to changed engine specifications. Motive equipment also has more operator view and serviceability constraints for the equipment manufacturer to accommodate than portable equipment. In addition, for both motive and portable categories, smaller equipment was more often considered to be difficult for manufacturers (see Table 4-12). Because a compact design is often most important for smaller equipment, these designs generally have disproportionately smaller engine compartments. In addition, all equipment models undergoing a change to air-to-air aftercooling were considered to need extensive redesign.

Table 4-17
Breakdown for Level of Effort in
Estimating Fixed Costs

HP Range	Motive	Portable
0-37 kW (0-50 hp)	extensive= 80% moderate= 20%	extensive= 50% moderate= 50%
37-75 kW (50-100 hp)	extensive= 70% moderate= 30%	extensive= 50% moderate= 50%
75-130 kW (100-175 hp)	extensive= 100% moderate= 0%	extensive= 100% moderate= 0%
130-450 kW (175-600 hp)	extensive= 80% moderate= 20%	extensive= 80% moderate= 20%
450- 560 kW (600-750 hp)	extensive= 90% moderate= 10%	extensive= 90% moderate= 10%
560+ kW (750+ hp)	extensive= 10% moderate= 90%	extensive= 10% moderate= 90%

The number of sales per equipment product line was an important parameter in determining the amortized unit fixed costs from the fixed cost per product line. These sales volume estimates were extracted from the PSR database by adding up average annual sales over a five-year period for those equipment models that had sales in 1995, with adjustments for stationary applications and global sales volumes.[13] The PSR sales database excludes imported equipment data, and thus, the equipment sales numbers are based on domestic (U.S.) sales only. It is estimated that imported equipment could account for as much as 20 percent of the total sales. Incorporating this missing data may change the calculations somewhat, but it is not clear whether the average sales volumes would increase or decrease. On the other hand, as for engine costs, equipment manufacturers will be able to amortize fixed costs over global sales volumes to reduce the cost impact of redesigning equipment. On average, approximately half of manufacturers' equipment sales go to other countries.[14] As described for engine costs, to test the sensitivity of different amortization calculations, Appendix A shows the effect of distributing fixed costs over only half of equipment sales outside the U.S.

b. *effort needed for re-engineering equipment*

As described above, the fixed cost was determined only for the effort needed by equipment manufacturers to accommodate the emissions control of complying engines. First, for each product line of motive applications needing extensive redesign, EPA estimated that the combined R&D and tooling level of effort needed by equipment manufacturers, which includes the effort needed for testing, would be approximately 4,600 hours of effort. This includes 1,600 hours of junior engineers' time and 450 hours of senior engineers' time. In addition, 2,500 hours of technicians' time is included for testing, operating, repairing, and maintaining equipment, machines, and tools. This level of effort is equivalent to about $315,000. Second, for each product line of motive applications needing moderate redesign, EPA estimated that the combined R&D and tooling level of effort needed by equipment manufacturers would be approximately 2,400 hours of effort distributed similarly, including the effort needed for testing, which is equivalent to about $150,000.

Third, for each product line of portable applications needing extensive redesign, EPA estimated that the combined R&D and tooling level of effort needed by equipment manufacturers, which does not include testing, would be approximately 750 hours of effort. This includes 450 hours of junior engineers' time, 120 hours of senior engineers' time, and 230 hours for technicians' time, which is equivalent to about $60,000. Lastly, for each product line of portable applications needing moderate redesign, EPA estimated that the combined R&D and tooling level of effort needed by equipment manufacturers, which does not include testing, would be approximately 270 hours of effort distributed similarly, which is equivalent to about $21,000.

c. *effort needed for changing product support literature*

In addition, EPA added to the R&D cost (and thus the fixed cost) the effort for equipment manufacturers to modify product support literature (dealer training manuals, operator manuals, service manuals, etc.) due to the product changes resulting from the new emission standards. For each product line of motive applications, EPA estimated that the level of effort needed by equipment manufacturers to modify the manuals for retraining their dealers to be about 100 hours, with the needed clerical and printing support (about 80 hours of junior engineering time, 20 hours of senior engineering time, and 4 hours of clerical time), which is equivalent to about $10,000. For each product line of portable applications, EPA estimated two separate costs of literature changes for extensive and moderate redesigns. EPA projected that the level of effort needed by equipment manufacturers to modify manuals for each product line of portable equipment needing extensive redesign to be about 50 hours (distributed similarly), which is equivalent to about $5,000. For each product line of portable equipment needing moderate redesign the effort needed by equipment manufacturers would be about 30 hours, which is equivalent to about $2,500.

d. total fixed costs

In summary, the total fixed costs for each product line of motive equipment were estimated to be about $330,000 and $165,000 for the extensive and moderately redesigned product lines, respectively, and the total fixed costs for each product line of portable equipment were estimated to be about $70,000 and $23,000 for the extensive and moderately redesigned product lines, respectively. Using these figures, EPA calculated an amortized fixed cost per unit, as shown in Table 4-18.

Table 4-18
Total Fixed Costs per Equipment Piece for Both Tiers of Standards Combined

Power	Type	No. of Product Lines	Annual Sales per Product Line	Effort	Distribution of Effort	First Year Unit Cost	Weighted First Year Unit Cost	
<37 kW (<50 hp)	Motive	401	363	Extensive	80%	$53	$48	$33
				Moderate	20%	$27		
	Portable	535	210	Extensive	50%	$19	$13	
				Moderate	50%	$6		
37-75 kW (50-100 hp)	Motive	625	188	Extensive	70%	$250	$213	$151
				Moderate	30%	$125		
	Portable	342	183	Extensive	50%	$53	$35	
				Moderate	50%	$18		
75-130 kW (100-175 hp)	Motive	503	75	Extensive	100%	$630	$630	$565
				Moderate	0%	$315		
	Portable	255	34	Extensive	100%	$284	$284	
				Moderate	0%	$95		
130-450 kW (175-600 hp)	Motive	926	104	Extensive	80%	$452	$406	$422
				Moderate	20%	$226		
	Portable	523	13	Extensive	80%	$753	$652	
				Moderate	20%	$251		
450-560 kW (600-750 hp)	Motive	70	24	Extensive	90%	$1921	$1825	$1707
				Moderate	10%	$961		
	Portable	75	7	Extensive	90%	$1408	$1314	
				Moderate	10%	$469		
560+ kW (750+ hp)	Motive	68	70	Extensive	10%	$675	$371	$357
				Moderate	90%	$337		
	Portable	19	81	Extensive	10%	$468	$187	
				Moderate	90%	$156		

For < 37 kW equipment, the cost per product line is first discounted by 2/3 since most indirect engines in this power category already meet the standards, and second this discounted cost per model is increased by 25 percent since the standards are the first and the lead time is short for this power category.

Similar to costs described above in the engine cost section of this chapter, the widely varying fixed cost estimates and sales volumes for different size equipment create broad diversities in the estimated unit costs. The low cost of about $30 for equipment utilizing engines rated under 37 kW is due primarily to the expectation that many of the engines already meet Tier 1 or even Tier 2 standards. In addition, the low costs for equipment with engines rated between 37 and 75 kW reflect the relatively high sales volume of this range even though the equipment is expected to need a greater level of effort to accommodate complying engines than bigger equipment. The highest cost of $1,707 for equipment utilizing engines rated between 450 and 560 kW demonstrates that high unit costs are due to amortizing large fixed costs over small sales volumes, even though product lines of large equipment are expected to need relatively less redesign effort.

3. Variable costs

EPA expects that the significant effort to redesign nonroad equipment to accommodate new engines will be reflected primarily in the fixed costs for R&D and retooling. While variable costs resulting from the new emission standards will likely be much smaller, the analysis next considers hardware costs for additional or more expensive materials that may be required as a result of changes to engine size or performance.

For the engine compartment modifications, EPA projects that about 50 percent of the affected equipment will require slightly more steel. This increase in steel would be done for miscellaneous steel changes that may include increasing the amount of material in side panels, hoods, brackets, mounts, etc. More specifically, for this portion of the equipment, EPA estimates a 10 percent increase in the amount of steel used, at a cost of approximately 30 cents per pound. Including markup for overhead and profits, the total incremental retail price equivalent (RPE) hardware costs related to these steel modifications range from $3 to $6 per unit for those units that need more steel (see Table 4-19).

In addition, the analysis accounts for additional expenses for other materials, such as weldments, plastics, castings, gaskets, seals, and hoses. As with the projection for additional steel, not all equipment is expected to require changes to the amount or type of these materials. Considering the complexity of designs and the potential for any or all of these materials to involve additional costs, the analysis factors in an estimated cost five times greater than that for the steel alone.

Table 4-19
Estimated Incremental Variable Costs

	0-37 kW	37-75 kW	75-130 kW	130-450 kW	450-560 kW	560+ kW
steel	$2	$2	$3	$4	$6	$6
miscellaneous hardware	$10	$10	$15	$20	$30	$30
markup	$3	$3	$5	$7	$10	$10
Total hardware RPE	**$15**	**$15**	**$23**	**$31**	**$46**	**$46**

D. Summary of Total Projected Cost

1. First-year costs

Fixed and variable costs are combined in Table 4-20 to show the total unit cost for equipment modified to accommodate engines designed to new tiers of emission standards. As described above in Section II.B of this chapter, EPA then allocated three-fourths of these total costs to the first tier of standards and one-fourth of these total costs to the second tier of standards. For engines rated over 560 kW, the analysis attributes all costs to Tier 2, which is the only set of new standards for these engines. The costs shown in Table 4-20 reflect this breakdown between the two tiers. For example, for the equipment between 130 and 450 kW, three-fourths of the $453 total cost ($340) would be the Tier 2 cost per unit, and one-fourth ($113) would be the Tier 3 cost per unit.

In summary, for the new Tier 1 standards that only apply to equipment with engines rated under 37 kW, EPA projected the incremental cost on this equipment to be about $25. For the Tier 2 standards, equipment with engines rated between 37 and 75 kW are expected to have incremental costs up to $125, and the equipment with larger engines may incur incremental costs up to $400 or even $1300. The incremental costs of the Tier 3 standards are expected to range from $40 to $400. Table 4-20 shows these costs for the various power ranges and adds the projected engine costs for a total cost impact for purchasers of new equipment.

Table 4-20
Incremental Unit Cost of Complying
with New Emission Standards—Equipment

Equipment Modification	Weighted Unit Cost					
	0-37 kW	37-75 kW	75-130 kW	130-450 kW	450-560 kW	560+ kW
Tier 1						
Total hardware	$8	—	—	—	—	—
Total fixed costs	$16	—	—	—	—	—
Total first-year costs						
equipment changes	$24	—	—	—	—	—
engine changes	$34					
total	$56					
Tier 2						
Total hardware	$3	$12	$17	$23	$35	$46
Total fixed costs	$5	$113	$424	$317	$1281	$357
Total first-year costs						
equipment changes	$8	$125	$441	$340	$1315	$404
engine changes	$72	$124	$425	$464	$1354	$683
total	$80	$249	$866	$804	$2670	$1087
Tier 3						
Total hardware	—	$4	$6	$8	$12	—
Total fixed costs	—	$38	$141	$106	$427	—
Total first-year costs						
equipment changes	—	$42	$147	$113	$439	—
engine changes		$241	$511	$758	$1858	
total		$282	$658	$872	$2296	

To better understand the economic impact of the new standards on equipment manufacturers, the incremental costs are viewed in the context of their fraction of the total purchase price of equipment. Equipment prices vary widely, but comparing total costs with a sampling of the equipment list prices is illustrative. EPA collected quoted list prices on a several types of equipment with high sales volume representing the low and high end of prices for different engine ratings. Two ranges of engine power ratings were chosen: under 37 kW and between 185 and 335 kW (250 to 450 hp), the latter is in the middle of the 37 to 450 kW range. Using a range of these prices and accounting for an estimated 20 percent discount from list prices, EPA determined a best estimate of actual prices for nonroad diesel equipment (see Table 4-21).[15] Comparing the estimated unit costs for engines and equipment with the current purchase prices shows cost increases are almost all under 2 percent of purchase price, while most are well below 1 percent.

Table 4-21
Estimated Prices for New Nonroad Diesel Equipment

Power Range	Portable Equipment Estimated Sale Price	Motive Equipment Estimated Sale Price
0-37 kW (0-50 hp)	$1,600-12,000	$16,000-20,000
185-335 kW (250-450 hp)	$24,000-40,000	$130,000

2. Long-term costs

The long-term cost savings described above for engine costs also apply to equipment cost estimates. Fixed costs only apply until those costs are fully recovered. Also, EPA believes it is appropriate to use the manufacturing learning curve when assessing the economic impact to equipment manufacturers of accommodating complying engine technologies. EPA believes that the modifications expected for equipment manufacturers due to the new standards will require manufacture of new components and assemblies, which will lead to new manufacturing processes. Furthermore, as manufacturers learn more about these new manufacturing processes, they are expected to reduce their unit labor and material costs. These cost savings are calculated the same as for engine costs (i.e., a 20 percent reduction in year 3 and a further 20 percent reduction in year 6).

The estimated long-term costs for each equipment-power category for Tier 3 standards are shown in Table 4-22. The projected cost savings is small for the medium term due to the predominance of fixed costs. After those fixed costs are fully recovered though, the analysis projects a great reduction in the impact of the new standards.

Table 4-22
Projected Long-Term Increase in
Prices Due to Tier 3 Standards

Scenario	Years of Production*	Power (kW)			
		37-75	75-130	130-450	450-560
Equipment	1-2	$42	$147	$113	$439
	3-5	$41	$146	$112	$436
	6-10	$40	$145	$111	$434
	11+	$3	$4	$5	$7
Engine and Equipment	1-2	$282	$658	$872	$2296
	3-5	$244	$564	$734	$2127
	6-10	$160	$442	$545	$1991
	11+	$122	$301	$440	$543

*For equipment, year 3 costs are adjusted by reducing variable costs by 20 percent (fixed costs remain unchanged). Year 6 costs are adjusted by reducing variable costs an additional 20 percent and eliminating fixed costs for engines (fixed costs for equipment remain unchanged). Year 11 costs are adjusted by eliminating fixed costs for equipment changes.

