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

EPA

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources
Engine Programs and Compliance Division

August 1997

Table of Contents

CHAPTER 1: INTRODUCTION

EPA is proposing 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 Draft Regulatory Impact Analysis (Draft RIA) provides technical, economic, and environmental analyses of the proposed emission standards for the affected engines. The anticipated emission reductions would 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, proposed NOx and PM standards are reduced by up to two-thirds compared with current standards. Overall, the proposed requirements would 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 would be affected by the proposed rule. Chapter 3 provides a description of the range of technologies being considered for improving emission control 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 Initial Regulatory Flexibility Analysis. Chapter 5 presents the calculated reduction in emission levels resulting from the proposed standards, and Chapter 6 compares the costs and the emission reductions for an estimation of the cost-effectiveness of the rulemaking.

Table 1-1 lists the proposed 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.

---

[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
Proposed 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 Draft 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.

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	

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.

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 proposed 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 lacks a consistent data source for identifying additional companies.

A. Engines Rated Under 37 kW

These engines would be regulated for the first time by EPA with the proposed Tier 1 emission standards. 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 proposed 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**

---

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

(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 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 proposed 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.

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.

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 2-3
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**	**68.00%**
Grand Total	**208,801**		

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 proposed 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 proposed 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 proposed 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 proposed 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 discuss 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 of the proposed standards. 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 a 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 proposed 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 proposed 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 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 proposed 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 anticipate 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 proposed numerical standards and implementation dates, EPA depended heavily on extending the analysis of technological feasibility for the preceding proposal for highway heavy-duty engines. While the proposed standards for highway engines apply equally to all sizes of engines starting in the same year, the standards proposed 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 proposed 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 the proposed standards for nonroad engines. This analysis of diesel engine technologies is contained in Chapter 4 of the Draft RIA for the highway rule.[27]

By proposing 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 the electronic control software. The 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 these technologies developed for highway engines.

B. Engines Rated between 37 and 75 kW

This category is somewhat transitional in nature, because it contains both naturally aspirated engines, which more closely resemble engines rated under 37 kW, and turbocharged engines, which more closely resemble highway engines rated over 75 kW.

Turbocharged engines in this category would have an advantage in meeting the emission standards. In addition to the benefits gained from an optimized turbocharger with air-to-air aftercooling, manufacturers will continue to improve the combustion chamber and use retarded timing to meet the proposed Tier 2 standards. These standards are comparable to the standards for highway heavy-duty engines in effect beginning in model year 1998, but are somewhat less stringent. The technology used to bring highway engines into compliance can be readily transferred to turbocharged nonroad engines rated between 37 and 75 kW, given the substantial lead time provided. Though some upgrades to the fuel injection system are likely for the proposed Tier 2 standards, manufacturers are expected to rely extensively on converting to electronically controlled fuel injection to meet the Tier 3 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 through the use of these technologies, the highway standards will be feasible. EPA also believes that, given the further lead time provided for nonroad engines rated between 37 and 75 kW, the Tier 3 standards will be feasible using the technologies transferred from highway engines.

While turbocharged engines have an advantage in controlling emissions, the level of stringency for this power range was selected to allow continued use of naturally aspirated engines. Naturally aspirated engines are expected to adapt much of the technology from the larger engines for controlling emissions. Optimizing combustion chambers and improving fuel pumps provide a lot of potential for improving control of emissions from naturally aspirated engines. For those engines that need additional modifications to meet Tier 3 standards, electronic controls will be available to improve the overall performance of the engine, including more sophisticated control of injection variables. Manufacturers may also need to utilize EGR on some engines to meet the proposed Tier 3 standards. EPA believes that these design changes will lead to emission levels from naturally aspirated engines in this power range to be nearly as low as for engines rated over 75 kW.

C. Engines Rated under 37 kW

Engines rated under 37 kW, which are nearly all naturally aspirated, will use similar design approaches to those described for naturally aspirated engines rated over 37 kW. Nevertheless, the design features of the small engines and their greater cost sensitivity constrain the targeted level of emission control from these engines. A less stringent emission standard is therefore proposed for these engines.

Engines using indirect injection (IDI) are already controlled to levels below the proposed Tier 1 standards and, in most cases, even the proposed 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 proposed 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. For this reason, it is possible that by 2004 an electronically controlled engine will be available at a reasonable cost.[32] 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. Proposed 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 proposed 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 the proposed 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, sometimes dramatically.

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 proposed standards.

The impact of the proposed 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 proposed 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 proposed standards. Manufacturers will likely use only proven technology that is currently used in other engines, especially in diesel trucks.

Chapter 3 References

1.Herzog, P., Burgler, L., Winklhofer, E., Zelenda, P., and Carterllieri, W., "NOx Reduction Strategies for DI Diesel Engines," SAE Paper 920470, 1992.