III. Aggregate Costs to Society

The above analysis develops per-unit estimates of engine and equipment costs for each power category. With current data for engine sales for each category and projections for the future, these costs can be translated into a total cost to the nation for the emission standards in any year.[16] Accounting for the projected favorable impact of the new standards on operating costs, primarily from fuel savings in larger engines, would produce negative aggregate costs (net economic gains) in future years. However, because it is difficult to accurately assess the fuel economy impacts of hardware changes and the degree to which these savings would have developed in the absence of new emission standards, EPA has conservatively chosen to present aggregate costs to society without factoring in the expected changes in operating costs presented earlier in this chapter. Using only the increased purchase prices presented in this chapter leads to aggregate costs of about $5 million in the first year the new standards apply, increasing to a peak of about $550 million in 2010 as increasing numbers of engines become subject to the new standards. The following years show declining aggregate costs as the per-unit cost of compliance decreases, as described earlier in the chapter, resulting in a minimum aggregate cost of about $390 million in 2017. After 2017, stable engine costs applied to a slowly growing market lead to slowly increasing aggregate costs.

IV. Final Regulatory Flexibility Analysis

This section presents the results of the EPA's Final Regulatory Flexibility Analysis (Final RFA), which evaluates the impacts on small businesses expected from new nonroad diesel emission standards. As described below, the Final RFA largely confirms the conclusions of the Initial RFA performed as a part of the proposed rule. This analysis has the following objectives: (1) to specify an appropriate definition for "small business" for entities subject to the final rule, (2) to characterize small participants in the nonroad diesel equipment manufacturing industry (the industry evaluated in this analysis, as described below), (3) to assess the impact of the final rule standards on small equipment manufacturers, and (4) to evaluate the relief provided by regulatory alternatives.

A. Requirements of SBREFA and RFA

When proposing and promulgating rules subject to notice and comment under the Clean Air Act, EPA is generally required under the Regulatory Flexibility Act (RFA) to conduct a regulatory flexibility analysis unless EPA certifies that the requirements of a regulation will not cause a significant impact on a substantial number of small entities. The Regulatory Flexibility Act was amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA), which was signed into law on March 29, 1996, to strengthen its analytical and procedural requirements.

In developing the NPRM, EPA concluded that a significant impact on a substantial number of small entities was likely and completed the initial analysis on which this Final RFA is based. In responding to the provisions of SBREFA, EPA may use a variety of economic measures to assess economic impacts on small entities. The analyses in the Initial and Final RFAs use a measure known as the "sales test" to evaluate the impacts on small entities. The sales test involves calculation of the annualized compliance costs as a function of sales revenue.

B. Methodology

1. Data sources

The Power Systems Research (PSR) database OE Link is the primary data source for this analysis for product information about small and large equipment manufacturers. It includes the number of equipment models produced, the types of engines used, and annual sales for each equipment model. EPA believes that the PSR database is the most comprehensive source available on the nonroad equipment manufacturing industry. Dun and Bradstreet (D& B) was the main source of financial information, specifically for numbers of employees and the dollar value of annual sales. Financial information on 334 of the 581 equipment manufacturers listed in the PSR database was located (approximately 60 percent). These 334 equipment manufacturers produced 63 percent of the total 1995 diesel equipment from the PSR database. Because the ratio of total companies and ratio of total production represented by the 334 equipment manufacturers are nearly equal, this sample likely contains a proportionate number of large and small equipment manufacturers. This sample should therefore reflect the financial and production characteristics of the equipment manufacturers that may be affected by the final rule.

2. Definition of small equipment manufacturer

SBA defines a small business differently for different lines of business. In order to simplify the analysis, EPA looked at the effect of assuming, for the sake of the analysis, that a single definition using the threshold of 500 or fewer employees could be used to characterize all small nonroad diesel equipment manufacturers. This is the most commonly occurring among the SBA definitions that apply to these companies. Of the 334 nonroad diesel equipment manufacturers considered in the analysis, there were a total of 286 small manufacturers identified based on the specific line-of-business definitions of small business from SBA, and there were a total of 283 small manufacturers found according to the general 500-employee threshold. The 286 small equipment manufacturers identified based on the specific line-of-business definitions produced 25 percent of the total 1995 equipment, and the 283 small equipment manufacturers found using the general 500 employee threshold produced 24 percent of the total 1995 equipment. Because the differences in total number of small equipment manufacturers and the differences in percent of total production that these small manufacturers produce are so small, the more general definition of small business (500 or fewer employees) as defined by SBA for manufacturing companies was considered acceptable. Thus, the analysis focuses on the impacts of the final rule for 283 small businesses.

C. Characterization of Small Equipment Manufacturers

1. Generating model companies

EPA's analysis was based on a contract study performed by ICF, Incorporated.[17] The EPA/ICF study characterized the equipment industry by classifying industry segments in a manner that would be useful for the subsequent evaluation of potential impacts of compliance costs using the model company approach. To generate model small companies, nonroad diesel equipment manufacturers (from market data described above) were segmented by size, measured by sales (dollar value of annual sales) and total power. Total power is the product of individual engine power and the number of units sold. Total power for a nonroad equipment manufacturing company would be the sum of the products of the number of units of equipment produced and the power rating of the engine used in each piece of equipment. This measure helps provide insight into the amount of revenue generated from sales of equipment using diesel engines, and it highlights equipment manufacturers that are probably generating revenue from other lines of business and those companies that likely add minimal value to diesel engines when producing equipment. The segmentation produced six groups of small companies, each group represented by one model company. Small equipment manufacturers outside of these groups were not further evaluated in the model company analysis, which left 238 small companies remaining within the groups making up model companies.

2. Characterizing model companies

Table 4-23 provides summary data for characteristics of each group of small companies (or each model company), such as number of equipment types, number of models, number of engine types, total power, number of employees, number of units sold, and sales revenue. Each model company is developed from the median values of characteristics for each group of small companies; mean values were not chosen to avoid skewing the data. Although each group contains companies that manufacture multiple equipment types (applications), typical companies in all groups of small companies produce one type of equipment. In addition, each group contains at least one company that manufactures only one equipment model. Typical companies in all groups have fewer engine models than equipment models, indicating that engine models are shared by different equipment models within the companies.

Many applications are spread across multiple company groupings. For example, generator sets contribute to the top two thirds of sales (measured by total power sold) in Groups 1, 2, and 3. The high volume of these typically low-power units leads to companies in Groups 1, 2 and 3 producing an order of magnitude greater total power compared to companies in Groups 4, 5 and 6 (comparing 1 with 4, 2 with 5, and 3 with 6). Also, companies in Groups 1, 2 and 3 have greater total power-to-dollar sales ratios compared to companies in Groups 4, 5 and 6. Cranes account for the greatest portion of Group 6 sales (13 percent, measured by total power). These low-volume units have high value added (for example, a complex piece of equipment with several functions run by one engine), explaining why companies in Group 6 have similar dollar sales to those in Group 3, even though median unit sales for Group 6 are only 15 percent those of Group 3. These high value added companies require a similar number of employees to produce a much lower volume of units compared to the companies with less value added products. Comparing mean and median number of employees of Groups 1, 2, and 3 to Groups 4, 5 and 6, respectively, the values are very similar. Median sales for the same groups are also very similar.

Table 4-23
Characteristics of Model Company Groups

Characteristic	Model Company Number					
	1	2	3	4	5	6
Median Equipment Types	1	1	1	1	1	1
Average Equipment	1	1	1	1	1	1
Max Equipment Types	3	3	3	2	3	4
Min Equipment Types	1	1	1	1	1	1
Median No. of Models	2	5	7	2	3	4
Average No. of Models	4	6	9	3	3	6
Max No. of Models	13	22	29	12	9	17
Min No. of Models	1	1	2	1	1	1
Median Engine Models	2	5	7	2	3	4
Average Engine Models	4	6	9	2	3	6
Max Engine Models	11	22	29	5	9	17
Min Engine Models	1	1	1	1	1	1
Median Total hp	4,985	20,579	121,744	926	2,695	15,915
Average Total hp	9,318	33,291	136,150	896	3,801	29,461
Max Total hp	64,785	150,794	321,192	2,719	13,237	231,361
Min Total hp	430	5,550	32,138	105	294	1,540
Median Units Sold	55	222	1,022	15	41	155
Average Units Sold	154	462	1,424	40	66	390
Max Units Sold	1,241	2,259	4,793	438	258	3,377
Min Units Sold	5	33	174	2	3	10
Med. Units Sold <50hp	-	-	2	10	10	-
Avg. Units Sold <50hp	79	227	615	35	39	164
Max Units Sold <50hp	1,241	1,932	2,994	438	258	3,377
Min Units Sold <50hp	-	-	-	-	-	-
Median Equipment hp	78	100	122	38	74	104
Average Equipment hp	61	72	96	23	57	76
Min Equipment hp	4	15	20	4	7	8
Max Equipment hp	900	578	540	250	444	794
Median Employees	6	45	150	8	35	135
Average Employees	8	43	194	11	43	185
Max Employees	30	140	500	28	130	500
Min Employees	2	3	30	1	7	25
Median Sales	$ 550,966	$ 4,550,000	$ 20,000,000	$ 927,260	$ 4,163,873	$ 24,000,000
Average Sales	$ 724,816	$ 4,759,557	$ 26,946,453	$ 901,328	$ 5,128,141	$ 37,531,852
Max Sales	$ 1,900,000	$ 10,000,000	$ 85,555,429	$1,900,000	$ 10,000,000	$ 350,604,000
Min Sales	$ 120,000	$ 2,000,000	$ 12,000,000	$ 130,000	$ 2,000,000	$ 10,200,000

The EPA/ICF study found that the unit production and sales revenue data shows that some small companies in Groups 1 and 2 are currently facing financial hardship without the effects of new nonroad diesel regulations. This present financial condition of some companies provides an indication of the current effects on small companies from competition in the market.

D. Estimated Impacts on Small Equipment Manufacturers

1. Projected costs of the final standards

The original EPA/ICF study evaluated the impacts on small manufacturers of nonroad equipment by examining the effect of projected fixed costs resulting from the rule. (In the analysis, it was assumed that variable costs could generally be passed along as price increases without significant economic consequences.) On the basis of comments and further analysis, EPA has adjusted its estimates of fixed costs (see Section 6 of the Summary and Analysis of Comments document associated with this rule for a discussion of EPA's decision to revise the projected costs). As a result of these changes, EPA has reanalyzed the economic impacts of the rule on small equipment manufacturers, incorporating the revised fixed cost values.[18] Table 4-24 presents the revised fixed costs per product line. The presented cost figures are the total fixed costs that would be amortized in the first year of a five-year amortization.

As in the case of variable costs, manufacturers may also be successful in passing on fixed costs to the final consumer. To the extent that manufacturers are able to recover their fixed costs, the impacts estimated here would be mitigated. However, the costs presented in the table assume that manufacturers are not able to pass on any of the fixed costs to their customers.

Table 4-24
Compliance Cost by Engine Power Range

Power Range	Fixed Cost per Product Line
0-37 kW	$9,000
37-75 kW	$28,000
75-130 kW	$34,000
130-450 kW	$30,000
450- 560 kW	$26,000
560+ kW	$21,000

As in the original analysis, this analysis evaluates the economic impacts under two scenarios, the “base case” and “flexibility case.” The base case provides a measure of the effectiveness of these provisions by analyzing the impacts of the final rule if the regulatory flexibilities which are a part of this rule are ignored. The flexibility case is based on the availability and use of provisions that provide flexibility to equipment manufacturers in meeting the new standards by allowing them to exempt from the new emission standards certain percentages of the equipment pieces they sell for the first seven years after the standards are implemented. The flexibility case also incorporates the availability and use of an additional provision which will allow equipment manufacturers with lower-volume production lines to exempt a specific number of pieces of equipment for each power category.

It should be noted that the two flexibility provisions considered in this analysis have been revised in the final rule to be more advantageous to equipment manufacturers; in addition, there are additional flexibility provisions in the final rule that for simplicity were not considered in this analysis. As a result, the complete package of flexibility provisions established by this final rule can be expected to ease the economic burdens on small businesses to a greater extent than the two provisions considered in this analysis.

2. Sales test

As with the original analysis in the Initial RFA, the "sales test" was conducted for each of the 334 companies (small and large). The number (and percent) of large and small manufacturers are shown in Table 4-25 for the ratio ranges of less than one percent, one to three percent, and more than three percent. These show that the impact of the final rule without flexibility provisions would be that more than 30 percent of small businesses would be economically impacted by greater than or equal to 1 percent.

Table 4-25
Compliance Cost Impacts as a Percentage of Sales Revenue by Company Size

Company Type	Number of Companies	< 1%	1-3%	>3%
Small	283	177	57	49
		63%	20%	17%
Large	51	51	0	0
		100%	0%	0%
Total	**334**	**288**	**57**	**49**

As demonstrated in Table 4-26, the flexibility provisions are projected to mitigate the impact of the final rule such that only 13 percent of small businesses are estimated to have an economic impact greater than 1 percent. Furthermore, the flexibility provisions reduced the number of small equipment manufacturers impacted by 1 percent or more from 106 to 32, approximately a 60 percent decrease. Thus, the analysis indicates that these flexibility provisions will dramatically reduce the impacts of the emission standards.

Table 4-26
Compliance Cost Impacts with Flexibility Provisions
as a Percentage of Sales Revenue by Company Size

Company Type	Total	< 1%	1-3%	>3%
Small	283	251	11	21
		89%	4%	7%
Large	51	51	0	0
		100%	0%	0%
Total	**334**	**302**	**11**	**21**

Some of the small companies that are projected to experience an impact of 3 percent or greater with the flexibility provisions were Group 1 and 2 companies. Based on the finding that some of these companies are already likely experiencing financial difficulty, it is not surprising that a small number of companies are estimated to experience a greater impact from the standards. ICF's study further describes the circumstances surrounding the likely current financial instability of small companies in Groups 1 and 2.

E. Summary of Projected Economic Impacts for Small Businesses

The flexibility provisions dramatically reduce the estimated economic impacts of the regulations on small equipment manufacturers, decreasing the percentage of small equipment manufacturers that would experience a 1 percent or greater impact from 37 to 11 percent of small companies. EPA considers the flexibility provisions to be a significant regulatory alternative because they enable the Agency to accomplish the objectives of the final rule while minimizing significant economic impacts on small equipment manufacturers.

In addition, the impact on small equipment manufacturers in comparison to large manufacturers is not substantially greater. Generally, small companies with low sales revenue that produce a large number of units (measured as the sum of power times units) would have the greatest relative impact. For those small companies that did appear to experience the greatest relative impact by the final rule (i.e., from Group 1 and 2 companies), it is important to note that this analysis did not focus on the present financial health of equipment manufacturers, which would provide an element of uncertainty in the evaluation of estimated impacts. Based on production and sales information, some companies in Groups 1 and 2 seem to be currently in poor financial health, because they have a low revenue based on total power production. The rule would therefore be expected to have a small effect on the financial health of small equipment manufacturers compared with the current effects of competition in the market.

F. Regulatory Alternatives to Reduce Impacts

Under section 609(b) of the Regulatory Flexibility Act as added by SBREFA, EPA convened a Small Business Advocacy Review Panel on March 25, 1997. The purpose of the Panel was to collect the advice and recommendations of representatives of small entities that will be affected by the rule and to report on those comments and the Panel's findings as to issues related to the key elements of an initial regulatory flexibility analysis under section 603 of the Regulatory Flexibility Act. Those elements of an initial regulatory flexibility analysis are:

- The number of small entities to which the proposed rule will apply.
- Projected reporting, record keeping, and other compliance requirements of the proposed rule, including the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record.
- Other relevant federal rules which may duplicate, overlap, or conflict with the proposed rule.
- Any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the proposed rule on small entities.

Once completed, the Panel report was provided to the Agency and included in the rulemaking record. The Panel, consisting of representatives of the Small Business Administration, the Office of Management and Budget, and EPA, issued a report on May 23, 1997 entitled, *Final Report of the SBREFA Small Business Advocacy Review Panel for Control of Emissions of Air Pollution from Nonroad Diesel Engines,* which may be found in the docket for this rulemaking.[19] The Panel findings and recommendations on these issues and EPA's response to these findings are described below in summary.

Accordingly, during the development of the proposal, EPA and the SBREFA Panel were in contact with representatives of four separate but related industries that will be subject to this rule and that contain small businesses as defined by regulations of the Small Business Administration (SBA): nonroad diesel engine manufacturing, manufacturing of nonroad diesel equipment, the rebuilding or remanufacturing of diesel nonroad engines, and post-manufacturer marinizing of diesel engines. (Post-manufacture marinizers generally purchase complete or partially complete engines and add parts to adapt them for propulsion or auxiliary marine use.) According to SBA's regulations (13 CFR 121), businesses with no more than the following numbers of employees or dollars of annual receipts are considered "small entities" for purposes of a regulatory flexibility analysis (the definition of small manufacturer of nonroad diesel equipment is discussed further in Section IV.B.2. above):

Manufacturers of engines (including marinizers)	1000 employees
Equipment manufacturers	
- Manufacturers of construction equipment	750 employees
- Manufacturers of industrial trucks (forklifts)	750 employees
- Manufacturers of other nonroad equipment	500 employees
Rebuilders/Remanufacturers of engines	$5 million

There are several hundred small nonroad equipment manufacturers, one small nonroad engine manufacturer, many small nonroad engine rebuilders/remanufacturers, and an estimated ten small post-manufacture engine marinizers subject the rule.

Regarding the proposed reporting and record keeping requirements, only equipment manufacturers commented. Equipment manufacturers commented that under the flexibility provisions, they should only be required to maintain accurate records of the engine types installed in equipment. These records would not be routinely submitted to EPA, but would be available upon request. The commenters believe this approach would minimize the administrative burden on equipment manufacturers while providing for market-driven "self-policing" among competing companies (due to the likelihood that competitors would alert EPA to abuses of the flexibility provisions). It should be noted that no record keeping requirements would be imposed on equipment manufacturers that choose not to take advantage of the voluntary flexibility provisions. The panel encouraged EPA to minimize the need for reporting and record keeping. As described in the final rule, EPA will require that equipment manufacturers maintain accurate records of the production of equipment, installed engines, and calculations used to determine the percent-of-production allowances. Manufacturers are required to make these records available to EPA upon request. EPA intends to conduct only limited audits of these records; the Agency anticipates that scrutiny by equipment manufacturers of their competitors' products will help identify potential candidates for audits.

Again, only equipment manufacturers commented about the proposed rule's overlap with other federal rules. A representative of the diesel forklift industry stated that Occupational Safety and Health Administration (OSHA) ambient carbon monoxide (CO) limits, especially as applied in the state of Minnesota, need to be evaluated for any overlap with the engine-based standards. No other potential overlaps with other federal rules were noted. The panel encouraged EPA to consider this potential overlap with OSHA CO limits. EPA has considered the potential overlap with OSHA requirements and has concluded that no changes to this final rule are appropriate because OSHA CO limits (and state requirements for CO monitoring such as those in place in Minnesota), focus on indoor ambient air concentrations, expressed in parts per million. Coordination of these requirements with EPA CO standards, which are focused on per-engine emission reductions to achieve National Ambient Air Quality Standards, would have to account for highly variable activities that greatly influence indoor CO concentrations, such as room ventilation rates and machine operating hours. These activities are beyond the scope of the final rule. Comments received on the NPRM provided no additional information or suggestions for coordinating federal regulations.

Small manufacturers of nonroad equipment and their representatives suggested alternative ways in which the provisions of the draft proposal might be improved. The Panel believed that a set of five alternatives, considered as an integrated package, would provide significant flexibility and burden reduction for small entities subject to the draft proposed rule. The Panel believed that EPA should consider conducting further analysis on these five alternatives and proposing or soliciting comment on them in the proposal. The five alternatives were: (1) flexibility for equipment manufacturers to aggregate and use exemption allowances on a schedule that best suited their needs, (2) equivalent flexibility for manufacturers of equipment using small engines as for those using larger engines, (3) provision for equipment manufacturers to purchase credits in the averaging, banking, and trading program and to use those credits to exempt more equipment, (4) dropping of the requirement that the small volume allowance be restricted to a single equipment model, and (5) adoption of a hardship relief provision. EPA proposed all 5 recommended provisions.

After evaluating the comments received on the proposed regulatory alternatives, EPA is adopting some of the provisions put forward by the Panel, as well as several alternative provisions that, as a whole provide small businesses with equivalent or better flexibility compared to the program embodied in the Panel recommendations. These final flexibility provisions, and EPA’s rationale for adopting them, are discussed in detail in the final rule preamble and in the Summary and Analysis of Comments. EPA believes that the set of provisions established in the final rule will provide adequate compliance flexibility for equipment manufacturers, including those that are small, while meeting the Agency’s air quality goals. The Agency believes that these provisions represent a very significant mitigation of the economic impacts on small equipment manufacturers compared to the impacts that might otherwise have occurred.

Chapter 4 References

1.“Estimated Economic Impact of New Emission Standards for Heavy-Duty On-Highway Engines,” Acurex Environmental Corporation Final Report (FR 97-103), March 31, 1997. The Acurex Environmental Corporation has since changed its name to Arcadis Geraghty & Miller.

2.“Incremental Costs for Nonroad Engines: Mechanical to Electronic,” Memorandum from Lou Browning, Acurex Environmental, to Alan Stout, EPA, April 1, 1997.

3."Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula," Jack Faucett Associates, Report No. JACKFAU-85-322-3, September 1985.

4.“Certification Data from Nonroad Diesel Engines,” EPA memorandum from Phil Carlson to Docket A-96-40, August 8, 1997.

5.“Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines,” September 16, 1997.

6. “Economic Evaluation of Regulations on Exhaust Emissions from Large Nonroad, Compression Ignition Engines,” David Harrison, et al, National Economic Research Associates, October 29, 1997.

7.“Big Changes for Cummins’ B Series,” *Diesel Progress*, May 1997, page 14.

8.“Incremental Costs for Nonroad Engines: Mechanical to Electronic,” Memorandum from Lou Browning, Acurex Environmental, to Alan Stout, EPA, April 1, 1997.

9.“Engine Price, On-Highway and Nonroad,” Memorandum from Thomas Uden, ICF, Inc., to Alan Stout, EPA, August 7, 1997.

10.“Treating Progress functions as a Managerial Opportunity,” J. Dutton and A. Thomas, Academy of Management Review, Vol. 9, No. 2, page 235, 1984.

11.“Learning Curves in Manufacturing,” L. Argote and D. Epple, *Science*, February 1990, Vol. 247, page 920.

12.“Methodology to Develop the Categories for the Effort Needed by Nonroad Equipment Manufacturers in Accommodating Complying Diesel Engines,” EPA memorandum from Bryan J. Manning to Public Docket A-96-40.

13.“Methodology to Determine Number of Product Lines and their Sales Volume for Nonroad Diesel Equipment Cost Analysis,” EPA memorandum from Alan Stout to Public Docket A-96-40.

14. “Economic Evaluation of Regulations on Exhaust Emissions from Large Nonroad, Compression Ignition Engines,” David Harrison, et al, National Economic Research Associates, October 29, 1997.

15.“Methodology to Develop Nonroad Diesel Equipment Sales Prices,” EPA memorandum from Bryan J. Manning to Public Docket A-96-40.

16.Engine sales data is from the PSR OE Link database.

17.“Small Business Impact Assessment: Nonroad Compression-Ignition Equipment Manufacturers,” Draft Final Report from ICF Incorporated, prepared for U.S. EPA under Contract Number 68-C5-0010, Work Assignment Number 211, June 1997.

18.“Revised Results for the Small Business Impact Assessment: Nonroad Compression Ignition Equipment Manufacturers;” Memorandum from Thomas Uden, ICF Kaiser, to Tad Wysor, EPA, July, 1998.

19.“Final Report of the SBREFA Small Business Advocacy Review Panel for Control of Emissions of Air Pollution from Nonroad Diesel Engines,” May 23, 1997.

CHAPTER 5: ENVIRONMENTAL IMPACT

Nonroad diesel equipment performs a large portion of our nation's work, and also has been shown to contribute to decreased air quality in our nation's cities. To more fully understand both the contributions that nonroad equipment makes toward various atmospheric pollutants and the benefits that can be derived from more stringent emission standards, EPA developed a new computer model for projecting nonroad emissions inventories called NONROAD. This chapter has several purposes. First, the chapter reviews the latest scientific information relating to adverse health and environmental effects of the regulated pollutants. Then, it analyzes the results of the new NONROAD model to understand the impact the new emission standards are projected to have on the emissions of oxides of nitrogen (NOx), primary and secondary particulate matter (PM), and volatile organic compounds (VOCs), both on a nationwide basis and a per-machine basis.

I. Health and Welfare Effects of Pollutants from Nonroad Engines

As part of the periodic review of the ozone and PM air quality standards required under the Clean Air Act, EPA has recently assessed the impacts of ozone and PM on human health and welfare, taking into account the most relevant, peer-reviewed scientific information available. The paragraphs below review some of EPA’s key concerns at this time, as compiled in the Agency’s Criteria Documents and Staff Papers for ozone and PM. The Criteria Documents prepared by the Office of Research and Development consist of EPA’s latest summaries of scientific and technical information on each pollutant. The Staff Papers on ozone and PM are prepared by the Office of Air Quality Planning and Standards, and summarize the policy-relevant key findings regarding health and welfare effects.

A. Ozone

Over the past few decades, many researchers have investigated the health effects associated with both short-term (one- to three-hour) and prolonged acute (six- to eight-hour) exposures to ozone. In particular, in the past decade, numerous controlled-exposure studies of moderately exercising human subjects have been conducted which collectively allow a quantification of the relationships between prolonged acute ozone exposure and the response of people’s respiratory systems under a variety of environmental conditions. To this experimental work has been added field and epidemiological studies which provide further evidence of associations between short-term and prolonged acute ozone exposures and health effects ranging from respiratory symptoms and lung function decrements to increased hospital admissions for respiratory causes. In addition to these health effects, daily mortality studies have suggested a possible association between ambient ozone levels and an increased risk of premature death.

Most of the recent controlled-exposure ozone studies have shown that respiratory effects similar to those found in the short-term exposure studies occur when human subjects are exposed to ozone concentrations as low as 0.08 ppm while engaging in intermittent, moderate exercise for six to eight hours. These effects occur even though ozone concentrations and levels of exertion are lower than in the earlier short-term exposure studies and appear to build up over time, peaking in the six- to eight-hour time frame. Other effects, such as the presence of biochemical indicators of pulmonary inflammation and increased susceptibility to infection, have also been reported for prolonged exposures and, in some cases, for short-term exposures. Although the biological effects reported in laboratory animal studies can be extrapolated to human health effects only with great uncertainty, a large body of toxicological evidence exists which suggests that repeated exposures to ozone causes pulmonary inflammation similar to that found in humans and over periods of months to years can accelerate aging of the lungs and cause structural damage to the lungs.

In addition to the effects on human health, ozone is known to adversely affect the environment in many ways. These effects include reduced yield for commodity crops, for fruits and vegetables, and commercial forests; ecosystem and vegetation effects in such areas as National Parks (Class I areas); damage to urban grass, flowers, shrubs, and trees; reduced yield in tree seedlings and noncommercial forests; increased susceptibility of plants to pests; materials damage; and visibility. Nitrogen oxides (NOx), key precursors to ozone, also result in nitrogen deposition into sensitive nitrogen-saturated coastal estuaries and ecosystems, causing increased growth of algae and other plants.

B. Particulate Matter

Particulate matter (PM) represents a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. Human-generated sources of particles include a variety of stationary and mobile sources. Particles may be emitted directly to the atmosphere or may be formed by transformations of gaseous emissions such as sulfur dioxide or nitrogen oxides. The major chemical and physical properties of PM vary greatly with time, region, meteorology, and source category, thus complicating the assessment of health and welfare effects as related to various indicators of particulate pollution. At elevated concentrations, particulate matter can adversely affect human health, visibility, and materials. Components of particulate matter (e.g., sulfuric or nitric acid) contribute to acid deposition.

Key EPA findings can be summarized as follows:

1. Health risks posed by inhaled particles are affected both by the penetration and deposition of particles in the various regions of the respiratory tract, and by the biological responses to these deposited materials.

2. The risks of adverse effects associated with deposition of ambient particles in the thorax (tracheobronchial and alveolar regions of the respiratory tract) are markedly greater than for

deposition in the extrathoracic (head) region. Maximum particle penetration to the thoracic regions occurs during oronasal or mouth breathing.

3. The key health effects categories associated with PM include premature death; aggravation of respiratory and cardiovascular disease, as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days; changes in lung function and increased respiratory symptoms; changes to lung tissues and structure; and altered respiratory defense mechanisms. Most of these effects have been consistently associated with ambient PM concentrations, which have been used as a measure of population exposure, in a large number of community epidemiological studies. Additional information and insights on these effects are provided by studies of animal toxicology and controlled human exposures to various constituents of PM conducted at higher than ambient concentrations. Although mechanisms by which particles cause effects are not well known, there is general agreement that the cardio-respiratory system is the major target of PM effects.

4. Based on a qualitative assessment of the epidemiological evidence of effects associated with PM for populations that appear to be at greatest risk with respect to particular health endpoints, the EPA has concluded the following with respect to sensitive populations:

    a. Individuals with respiratory disease (e.g., chronic obstructive pulmonary disease, acute bronchitis) and cardiovascular disease (e.g., ischemic heart disease) are at greater risk of premature mortality and hospitalization due to exposure to ambient PM.

    b. Individuals with infectious respiratory disease (e.g., pneumonia) are at greater risk of premature mortality and morbidity (e.g., hospitalization, aggravation of respiratory symptoms) due to exposure to ambient PM. Also, exposure to PM may increase individuals’ susceptibility to respiratory infections.

    c. Elderly individuals are also at greater risk of premature mortality and hospitalization for cardiopulmonary problems due to exposure to ambient PM.

    d. Children are at greater risk of increased respiratory symptoms and decreased lung function due to exposure to ambient PM.

    e. Asthmatic individuals are at risk of exacerbation of symptoms associated with asthma, and increased need for medical attention, due to exposure to PM.

5. There are fundamental physical and chemical differences between fine and coarse fraction particles and it is reasonable to expect that differences may exist between the two subclasses of PM-10 in both the nature of potential effects and the relative concentrations required to produce such effects. The specific components of PM that could be of concern to health include components typically within the fine fraction (e.g., acid aerosols, sulfates, nitrates, transition metals, diesel particles, and ultra fine particles), and other components typically

within the coarse fraction (e.g., silica and resuspended dust). While components of both fractions can produce health effects, in general, the fine fraction appears to contain more of the reactive substances potentially linked to the kinds of effects observed in the epidemiological studies. The fine fraction also contains the largest number of particles and a much larger aggregate surface area than the coarse fraction which enables the fine fraction to have a substantially greater potential for absorption and deposition in the thoracic region, as well as for dissolution or absorption of pollutant gases.

With respect to welfare or secondary effects, fine particles have been clearly associated with the impairment of visibility over urban areas and large multi-state regions. Fine particles, or major constituents thereof, also are implicated in materials damage, soiling and acid deposition. Coarse fraction particles contribute to soiling and materials damage.

Particulate pollution is a problem affecting localities, both urban and nonurban, in all regions of the United States. Manmade emissions that contribute to airborne particulate matter result principally from stationary point sources (fuel combustion and industrial processes), industrial process fugitive particulate emission sources, nonindustrial fugitive sources (roadway dust from paved and unpaved roads, wind erosion from cropland, etc.) and transportation sources. In addition to manmade emissions, consideration must also be given to natural emissions including dust, sea spray, volcanic emissions, biogenic emanation (e.g., pollen from plants), and emissions from wild fires when assessing particulate pollution and devising control strategies.

C. Carbon Monoxide and Smoke

Though carbon monoxide (CO) and smoke are not the primary focus of this rule, EPA is establishing new standards for both CO (for all engine categories subject to this regulation) and smoke (for engines rated from 0 to 37 kW) in this rule. CO has long been known to have substantial adverse effects on human health and welfare, including toxic effects on blood and tissues, and effects on organ functions, and has been linked to fetal brain damage, increased risk for people with heart disease, and reduced visual perception, cognitive functions and aerobic capacity. As shown in EPA’s Nonroad Engine and Vehicle Emissions Study (NEVES), nonroad diesel engines contribute to emissions of carbon monoxide in nonattainment areas.

Smoke from compression-ignition engines, including those below 37 kW, has long been associated with adverse effects on human welfare, including considerable economic, visibility and aesthetic damage. The carbon particles that make up diesel smoke cause reduced visibility, soiling of urban buildings, homes, personal property, clothes, and skin, and are associated with increased odor, coughing, and eye irritation. In addition, the particles causing visible smoke are the same as those associated with the significant threats to human health described above for particulate matter.

II. The NONROAD Model

In order to quantify the level of emission inventories from nonroad equipment and to estimate the impact of future standards on those inventories, EPA has developed a new computer model called the NONROAD Model. EPA has replaced the model used in the NPRM analysis with this new NONROAD model in order to predict the emissions impact of the new standards being finalized. Much of the information used in the new NONROAD model is the same as the information used in the model to analyze the environmental impact of the proposal. The following section highlights the areas where significant changes in the modeling performed for the proposal and the modeling for this final rule analysis exist.

For a complete description of EPA's new NONROAD model, the reader is referred to the technical reports and program documentation prepared by EPA in support of the NONROAD model development. These reports and documentation describe the operation of the model and provide detailed information on the inputs that go into the model and how they were developed. Copies of the technical reports and model documentation have been placed in the public docket for this rulemaking.

A. Emission Factors

EPA has updated the emission factors for engines manufactured prior to the existing Tier 1 standards (which apply to engines at or above 37 kW). In the emissions model used in the proposal, EPA based all of the pre-control emission factors on those found in the NEVES report. The emission factors contained in the NEVES report were based on 1970s-era engines. Recent testing on newer pre-control engines above 37 kW shows that the emission levels of engines have dropped compared to the levels presented in the NEVES report. Table 5-1 presents the pre-control emission levels assumed in the NONROAD model for 1988 and later model year engines at or above 37 kW. (These levels are assumed to apply until the effective model year of the existing Tier 1 standards.) The reader is directed to EPA's technical report, "Exhaust Emission Factors for Nonroad Engine Modeling -- Compression Ignition" for a more detailed explanation of the updated pre-control emission factors.

Table 5-1
Emission Factors for 1988 and later Model Year
Pre-control Nonroad Engines at or above 37 kW, g/kW-hr (g/bhp-hr)

Engine Category	HC	CO	NOx	PM
≥37 to 75 kW	1.32 (0.99)	4.65 (3.49)	11.07 (8.30)	0.96 (0.72)
≥75 kW	0.91 (0.68)	3.60 (2.70)	11.17 (8.38)	0.54 (0.40)

For engines below 37 kW, where very little information on the emission levels of pre-control engines exists, the NONROAD model uses information from the California ARB's model for nonroad emissions (known as "OFF-ROAD"). The direct injection levels and indirect injection levels were combined based on the technology weightings presented in the RIA for the proposal. Table 5-2 contains the resulting emission factors assumed in the NONROAD model for engines below 37 kW.

Table 5-2
Emission Factors for Pre-control
Nonroad Engines less than 37 kW, g/kW-hr (g/bhp-hr)

Engine Category	HC	CO	NOx	PM
0 to 12 kW	2.0 (1.5)	6.7 (5.0)	13.3 (10.0)	1.33 (1.0)
≥12 to 37 kW	2.4 (1.8)	6.7 (5.0)	9.2 (6.9)	1.07 (0.8)

EPA's NONROAD model assumes the same NMHC and NOx emission factors for engines covered under the new standards as the emissions model used in the proposal. Tables 5-3 and 5-4 present the NMHC and NOx emission levels assumed in the NONROAD model for engines meeting the new standards, respectively.

Table 5-3
Estimated Certification NMHC Levels, g/kW-hr (g/hp-hr)

Power Range (kW)	Tier 1	Tier 2	Tier 3
0 to 8	2.1 (1.6)	0.8 (0.6)	Not applicable
>8 to 19	0.9 (0.7)		
>19 to 37	1.1 (0.8)		
>37 to 75	0.9 (0.7)	0.5 (0.4)	0.3 (0.2)
>75 to 130	0.5 (0.4)		
>130 to 225			
>225 to 450	0.4 (0.3)	0.4 (0.3)	
>450 to 560			
>560			Not applicable

Table 5-4
Estimated Certification NOx Levels, g/kW-hr (g/hp-hr)

Power Range (kW)	Tier 1	Tier 2	Tier 3
0 to 8	7.9 (5.9)	6.7 (5.0)	Not applicable
>8 to 19	7.0 (5.2)		
>19 to 37	7.4 (5.5)		
>37 to 75	9.2 (6.9)	7.0 (5.2)	4.4 (3.3)
>75 to 130		6.0 (4.5)	3.7 (2.8)
>130 to 225			
>225 to 450			
>450 to 560			
>560			Not applicable

Although the Tier 1 rule established new standards for PM, no PM benefits were claimed in that rule. This was due to the fact that, although a lower PM standard was established for a steady-state test cycle, there was a great deal of uncertainty over the levels of in-use PM emissions that might result from the transient operation of these engines. For this analysis, EPA has continued to assume no benefit for PM from the existing Tier 1 standards. Therefore, the PM emission factors assumed for engines covered under the existing Tier 1 standards are the pre-control levels listed in Table 5-1. In order to estimate the PM benefit of the new standards, EPA assumed that engines covered by the new standards would emit at the level of the new standards, and then applied EPA's best current estimates of in-use operation adjustment factors for PM emission levels, as described in section II.B below. These factors and other assumptions in the model are still under review, and will continue to be improved in the future as new information becomes available.

Because of the continued uncertainties about the degree to which the steady-state test procedure will control PM emissions in use, especially from the many nonroad engines that frequently operate in transient modes, EPA cannot be certain that any assessment made at this time of the expected PM emission reductions due to the new standards will be completely accurate. Nevertheless, EPA has attempted to make a reasonable estimate of these reductions. EPA believes this approach provides a reasonable estimate of PM benefits from the new standards but actual benefits could vary significantly from these levels.

B. In-Use Operation Adjustments

Nonroad engines often operate under conditions unlike that of the steady-state ISO-C1 testing procedure typically used in emissions testing. This alternate operation can cause a change in the emission characteristics of nonroad CI engines. The emissions model used in the NPRM analysis contained no adjustment to the post-control emission factors for different types of in-use operation. (The pre-control emission factors taken from the NEVES report already included a “transient” operation adjustment. However, the emission levels from Tier 1 and later engines were not adjusted for in-use operation.)

In order to estimate the impact of in-use operating conditions on nonroad emissions, the NONROAD model uses in-use adjustment factors that were derived from emission testing designed to represent typical operational behavior of nonroad equipment. The adjustment factors were based on testing performed under a joint EPA and EMA project that was designed to develop more realistic test cycles for nonroad engine emissions characterization. The project developed cycles to represent typical operation of an agricultural tractor, a crawler dozer, and a backhoe\loader. The cycles were developed from data acquired from instrumenting one piece of each type of equipment. This data was used to construct appropriate test cycles from statistical criteria developed by EPA and EMA. Southwest Research Institute then tested nine late-model nonroad engines using the steady-state ISO-C1 certification procedure and the three nonroad test cycles. Table 5-5 contains the average adjustment factors based on testing of the nine engines.

Table 5-5
In-use Adjustment Factor used in the NONROAD Model
(Ratio of Application Test Cycle to Steady-State ISO-C1 Emissions)

Test Cycle	HC	CO	NOx	PM
Agricultural Tractor	0.89	0.42	0.99	0.64
Backhoe\Loader	2.19	2.31	1.03	2.04
Crawler Dozer	0.93	1.27	0.99	1.21

To apply the in-use adjustment factors listed in Table 5-5 to the entire CI equipment, EPA matched the individual nonroad applications contained in the NONROAD model with the test cycle that is thought to most closely represent the in-use activity for each application. For those applications where steady-state operation is typical, no adjustment to the emission factors is made. To determine the estimated in-use emission level for each application, the emission factors described in Tables 5-1 through 5-4 were multiplied by the appropriate in-use adjustment factor to create the emission factor inputs used in the NONROAD model. It should be noted that EPA plans to continue investigating the effects in-use behavior on emissions and improve these adjustment factors in the future as new information becomes available. EPA’s technical report, “Exhaust Emission Factors for Nonroad Engine Modeling -- Compression-Ignition,” contains a more thorough description of how the in-use operation adjustments were derived.

C. Equipment Population Estimates

The NONROAD model has population estimates of nonroad equipment covered by the new standards. The modeling performed in support of the NPRM used 1995 population estimates from the Power Systems Research (PSR) PartsLink database. The NONROAD model uses the 1996 population estimates from the same database as the basis for the base populations.

D. Growth Estimates

Essential to the determination of future emissions is the ability to accurately estimate the growth in nonroad equipment activity. For this final rule analysis, EPA looked at growth factors developed from two different sources: economic projections from the BEA and historical trends in growth in nonroad engine population from the PSR PartsLink Database.

Historically, EPA has used economic indicators such as the those provided by the Department of Commerce's Bureau of Economic Analysis (BEA). The BEA growth estimates are prospective and are developed for various sectors of the economy. BEA growth indicators have been widely used by states in preparing emission inventories for their State Implementation Plans (SIP) and most recently for the Ozone Transport Assessment Group (OTAG), a consortium of states and EPA to determine effective control strategies for ozone attainment. BEA growth indicators have also been the basis for EPA's Trends Report. BEA provides economic indicators by state or as a national average for numbers of employees, inflation adjusted national dollars of earnings, and inflation adjusted aggregate gross state products (GSP) dollars of earnings. The sector specific BEA-based growth estimates used in this analysis are shown in Table 5-6. These growth projections are from the most recent BEA estimates (July 1995) and are related to a 1995 base year.

Table 5-6
Growth Factors for Nonroad Sectors
based on BEA Economic Indicators

Sector	Average Annual BEA-based Predicted Growth (%)
Airport Service	5.5
Construction	1.0
Farm	2.4
Industrial	1.9
Lawn and Garden	1.0
Light Commercial	1.9
Logging	7.4
Railway	-0.9
Recreational	1.0

BEA projections are for economic growth in broad sectors of the economy and may not correlate completely with the growth in nonroad diesel equipment used by those sectors. For the equipment categories covered by this rule, there is some indication that past rates of growth in sales of equipment and fuel may be higher than BEA projections for future growth. An examination of the past growth of the United States nonroad diesel annual populations from PSR's PartsLink Database for the years 1989 to 1996 indicates that overall historical population growth (and hence, sales growth) may be higher than BEA projections of future growth.[1] Using the PSR PartsLink database, EPA has developed sector specific growth factors for nonroad diesel equipment based on a retrospective analysis of 1989 to 1996 equipment populations. The sector specific PSR-based growth estimates used in this analysis are shown in Table 5-7. EPA's technical report, "Nonroad Engine Growth Estimates," provides a more detailed description of the development of the growth rates based on the BEA and PSR information.

Table 5-7
Growth Factors for Nonroad Diesel Equipment Sectors
based on PSR Population Estimates

Sector	Average Annual PSR-based Predicted Growth (%)
Airport Service	8.3
Construction	3.3
Farm	3.1
Industrial	3.6
Lawn and Garden	9.1
Light Commercial	5.3
Logging	-1.2
Railway	4.5
Recreational	3.8

Due to the significant differences in the two sets of growth rates, EPA has used both sets of growth information to evaluate the impacts of the new standards. It should be noted that the draft version of the NONROAD model contains only the growth rates based on the PSR population estimates.

III. Emission Inventory Estimates

Because this rule is concerned primarily with three major pollutants (NOx, HC, and PM), eight different market segments (and even more numerous individual applications), and different tiers of standards depending upon the power range, there are countless ways to present the results of the modeling performed in support of this rulemaking. The following section presents the inventories for each of the three pollutants and the total reductions expected under the new standards. A memo containing a more detailed presentation of the modeling results has been placed in the public docket for the rulemaking.[2]

A. Equipment Manufacturer Allowance Impacts

Along with the new engine standards, EPA is adopting flexibility allowances for equipment manufacturers. There are two flexibility provisions in the rule with the potential to have significant impacts on emissions projections. They are the “Percentage Phase-in Allowance” provision and the “Small Volume Allowance” provision. Equipment manufacturers are allowed to take advantage of one, but not both, of these provisions. During the first seven years of implementation of the Tier 1 standards for engines rated below 37 kW, or the Tier 2 standards for larger engines, not all pieces of equipment are required to meet the new standard.

Under the Percentage Phase-in Allowance provisions, a manufacturer may exempt up to a cumulative total of eighty percent of the production over the first seven years a new standard applies. (This applies separately to each regulatory power category). The engines used in such exempted equipment will only have to meet the previous standard which is either the Tier 1 standard in the case of equipment at or above 37 kW, or unregulated in the case of equipment under 37 kW. For these categories of engines where there is an overlap in standards whereby the exemption allowance extends into the Tier 3 set of standards (this only occurs in equipment at or above 37 kW), the standard for the exempted equipment continues to be the Tier 1 standard.

Under the Small Volume Allowance provisions, a manufacturer may exempt up to a cumulative total of 700 units over the first seven years a new standard applies. (This applies separately to each regulatory power category.) Again, the engines used in such exempted equipment will only have to meet the previous standard which is either the Tier 1 standard in the case of equipment at or above 37 kW, or unregulated in the case of equipment under 37 kW.

Realistically, each manufacturer will choose the exemption provision that best meets its needs. Some will opt into one of the options described above, while others may not opt into either of these programs. For the purposes of emissions modeling, and thus to determine the expected benefits from this rule, EPA assumed that manufacturers took full advantage of the Percentage Phase-in Allowance provisions. EPA believes this results in a conservative estimate (i.e., yields lower benefits) of the environmental impact of the new standards.

B. Emission Model Results

1. Projected emission inventories and reductions

Table 5-8 presents the NOx inventory under the current Tier 1 standards and the emission reductions expected from the new standards for future years in five year increments using both the PSR and the BEA growth assumptions. It is evident from Table 5-8 that the PSR figures yield higher reduction estimates than the BEA growth assumptions, as would be expected. It is reasonable to assume that the actual emission reductions are located somewhere between these two sets of numbers.

Table 5-8
NOx Inventories and Reductions (Short tons/Year)

Calendar Year	NOx Emission Inventories Under the Current Standards		NOx Reductions Due to the New Standards	
	Assuming BEA Growth	Assuming PSR Growth	Assuming BEA Growth (% Reduction)	Assuming PSR Growth (% Reduction)
1995	2,867,000	2,867,000	0	0
2000	2,740,000	2,932,000	13,300 (0.5%)	16,000 (0.6%)
2005	2,715,000	3,240,000	264,000 (9.7%)	340,000 (10.5%)
2010	2,827,000	3,787,000	873,000 (30.9%)	1,211,000 (32.0%)
2015	2,946,000	4,530,000	1,347,000 (45.7%)	2,086,000 (46.0%)
2020	3,005,000	5,445,000	1,541,000 (51.3%)	2,756,000 (50.6%)

Based on the information in Table 5-8, the new standards should decrease overall NOx emissions from nonroad sources by over 30% beyond the levels expected under the current Tier 1 standards in the year 2010 and by over 50% by the year 2020. Figures 5-1 and 5-2 illustrate the relationship between NOx inventories under the existing Tier 1 standards and the new standards for the PSR and BEA growth assumptions, respectively. Note that with the PSR growth assumptions, under the Tier 1 rule there is a net increase in emissions from 1995 to 2010, whereas with the BEA growth assumptions, there is a net decrease in emissions during the same time period. Under both growth scenarios, the new standards yield a net decrease in the NOx emissions inventory out to the year 2020.

Hydrocarbons, though not as significant as NOx on a total tonnage basis, will still see some reductions because of the new standards. Table 5-9 presents the HC inventory under the existing Tier 1 standards and the emission expected from the new standards for future years in five year increments using both the BEA and the PSR growth assumptions.

Figure 5-1

NOx Emissions with PSR Growth

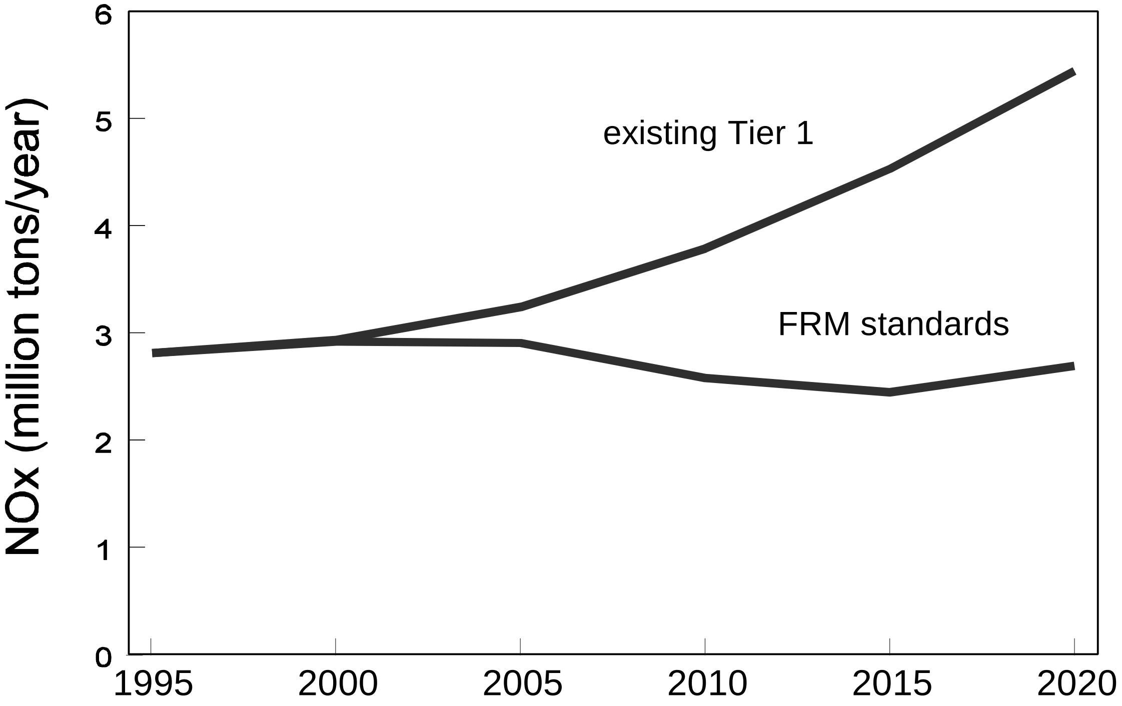


Figure 5-2

NOx Emissions with BEA Growth

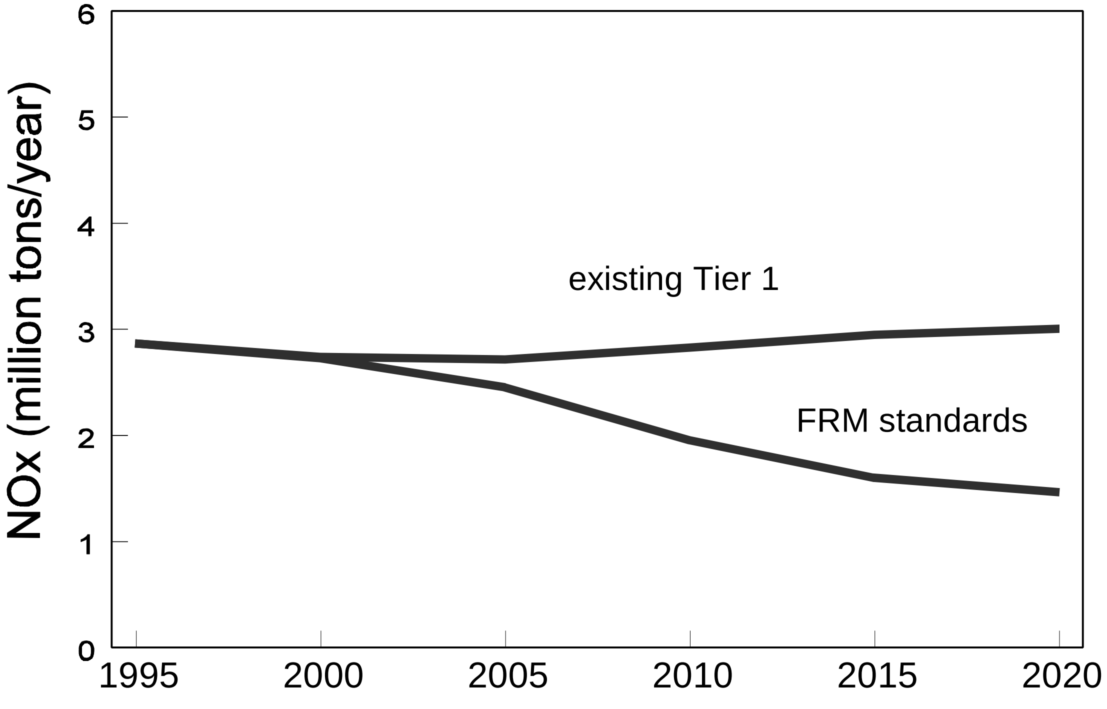


Table 5-9
Hydrocarbon Inventories and Reductions (Short tons/year)

Calendar Year	HC Emission Inventories Under the Current Standards		HC Reductions Due to the New Standards	
	Assuming BEA Growth	Assuming PSR Growth	Assuming BEA Growth (% Reduction)	Assuming PSR Growth (% Reduction)
1995	397,000	397,000	0	0
2000	337,000	361,000	9,000 (2.7%)	11,000 (3.0%)
2005	300,000	364,000	40,000 (13.3%)	55,000 (15.0%)
2010	301,000	419,000	108,000 (35.9%)	162,000 (38.7%)
2015	311,000	506,000	159,000 (51.3%)	271,000 (53.6%)
2020	317,000	619,000	179,000 (56.4%)	361,000 (58.3%)

By the year 2010, a decrease of more than 30% in hydrocarbons is projected under this rule regardless of the growth scenario. By the year 2020, more than a 50% reduction in hydrocarbons can be expected. Figures 5-3 and 5-4 illustrate the relationship between the existing Tier 1 HC inventories and the HC inventories under the new standards for the PSR and BEA growth assumptions, respectively.

Table 5-10 presents the PM inventory under the current Tier 1 standards and the emission reductions expected from the new standards for future years in five year increments using both the PSR and BEA growth assumptions.

Figure 5-3

HC Emissions with PSR Growth

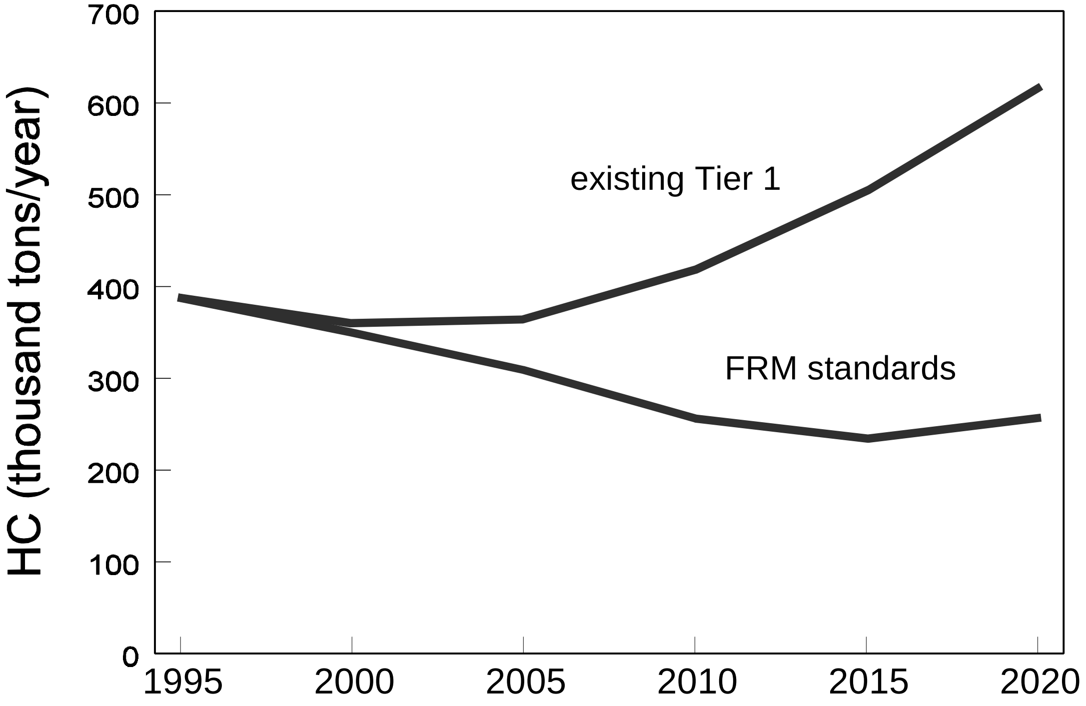


Figure 5-4

HC Emissions with BEA Growth

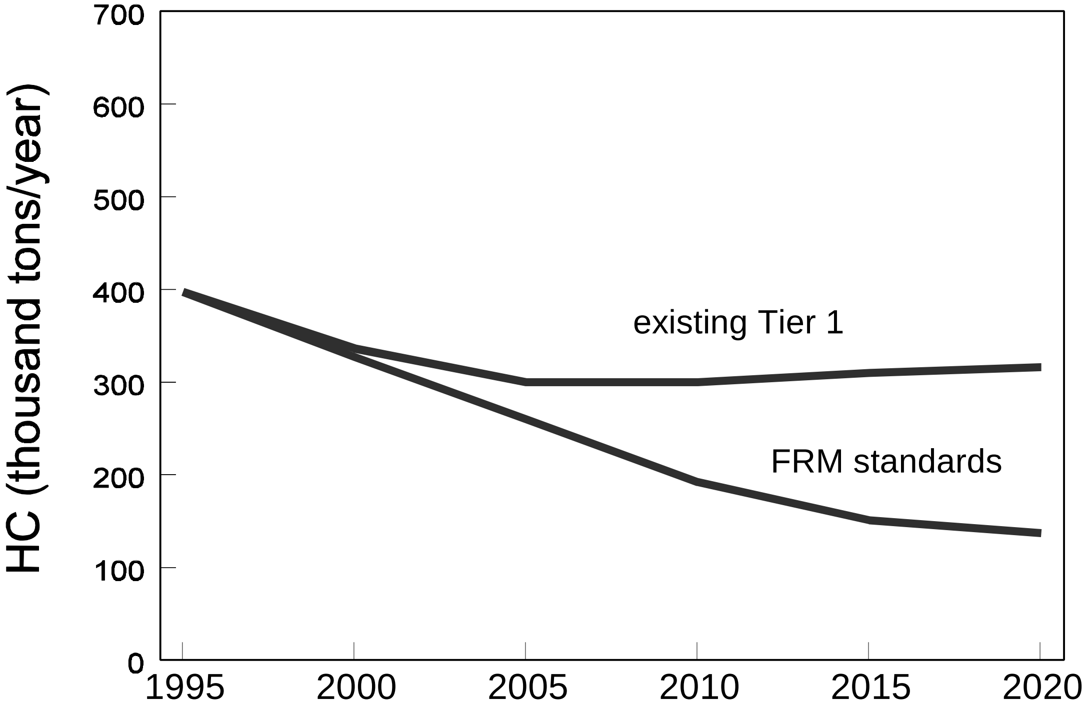


Table 5-10
PM Inventories and Reductions (Short tons/year)

Calendar Year	PM Emission Inventories Under the Current Standards		PM Reductions Due to the New Standards	
	Assuming BEA Growth	Assuming PSR Growth	Assuming BEA Growth (% Reduction)	Assuming PSR Growth (% Reduction)
1995	283,000	283,000	0	0
2000	271,000	294,000	2,000 (0.7%)	2,000 (0.7%)
2005	279,000	341,000	40,000 (14.3%)	52,000 (15.1%)
2010	295,000	410,000	100,000 (33.8%)	140,000 (34.1%)
2015	308,000	497,000	133,000 (43.2%)	210,000 (42.3%)
2020	315,000	604,000	145,000 (46.0%)	266,000 (44.0%)

Figures 5-5 and 5-6 illustrate the relationship between the PM inventories under the current standards and the projected PM inventories under the final rule for the PSR and BEA growth assumptions, respectively. In each case there is a net decrease in PM emissions from the baseline of about 30% in the year 2010 and over 40% in 2020. As noted earlier, because of the continued uncertainties about the degree to which the steady-state test procedure will control PM emissions in use, especially from the many nonroad engines that frequently operate in transient modes, EPA cannot be certain that any assessment made at this time of the expected PM emission reductions due to the new standards will be completely accurate. The PM reductions indicated here result from EPA's best current estimates of adjustment factors for in-use PM emissions levels, as reflected in the NONROAD model. These factors and other assumptions in the model are still under review, and will continue to be improved in the future as new information becomes available.

2. Secondary nitrate particulates

The NOx reductions resulting from this rule are expected to reduce the concentrations of secondary nitrate particulates. This is because NOx can react with ammonia in the atmosphere to form ammonium nitrate particulates, especially when ambient sulfur levels are relatively low. EPA contracted with Systems Applications International (SAI) to investigate the formation of secondary nitrate particulates in the United States.[3] SAI used a combination of ambient concentration data and computer modeling that simulates atmospheric conditions to estimate the

Figure 5-5

Direct PM Emissions with PSR Growth

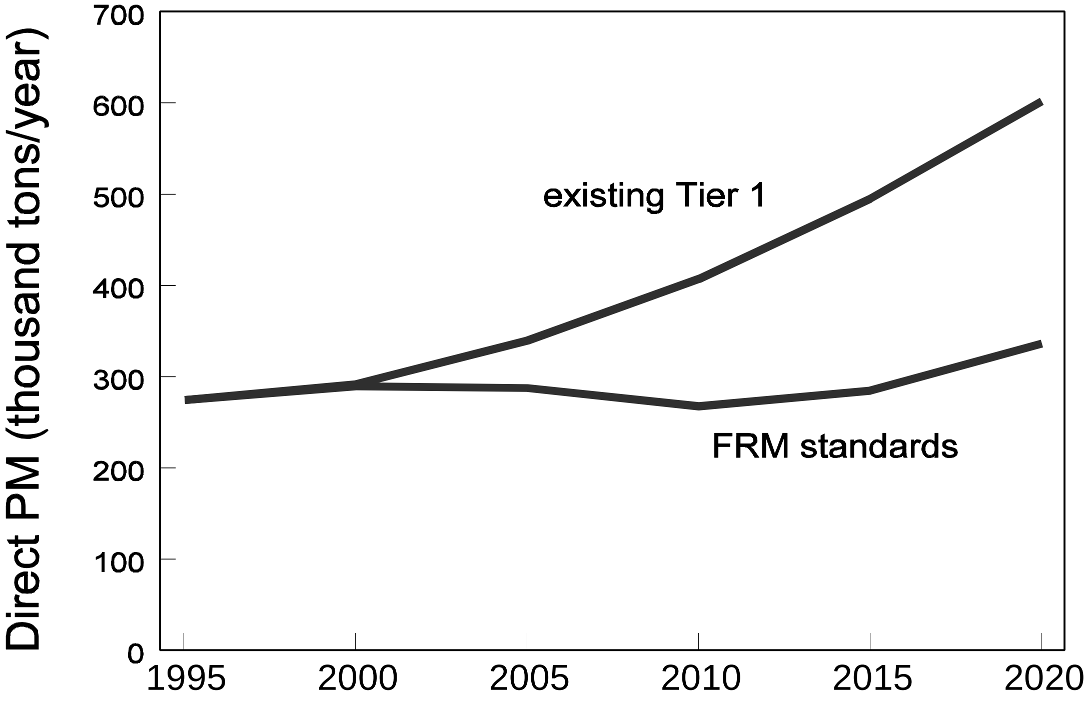
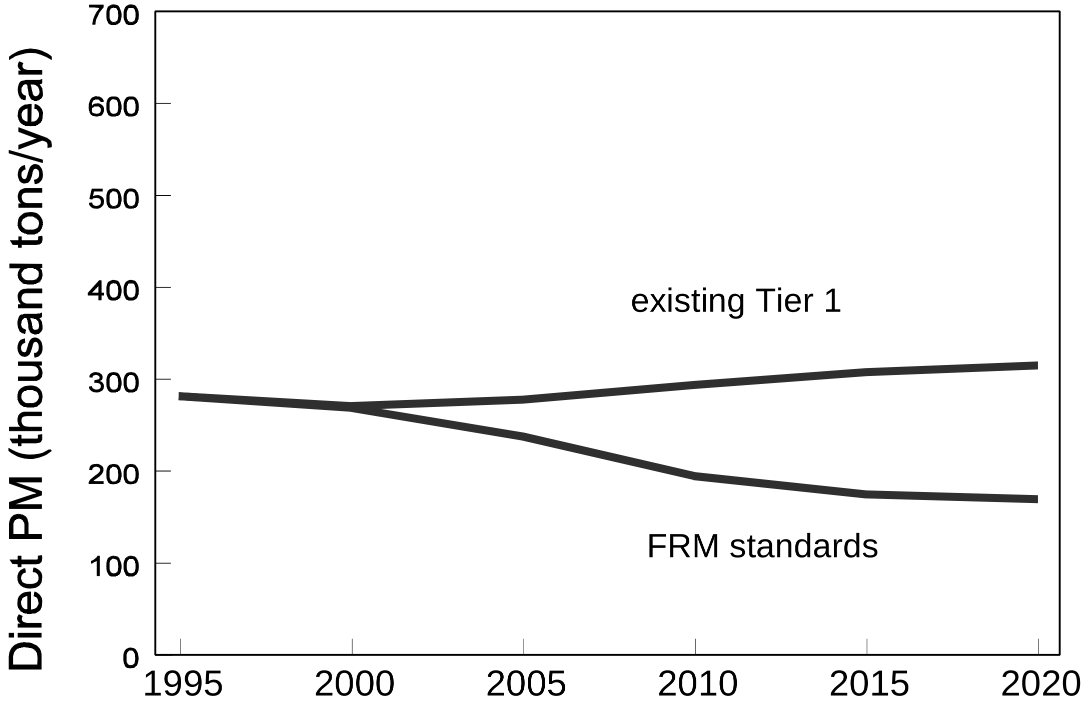


Figure 5-6

Direct PM Emissions with BEA Growth



conversion of NOx to PM nitrate. For the purpose of modeling, the continental 48 states were divided into nine regions, and rural areas were distinguished from urban areas. The model was designed to perform the equilibrium calculation to estimate particulate nitrate formation for different regions, seasons, and times of day and then was calibrated using ambient data.

Ambient data were collected from 72 ozone, 64 NOx, and 14 non-methane organic compound (NMOC) monitoring sites for use in the oxidation calculations. Data were also collected from 45 nitrate/NOx monitoring sites for use in the equilibrium calculations. SAI admitted that the available data from monitoring sites in some regions were limited and stated that more data would improve confidence in the results from these regions. In addition, the distribution of monitoring sites between rural and urban areas does not necessarily reflect the distribution of nonroad equipment operation. EPA has, however, reviewed the SAI report and its associated uncertainty analysis and believes that is the best estimate of atmospheric NOx to PM nitrate conversion rates available today.

The results from the SAI report state that the fraction of NOx converted to nitrates (g/g) ranges from 0.01 in the northeast to 0.07 in southern California. Based on population and usage figures for the various regions, the average fraction of NOx converted to nitrates is approximately 0.04 based on information derived from work on EPA's highway heavy-duty engine NPRM[4]. This value changes slightly from year-to-year due to the effects of ozone and oxides of sulfur (SOx) projections on the calculations for future years. The effects of the conversion fraction on future PM reductions is shown in Table 5-11.

Table 5-11
Estimated Secondary PM Reductions (Short tons/year)

Calendar Year	Total NOx Emission Reductions		Equivalent Secondary PM Emission Reductions	
	BEA Growth	PSR Growth	BEA Growth	PSR Growth
2005	264,000	340,000	10,600	13,600
2010	873,000	1,211,000	34,900	48,400
2015	1,346,000	2,086,000	53,800	83,400
2020	1,541,000	2,756,000	61,600	110,200

IV. Emission Reductions Per Piece of Equipment

The following section describes the development of the NMHC + NOx emissions and PM emission estimates on a per-machine basis. The emission reduction estimates were developed to estimate the cost-effectiveness of the new standards on a per-machine basis, as presented in Chapter 6. The per-machine reductions have been estimated for the six power categories for which cost estimates were developed in Chapter 4. The estimates are made for an average piece of machinery in each of the power ranges. Although the emissions vary from one nonroad application to another, EPA is presenting the average numbers to show reductions achieved from a typical piece of nonroad equipment. In order to estimate the emissions from a piece of nonroad equipment, information on the emission level of the engine, the power of the engine, the load factor of the engine, the annual hours of use of the engine, and the lifetime of the engine are needed. The values used to predict per-machine emissions in this analysis and the methodology for determining the values are presented below.

A. Per-Engine Emission Levels

To project the impact of the new standards, EPA must estimate the emission levels of engines prior to the time the new standards take effect and the emission levels once the new standards go into effect. Tables 5-12 and 5-13 contain the estimated NMHC + NOx emission levels and PM emission levels assumed by EPA in projecting the impact of the new standards, respectively. For the 0 to 37 kW category and the 130 to 450 kW category, where more than one power subcategory was combined, EPA weighted the appropriate subcategory emissions levels (contained in Tables 5-1 through 5-4) by population to determine the emission level for the overall power category.

Table 5-12
Estimated NMHC + NOx Emission Levels, g/kW-hr (g/hp-hr)

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control	12.4 (9.3)	—	—	—	—	—
Tier 1	8.3 (6.2)	10.2 (7.6)	9.8 (7.3)	9.8 (7.3)	9.7 (7.2)	9.7 (7.2)
Tier 2	7.5 (5.6)	7.5 (5.6)	6.6 (4.9)	6.6 (4.9)	6.4 (4.8)	6.4 (4.8)
Tier 3	—	4.7 (3.5)	4.0 (3.0)	4.0 (3.0)	4.0 (3.0)	—

Table 5-13
Estimated PM Emission Levels, g/kW-hr (g/hp-hr)

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control	1.13 (0.85)	—	—	—	—	—
Tier 1	0.81 (0.61)	0.96 (0.72)	0.54 (0.40)	0.54 (0.40)	0.54 (0.40)	0.54 (0.40)
Tier 2	0.70 (0.52)	0.40 (0.30)	0.29 (0.22)	0.20 (0.15)	0.20 (0.15)	0.20 (0.15)
Tier 3	—	—	—	—	—	—

As discussed in Chapter 4, some technology upgrades associated with this program may have been introduced absent the changes in emission standards. Any emission reductions that would normally have occurred with improvements in technology should not be considered in determining the benefits and cost effectiveness of new emission standards. However, EPA believes that as manufacturers modernize and improve the technologies used on nonroad engines, they are faced with many choices on how to employ the new technologies to the greatest advantage for their customers. Many times, in the absence of requirements to meet tighter emission standards, the manufacturer will design the parameters of a new technology, or similarly, redesign the existing engine, to minimize fuel consumption or some other desirable trait, while not taking advantage of the emissions control capability of the new technology. Because none of these technologies leads to inherently lower emissions, EPA has not made any adjustments to the emission reduction or cost-effectiveness calculations to account for emission benefits that would have occurred independent of the new standards.

B. Average Power

To estimate the average power for equipment in each power category, EPA used the PartsLink database from Power Systems Research to estimate the population and power ratings of nonroad diesel applications within each of the six different power categories that are expected to be covered by the new standards. To simplify the calculations, EPA used the most common applications within each power category that represent 90% of the category's population. For each of the most common applications, EPA used the information on all the individual engines within the application and determined a population-weighted average power for each power category. For those equipment applications where a certain fraction of the equipment is not expected to be categorized as a mobile source nonroad application (and therefore not subject to the nonroad engine standards), such as generator sets or pumps, EPA excluded the estimated fraction of engines from the average power calculations. Table 5-14 presents the resulting population-weighted average power for the different power categories.

Table 5-14
Average Power

Power Range (kW)	Average Power, kW (hp)
0-37	20.5 (27.5)
37-75	51.2 (68.7)
75-130	96.0 (128.8)
130-450	172.0 (230.6)
450-560	476.7 (639.3)
>560	596.8 (800.3)

C. Average Load Factor

To estimate the average load factor for a typical piece of equipment, EPA again used the PartsLink database from Power Systems Research to estimate the population and load factor of nonroad diesel applications within each of the six different power ranges that are expected to be covered by the new standards. As noted earlier, to simplify the calculations, EPA used the most common applications within each power range that represent 90% of the category's population. For each of the most common applications, EPA used the application-specific load factor and determined a population-weighted average load factor for each power range. As noted above, for those equipment applications where a certain fraction of the equipment is not expected to be categorized as a mobile source nonroad application (and therefore not subject to the nonroad engine standards), such as certain generator sets or pumps that are not moved for more than a year, EPA excluded the estimated fraction of engines from the average load factor calculations. Table 5-15 presents the resulting population-weighted average load factors for the different power ranges.

Table 5-15
Average Load Factor

Power Range (kW)	Average Load Factor
0-37	0.57
37-75	0.55
75-130	0.63
130-450	0.65
450-560	0.67
>560	0.63

D. Average Annual Hours

To estimate the average annual hours for a typical piece of equipment, EPA again used the PartsLink database from Power Systems Research to estimate the population and annual hours of usage for nonroad diesel applications within each of the six different power ranges that are expected to be covered by the new standards. As noted earlier, to simplify the calculations, EPA used the most common applications within each power range that represented 90% of the categories population. For each of the most common applications, EPA used the application-specific annual hours of operation and determined a population-weighted average annual hours of operation for each power range. Again, for those equipment applications where a certain fraction of the equipment is not expected to be categorized as a mobile source nonroad application (and therefore not subject to the nonroad engine standards), such as generator sets or pumps, EPA excluded the estimated fraction of engines from the average annual hours calculations. Table 5-

16 presents the resulting population-weighted average annual hours of operation for the different power ranges.

Table 5-16
Average Annual Hours of Operation

Power Range (kW)	Average Annual Hours
0-37	695
37-75	815
75-130	622
130-450	576
450-560	1073
>560	1056

E. Projected Annual Emissions Levels and Emission Reductions

Using the information presented in Tables 5-12 through 5-16 and the equation used for calculating emissions from nonroad equipment, EPA calculated the annual NMHC + NOx emissions and annual PM emissions expected from typical nonroad diesel equipment from current engines certified at the existing Tier 1 standards (or pre-control levels for engines <37 kW) and engines designed to meet the new standards. Tables 5-17 and 5-18 contain the annual NMHC + NOx emissions estimates and annual PM emissions estimates, respectively.

Table 5-17
Annual NMHC + NOx Emissions, short tons

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control	0.11	—	—	—	—	—
Tier 1	0.08	0.26	0.41	0.70	3.71	4.38
Tier 2	0.07	0.19	0.28	0.47	2.50	2.97
Tier 3	—	0.12	0.17	0.29	1.56	—

Table 5-18
Annual PM Emissions, short tons

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control	0.01	—	—	—	—	—
Tier 1	0.01	0.03	0.02	0.04	0.32	0.43
Tier 2	0.01	0.01	0.01	0.01	0.12	0.16

Table 5-19 and Table 5-20 contain the annual NMHC + NOx emission reductions and annual PM emission reductions resulting from the new standards, respectively.

Table 5-19
Annual NMHC + NOx Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.038	—	—	—	—	—
Tier 1 to Tier 2	0.007	0.070	0.133	0.228	1.214	1.411
Tier 2 to Tier 3	—	0.073	0.108	0.183	0.934	—

Table 5-20
Annual PM Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.003	—	—	—	—	—
Tier 1 to Tier 2	0.001	0.017	0.010	0.023	0.197	0.267

F. Average Lifetime

To calculate the emission reductions that will occur over the lifetime of nonroad equipment due to the new standards, it is necessary to know the lifetime of nonroad equipment. The equation that is used to calculate average lifetime of nonroad equipment relies on the annual hours of use, the load factor of the equipment, and the estimated engine life at full load for nonroad equipment. Using average load factor and average annual hours of use information contained in Tables 5-15 and 5-16, respectively, and information on the engine life at full load information[5], the average lifetime of nonroad equipment was calculated by power range and is presented in Table 5-21. The average lifetime for the different types of lawn and garden equipment is not calculated in the same manner. Each lawn and garden application has an average lifetime associated with it. For nonroad equipment under 37 kW, where diesel lawn and garden applications exist, the average lifetime results presented in Table 5-21 are a population-weighted value of the lawn and garden application results and the results of the remaining applications (other than lawn and garden equipment).

Table 5-21
Average Lifetime (years)

Power Range (kW)	Average Lifetime
0-37	6.2
37-75	9.0
75-130	10.2
130-450	10.7
450-560	8.4
>560	9.0

G. Lifetime Emission Reductions

The lifetime emission reductions due to the new standards were calculated based on the annual emission reductions contained in Table 5-19 and Table 5-20 and the average lifetimes contained in Table 5-21. Table 5-22 and Table 5-23 contain the lifetime NMHC + NOx emission reductions and PM emission reductions, respectively, on a nondiscounted basis. Table 5-24 and Table 5-25 contain the lifetime NMHC + NOx emission reductions and PM emission reductions, respectively on a discounted basis, assuming a 7% discount rate.

Table 5-22
Nondiscounted Lifetime NMHC + NOx Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.23	—	—	—	—	—
Tier 1 to Tier 2	0.05	0.63	1.36	2.44	10.14	12.69
Tier 2 to Tier 3	—	0.65	1.10	1.95	7.80	—

Table 5-23
Nondiscounted Lifetime PM Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.017	—	—	—	—	—
Tier 1 to Tier 2	0.006	0.150	0.105	0.246	1.648	2.406

Table 5-24
Discounted Lifetime NMHC + NOx Emission Reductions, short tons

Control Increment	Power Range (kW					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.20	—	—	—	—	—
Tier 1 to Tier 2	0.04	0.49	1.02	1.82	7.68	9.83
Tier 2 to Tier 3	—	0.51	0.82	1.46	5.91	—

Table 5-25
Discounted Lifetime PM Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Pre-control to Tier 1	0.014	—	—	—	—	—
Tier 1 to Tier 2	0.005	0.116	0.079	0.184	1.248	1.865

V. Conclusions

The amount of emission reductions that will be achieved with the implementation of the new standards is quite substantial. The chief pollutant, NOx, is expected to see emission reductions beyond 30% below the levels expected under the current Tier 1 standards (that are just now being implemented) by the year 2010. The NOx reductions due to the new standards will increase to over 50% in the year 2020. Under the new standards, HC and PM are expected to show reductions of about 55% and 45%, respectively, by the year 2020. Additional reductions in PM can be expected, due to the effect of NOx reductions on the formation of secondary nitrate particulates, amounting to approximately 110,000 tons/year nationwide by the year 2020 (assuming PSR growth rates).

A review of the emission levels in Figures 5-1 to 5-6 show that while the Tier 1 program achieves some initial reductions in NOx, the rate of growth of the industry soon leads to net increases in the inventories of all pollutants. With the new standards, however, the projected levels of inventories continue to decrease well into the 21st century.

Chapter 5 References

1. Power Systems Research, PartsLink Database, 1996.

2. "Results of the Emissions Modeling in Support of the Nonroad Diesel Engine FRM," EPA memorandum from Phil Carlson to Public Docket A-96-40, August 20, 1998.

3. "Benefits of Mobile Source NOx Related Particulate Matter Reductions," Systems Applications International, EPA Contract No. 68-C5-0010, WAN 1-8, October 1996.

4. 61 FR 33421 "Control of Emissions of Air Pollution from Highway Heavy-duty Engines", June 27, 1996.

5. Table 4 of "Nonroad CI Modeling Methodology and Request for Comment", EPA memorandum from Peter Caffrey to Public Docket A-96-40, July 1997.

CHAPTER 6: COST-EFFECTIVENESS

This chapter assesses the cost-effectiveness of the new NMHC + NOx emission standards for nonroad diesel engines. This analysis relies in part on cost information from Chapter 4 and emissions information from Chapter 5 to estimate the cost-effectiveness of the standards in terms of dollars per ton of total NMHC + NOx emission reductions. This chapter also examines the cost-effectiveness of the PM standards. Finally, the chapter compares the cost-effectiveness of the new provisions with the cost-effectiveness of other NOx and PM control strategies from previous EPA rules.

The analysis presented in this chapter is performed for nonroad diesel equipment broken down into the same power categories as presented in Chapter 4. The analysis is performed on a per-machine basis and examines total costs and total NMHC + NOx emission reductions over the typical lifetime of an average piece of nonroad equipment in each power category, discounted at a rate of seven percent to the beginning of the equipment's life. An estimate of the fleet-wide cost-effectiveness of the new standards, combining all of the power categories, is also presented. EPA has analyzed the cost-effectiveness of each new standard incremental to the previously applicable standard (i.e., Tier 2 standards incremental to Tier 1, Tier 3 standards incremental to Tier 2, and for engines rated under 37 kW, Tier 1 standards incremental to uncontrolled emission levels).

The cost-effectiveness is analyzed on a nationwide basis. In the recent rulemaking for highway heavy-duty diesel engines, EPA also presented a regional ozone control cost-effectiveness analysis in which the total life-cycle cost was divided by the discounted lifetime NMHC + NOx emission benefits adjusted for the fraction of emissions that occur in the regions expected to impact ozone levels in ozone nonattainment areas. (Air quality modeling indicates that these regions include all of the states that border on the Mississippi River, all of the states east of the Mississippi River, Texas, California, and any remaining ozone nonattainment areas west of the Mississippi River not already included.) The results of that analysis show that the regional cost-effectiveness values were 13 percent higher than the nationwide cost-effectiveness values. Because of the small difference between the two results, EPA is presenting only nationwide cost-effectiveness results for this analysis.

In addition to the primary benefit of reducing ozone within and transported into urban ozone nonattainment areas, the NOx reductions expected from the new nonroad diesel engine standards will have secondary benefits as well. These secondary benefits include impacts with respect to human mortality, human morbidity, agricultural yields, visibility, soiling (due to secondary particulate), and ecosystems (e.g., through the reduced effects of acid deposition and eutrophication). To estimate the monetary value of these secondary benefits to society, ICF Incorporated prepared a study in support of the recent highway heavy-duty engine rulemaking summarizing the results of a variety of studies that examined the value of ozone control on the secondary benefits highlighted above.[1] Table 6-1 contains a summary of the results of the ICF report. The total value of all the secondary benefits was estimated to be $878 per ton of NOx reduction. The cost-effectiveness analysis presented in this chapter does not assign any value to these secondary benefits. They are presented in this chapter for informational purposes only.

Table 6-1
Summary of Estimated Monetized Benefits per Ton

Benefit Category	Point Estimate of Benefits per Ton of NOx Reduction
Human Mortality	$312
Human Morbidity	$10
Agricultural Yields	$287
Soiling	$17
Ecosystems	$16
Visibility	$236

I. Cost-Effectiveness of the New Emission Standards

A. NMHC + NOx

The following section describes the cost-effectiveness of the new NMHC + NOx standards for the various power categories of nonroad equipment. As discussed in Chapter 4, the estimated cost of complying with the standards varies depending on the model year under consideration. The following section presents the per-machine cost-effectiveness results for the different model years during which the costs are expected to change. In calculating the cost-effectiveness numbers, the full lifecycle costs (both with and without the expected changes in operating costs included) were divided by the combined NOx and NMHC lifetime emission reductions as presented in Chapter 5.

The following section also presents the fleet-wide cost-effectiveness for the new engine standards. These fleet-wide cost-effectiveness numbers are calculated by weighting the various power category costs and emission reductions by the population estimates for nonroad equipment affected by the new standards in each power category. The populations for the different power categories of nonroad equipment were determined from the PSR PartsLink database. Table 6-2 contains the 1995 nonroad diesel equipment populations used in the fleet-wide analysis. (The populations listed in Table 6-2 exclude those nonroad applications which are expected to not meet EPA's definition of a mobile source nonroad engine such as generator sets that are not moved from a specific location in a given year.)

Table 6-2
1995 Nonroad Diesel Equipment
Populations by Power Category

Power Category	1995 Population
0-37 kW	2,555,000
37-75 kW	2,080,000
75-130 kW	1,410,000
130-450 kW	1,124,000
450-560 kW	11,000
>560 kW	19,000

A copy of the spreadsheets prepared for this cost-effectiveness analysis has been placed in the public docket for the final rulemaking.[2] The reader is directed to the spreadsheets for a complete version of the cost-effectiveness calculations.

Tables 6-3 through 6-8 contain the discounted cost-effectiveness values for the individual power categories of nonroad equipment based on the total net present value costs (excluding operating costs) as presented in Chapter 4 and the lifetime NMHC + NOx emission reductions as presented in Chapter 5. Table 6-9 contains the fleet-wide, discounted cost-effectiveness of the Tier 2 NMHC + NOx emission standards and the Tier 3 NMHC + NOx emission standards (without factoring in the effects of operating costs).

Table 6-3
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 0-37 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 1	1 to 2	$59	0.20	$300
	3 to 5	$57		$290
Tier 2	1 to 2	$80	0.04	$2,090
	3 to 5	$71		$1,850
	6 to 10	$35		$910
	11+	$29		$770

Table 6-4
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 37-75 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$249	0.49	$510
	3 to 5	$226		$460
Tier 3	1 to 2	$282	0.51	$560
	3 to 5	$244		$480
	6 to 10	$160		$320
	11+	$122		$240

Table 6-5
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 75-130 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$867	1.02	$850
	3 to 5	$784		$770
Tier 3	1 to 2	$658	0.82	$800
	3 to 5	$564		$690
	6 to 10	$442		$540
	11+	$301		$370

Table 6-6
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 130-450 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$804	1.82	$440
	3 to 5	$719		$400
Tier 3	1 to 2	$872	1.46	$600
	3 to 5	$734		$510
	6 to 10	$545		$380
	11+	$440		$300

Table 6-7
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 450-560 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$2,670	7.68	$350
	3 to 5	$2,523		$330
Tier 3	1 to 2	$2,296	5.91	$390
	3 to 5	$2,127		$360
	6 to 10	$1,991		$340
	11+	$543		$90

Table 6-8
Discounted Cost-effectiveness of the
NMHC + NOx Standards for Greater than 560 kW Engines (Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted, Engine and Equipment Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$1,087	9.83	$110
	3 to 5	$1,053		$110
	6 to 10	$1,025		$100
	11+	$109		$10

Table 6-9
Discounted Fleet-wide Cost-effectiveness of the NMHC + NOx Standards
(Excluding operating costs)

Level of Standard	Model Year Grouping	Discounted Cost-effectiveness ($/ton)
Tier 2	1 to 2	$600
	3 to 5	$540
Tier 3	1 to 2	$650
	3 to 5	$550
	6 to 10	$410
	11+	$300

Tables 6-10 through 6-15 contain the discounted cost-effectiveness values for the individual power categories of nonroad equipment based on the total net present value costs (including operating costs) as presented in Chapter 4 and the lifetime NMHC + NOx emission reductions as presented in Chapter 5. For those categories of engines where the operating cost is expected to offset the increased engine and equipment costs (due to improved fuel economy), the overall cost and cost-effectiveness is shown as zero in the tables. Table 6-16 contains the fleet-wide, discounted cost-effectiveness of the Tier 2 NMHC + NOx emission standards and the Tier 3 NMHC + NOx emission standards (factoring in the effects of operating costs).

Table 6-10
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 0-37 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 1	1 to 2	$103	0.20	$520
	3 to 5	$101		$510
Tier 2	1 to 2	$125	0.04	$3,240
	3 to 5	$115		$3,000
	6 to 10	$79		$2,060
	11+	$74		$1,920

Table 6-11
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 37-75 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$308	0.49	$630
	3 to 5	$285		$580
Tier 3	1 to 2	$379	0.51	$750
	3 to 5	$340		$670
	6 to 10	$256		$510
	11+	$219		$430

Table 6-12
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 75-130 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$719	1.02	$710
	3 to 5	$638		$630
Tier 3	1 to 2	$7	0.82	$10
	3 to 5	$0		$0
	6 to 10	$0		$0
	11+	$0		$0

Table 6-13
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 130-450 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$542	1.82	$300
	3 to 5	$456		$250
Tier 3	1 to 2	$46	1.46	$30
	3 to 5	$0		$0
	6 to 10	$0		$0
	11+	$0		$0

Table 6-14
Discounted Cost-effectiveness of the
NMHC + NOx Standards for 450-560 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$1,323	7.68	$170
	3 to 5	$1,176		$150
Tier 3	1 to 2	$1,085	5.91	$180
	3 to 5	$915		$160
	6 to 10	$779		$130
	11+	$0		$0

Table 6-15
Discounted Cost-effectiveness of the
NMHC + NOx Standards for Greater than 560 kW Engines (Including operating costs)

Level of Standard	Model Year Grouping	Discounted, Lifetime Costs	Discounted, Lifetime NMHC + NOx Reductions (tons)	Discounted, Per-machine Cost-effectiveness ($/ton)
Tier 2	1 to 2	$1,087	9.83	$110
	3 to 5	$1,053		$110
	6 to 10	$1,025		$100
	11+	$109		$10

Table 6-16
Discounted Fleet-wide Cost-effectiveness of the NMHC + NOx Standards
(Including operating costs)

Level of Standard	Model Year Grouping	Discounted Cost-effectiveness ($/ton)
Tier 2	1 to 2	$540
	3 to 5	$480
Tier 3	1 to 2	$220
	3 to 5	$130
	6 to 10	$0
	11+	$0

B. PM

EPA has also estimated the cost-effectiveness of the PM emission standards for nonroad diesel engines. The per-machine PM emission reduction estimates were developed in Chapter 5. For costs, EPA assumed half of the increased engine and equipment costs projected in Chapter 4 were allocated for PM control, and excluded operating costs. EPA believes this is a conservative assumption given the stringency of the NMHC + NOx standards and results in an upper end estimate of the cost-effectiveness for PM control. Table 6-17 contains the resulting fleet-wide cost-effectiveness of the PM standards. For this estimate, the Tier 1 standards for engines rated under 37 kW were combined with the Tier 2 standards for all power categories.

Table 6-17
Discounted Fleet-wide Cost-effectiveness of the PM Standards

Level of Standard	Model Year Grouping	Discounted Cost-effectiveness ($/ton)
Tier 1 and Tier 2 combined	1 to 2	$2,320
	3 to 5	$2,100
	6 to 10	$1,680
	11+	$700

II. Comparison with Cost-Effectiveness of Other Control Programs

In an effort to evaluate the cost-effectiveness of the new standards, EPA has summarized the cost-effectiveness results for three other recent EPA mobile source rulemakings that required reductions in NOx emissions, the primary focus of the new standards. Table 6-18 summarizes the cost-effectiveness results from the heavy-duty vehicle portion of the Clean Fuel Fleet Vehicle Program, Phase II of the Reformulated Gasoline Program and the most recent NMHC + NOx engine standards for highway heavy-duty diesel engines.

Table 6-18
Summary of Cost-Effectiveness Results for Recent EPA NOx Control Programs

EPA Rule	Pollutants Considered in Calculations	Cost-Effectiveness ($/ton)
Clean Fuel Fleet Vehicle Program (Heavy-duty)	NOx	$1,300 - $1,500
Reformulated Gasoline -- Phase II	NOx	$5,000
2.5 g/hp-hr NMHC + NOx Standard for Highway Heavy-Duty Engines	NMHC + NOx	$100-$600
Locomotive Engine Standards	NOx	$160 - $250

A comparison of the cost-effectiveness numbers in Table 6-18 with the cost-effectiveness results presented throughout this chapter for nonroad diesel engines shows that the cost-effectiveness of the new NMHC + NOx standards are more favorable than the cost-effectiveness of both the clean fuel fleet vehicle program and reformulated gasoline. The cost-effectiveness results of the new NMHC + NOx standards for nonroad diesel engines are comparable to the cost-effectiveness of the most recent highway heavy-duty NMHC + NOx standards and slightly less favorable than the locomotive engine NOx standards.

For comparison purposes, EPA has also summarized the cost-effectiveness results for two other recent EPA mobile source rulemakings that required reductions in PM emissions. Table 6-19 summarizes the cost-effectiveness results for the most recent urban bus engine PM standard and the urban bus retrofit/rebuild program. The PM cost-effectiveness results presented earlier in Table 6-17 are more favorable than either of the urban bus programs.

Table 6-19
Summary of Cost-Effectiveness Results
for Recent EPA Diesel PM Control Programs

EPA Rule	Cost-Effectiveness ($/ton)
0.05 g/hp-hr Urban Bus PM Standard	$10,000 - $16,000
Urban Bus Retrofit/Rebuild Program	$25,500

Chapter 6 References

1.“Benefits of Reducing Mobile Source NOx Emissions,” prepared by ICF Incorporated for Office of Mobile Sources, U.S. EPA, Draft Final, September 30, 1996.

2. “Cost Effectiveness and 20-Year Cost/Benefit Analysis of the New Nonroad Diesel Engine Standards,” EPA memorandum from Phil Carlson to Docket A-96-40, July 22, 1998.

Appendix to the Regulatory Impact Analysis

Table A-1 contains the year-by-year fleetwide costs and emission benefits associated with the new diesel nonroad engine standards for the 20-year period from 1999 to 2018. The fleetwide costs presented in Table A-1 do not include the impact of the new standards on operating costs, which in many cases are projected to lead to decreased costs. (The numbers presented in Table A-1 are <u>not</u> discounted.)

Table A-1
Costs and Emission Benefits of the New Diesel Nonroad Engine Standards

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons)		
		NOx	HC	PM
1999	$4,800,000	5,300	4,400	800
2000	$13,100,000	16,300	10,900	2,100
2001	$46,200,000	36,600	17,700	5,000
2002	$54,600,000	60,300	24,500	8,500
2003	$172,100,000	140,100	31,300	18,400
2004	$247,300,000	240,000	38,100	34,900
2005	$257,100,000	339,600	54,800	51,500
2006	$393,400,000	514,000	76,300	69,200
2007	$469,800,000	688,300	97,700	86,900
2008	$524,400,000	862,700	119,200	104,600
2009	$519,000,000	1,037,100	140,700	122,300
2010	$548,400,000	1,211,400	162,100	140,000
2011	$522,700,000	1,386,300	183,900	154,100
2012	$527,200,000	1,561,300	205,700	168,100
2013	$422,000,000	1,736,200	227,500	182,200
2014	$398,000,000	1,911,100	249,300	196,200
2015	$413,100,000	2,086,000	271,100	210,300
2016	$392,800,000	2,220,000	289,000	221,400
2017	$387,700,000	2,353,900	306,900	232,400
2018	$388,000,000	2,487,800	324,800	243,500

Table A-2 contains the discounted year-by-year fleetwide costs and emission benefits associated with the new diesel nonroad engine standards for the 20-year period from 1999 to 2018. The year-by-year results were discounted to 1999 and a discount rate of seven percent was assumed for the analysis. Again, the discounted fleetwide costs presented in Table A-2 do not include the impact of the new standards on operating costs, which in many cases are expected to decrease.

Table A-2
Discounted Costs and Emission Benefits of the New Diesel Nonroad Engine Standards

Calendar Year	Discounted Fleetwide Costs	Discounted Fleetwide Reductions (short tons)		
		NOx	HC	PM
1999	$4,800,000	5,300	4,400	800
2000	$12,200,000	15,200	10,200	2,000
2001	$40,400,000	32,000	15,500	4,400
2002	$44,500,000	49,200	20,000	6,900
2003	$131,300,000	106,900	23,900	14,000
2004	$176,300,000	171,100	27,200	24,900
2005	$171,300,000	226,300	36,500	34,300
2006	$245,000,000	320,100	47,500	43,100
2007	$273,400,000	400,600	56,900	50,600
2008	$285,200,000	469,300	64,800	56,900
2009	$263,900,000	527,200	71,500	62,200
2010	$260,600,000	575,500	77,000	66,500
2011	$232,100,000	615,500	81,700	68,400
2012	$218,800,000	647,900	85,400	69,800
2013	$163,700,000	673,300	88,200	70,600
2014	$144,200,000	692,700	90,400	71,100
2015	$139,900,000	706,600	91,800	71,200
2016	$124,300,000	702,800	91,500	70,100
2017	$114,700,000	696,400	90,800	68,800
2018	$107,300,000	687,900	89,800	67,300

Summing the discounted annual costs and discounted emission reductions over the twenty-year period yields a 20-year fleetwide cost of $3.2 billion and 20-year emission reductions of 8.3 million tons of NOx, 1.2 million tons of HC, and 0.9 million tons of PM. The resulting

20-year annualized fleetwide costs and emission reductions are $298 million per year and 786,000 tons per year of NOx, 110,000 tons per year of HC, and 87,000 tons per year of PM. A copy of the spreadsheet prepared for this 20-year cost and benefit analysis has been placed in the public docket for the final rulemaking. The reader is directed to the spreadsheets for a complete version of the analysis.

Sensitivity Analysis #1: Impact of Non-Emissions Cost Assumptions

As described in Chapter 4, EPA's cost and cost-effectiveness analyses are based on the assumption that half of the cost of certain technologies expected to be used to meet the new standards can be attributed to benefits unrelated to emissions control. In other words, EPA believes that manufacturers may have used those technologies on nonroad engines regardless of whether EPA set new standards. In order to analyze the sensitivity of the cost analysis to this assumption, EPA estimated the per-equipment costs by attributing the full cost of these technologies to the new emission standards.[1] EPA then estimated the effect of these increased costs on the 20-year costs to society. Table A-3 contains the year-by-year fleetwide costs associated with these increased cost estimates for the 20-year period from 1999 to 2018. By assuming all of the cost of technology is attributed to emissions, the 20-year fleetwide discounted cost is estimated to be $4.4 billion, approximately $1.2 billion higher than the base case results presented earlier in this appendix. The resulting 20-year annualized fleetwide costs are $411 million per year, approximately $115 million higher than the base case results presented earlier in this appendix. Table A-4 presents the cost-effectiveness of the standards using the costs developed for this sensitivity analysis.

Table A-3
Fleetwide Costs Assuming Full Cost is Attributed to Emissions Control
(Sensitivity Analysis #1)

Calendar Year	Undiscounted Fleetwide Costs	Discounted Fleetwide Costs
1999	$5,500,000	$5,500,000
2000	$14,800,000	$13,800,000
2001	$62,600,000	$54,700,000
2002	$74,100,000	$60,500,000
2003	$243,300,000	$185,600,000
2004	$349,100,000	$248,900,000
2005	$361,500,000	$240,900,000
2006	$519,600,000	$323,600,000
2007	$614,700,000	$357,700,000
2008	$705,600,000	$383,800,000
2009	$696,700,000	$354,200,000
2010	$726,600,000	$345,200,000
2011	$706,600,000	$313,800,000
2012	$714,400,000	$296,500,000
2013	$595,500,000	$230,900,000
2014	$578,700,000	$209,800,000
2015	$601,400,000	$203,700,000
2016	$583,900,000	$184,900,000
2017	$586,800,000	$173,600,000
2018	$595,500,000	$164,700,000

Table A-4
Cost-effectiveness of the NMHC + NOx Standards
Assuming Full Cost is Attributed to Emissions Control
(Sensitivity Analysis #1)

Standard	Power (kW)	Year of Production	Discounted Engine and Equipment Cost	Discounted Lifetime NMHC+NOx Reductions	Discounted Lifetime Cost-effectiveness
Tier 1	0-37	1	$66	0.20 tons	$560/ton
Tier 2	0-37	1	$135	0.04 tons	$3,510/ton
		6	$56		$1,470/ton
	37-75	1	$329	0.49 tons	$670/ton
	75-130	1	$1,255	1.02 tons	$1,230/ton
	130-450	1	$1,171	1.82 tons	$640/ton
	450-560	1	$3,283	7.68 tons	$430/ton
	>560	1	$1,715	9.83 tons	$170/ton
		6	$1,608		$160/ton
Tier 3	37-75	1	$483	0.51 tons	$950/ton
		6	$264		$520/ton
	75-130	1	$811	0.82 tons	$990/ton
		6	$532		$650/ton
	130-450	1	$1,027	1.46 tons	$710/ton
		6	$632		$430/ton
	450-560	1	$2,618	5.91 tons	$440/ton
		6	$2,298		$390/ton

Sensitivity Analysis #2: Impact of Global Sales Cost Distribution Assumption

As described in Chapter 4, EPA's cost and cost-effectiveness analyses are based on the assumption that manufacturers would spread their fixed costs over their world production of nonroad engines, based on a scenario of manufacturers offering a single low-emitting engine into a market with harmonized emission standards. Because there are regions of the world that are not likely to adopt the EPA standards, EPA has estimated the per-equipment costs based on the assumption that fixed costs could be distributed over only half of engines sold into other countries.[1] EPA then estimated the effect of these revised costs on the 20-year costs to society. By distributing costs over fewer engines, year by year cost estimates increase compared to the base case results presented earlier in this appendix. The 20-year fleetwide discounted cost is estimated to be $3.6 billion, approximately $0.4 billion higher than the base case results. The resulting 20-year annualized fleetwide costs are $339 million per year, approximately $40 million higher than the base case results presented earlier in this appendix.

Appendix References

1. “Sensitivity Tests of Nonroad Diesel Cost Estimates,” EPA memo from Alan Stout to Docket A-96-40, August 27, 1998.