2.Uyehara, O., "Factors that Affect NOx and Particulates in Diesel Engine Exhaust," SAE Paper 920695, 1992.

3.Durnholz, M., Eifler, G., Endres, H., "Exhaust-Gas Recirculation - A Measure to Reduce Exhaust Emission of DI Diesel Engines," SAE Paper 920715, 1992.

4.Bazari, Z., French, B., "Performance and Emissions Trade-Offs for a HSDI Diesel Engine - An Optimization Study," SAE Paper 930592, 1993.

5.“Estimated Economic Impact of New Emission Standards for Heavy-Duty On-Highway Engines," Acurex Environmental Corporation Final Report (FR-97-103), March 31, 1997, page 4-11.

6.See reference 4--SAE 930592

7.“Emission Control Technology for Diesel Trucks,” U.S. EPA Report to Congress, October 1993.

8.See reference 5 - Acurex Environmental Final Report, page 4-10

9.See reference 4--SAE 930592

10.See reference 1--SAE 920470

11.See reference 4--SAE 930592

12.Pierpont, D., Reitz,R., "Effects of Injection Pressure and Nozzle Geometry on DI Diesel Emissions and Performance," SAE Paper 950604, 1995.

13.See reference 1--SAE 920470

14.See reference 12--SAE 950604

15.Ghaffarpour, M and Baranescu, R, “NOx Reduction Using Injection Rate Shaping and Intercooling in Diesel Engines,” SAE Paper 960845, 1996

16.Piepont, D., Montgomery, D., Reitz, R., “Reducing Particulate and NOx Using Pilot Injection,” SAE Paper 950217, 1995.

17.“CAT’s HEUI System: A Look at the Future?,” *Diesel Progress*, April 1995, page 30.

18.See reference 1--SAE 920470

19.See reference 17--SAE 950217

20.Montgomery, D. and Reitz, R., “Six-Mode Cycle Evaluation of the Effect of EGR and Multiple Injections on Particulate and NOx Emissions from a D.I. Diesel Engine,” SAE Paper 960316, 1996

21.Yoshikawa, H., Umehara, T., Kurkawa, M., Sakagami, Y., Ikeda, T., “The EGR System for Diesel Engine Using a Low Voltage Soot Removal Device,” SAE Paper 930369, 1993.

22.Khalil, N., Levendis, Y., Abrams, R., “Reducing Diesel Particulate and NOx Emissions via Filtration and Particle-Free Exhaust Gas Recirculation,” SAE Paper 950736, 1995.

23.See reference 4--SAE 930592

24.Meeting between EPA and Manufacturers of Emission Controls Association, April 1995.

25.Voss, K., Bulent, Y., Hirt, C., and Farrauto, R., "Performance Characteristics of a Novel Diesel Oxidation Catalyst," SAE Paper 940239, 1994.

26.Johnson, J., Bagley, S., Gratz, L., Leddy, D., "A Review of Diesel Particulate Control Technology and Emissions Effects - 1992 Horning Memorial Award Lecture," SAE Paper 940233, 1994.

27.“Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines,” U.S. EPA, June 6, 1996.

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 proposed rulemaking lays out a proposal for a far-reaching schedule of emission standards 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 those proposed 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 proposed 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 proposed 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 proposed 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 proposed 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 Acurex Environmental Corporation.[1] In addition, Acurex 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 Proposed Standards

The following discussion provides a description and estimated costs for those technologies EPA projects will be needed to comply with the proposed emission standards. In some cases it is difficult to make a distinction between technologies needed to reduce emissions for compliance with emission standards and those technologies that offer other benefits for improved fuel economy and engine performance. EPA believes that without new emission standards, manufacturers would continue research on and eventually deploy many technological upgrades to improve engine performance or more cost-effectively control emissions. Turbocharging, aftercooling, and variable-valve timing are examples of technologies whose primary benefit is for improved performance. Modifications to fuel injection systems will also continue independently of new standards to improve engine performance, though some further development with a focus on NOx, HC, and PM emissions will certainly play an important role in achieving emission reduction targets.

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 would apply to engines starting in the first year of production under the new standards. Costs in subsequent years would be reduced as manufacturers pursue innovations to produce engines more efficiently. 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 proposed emission standards. The fact that manufacturers have nearly a full decade before implementation of the most challenging of the proposed 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 as a result of the proposed 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 for the next tier of proposed emission standards (i.e., Tier 2 standards for all engines except those rated under 37 kW). These redesigned engines will then serve as a platform for the other changes anticipated for the later standards. Manufacturers are expected to introduce electronic controls 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. For Tier 3 standards, EPA expects that many engines will see further fuel injection improvements and will incorporate a moderate degree of cooled exhaust gas recirculation.

1. Baseline technology packages

Most nonroad diesel engines rated between 130 and 560 kW are turbocharged, and, as a result of the Tier 1 standards, many models now have air-to-water aftercoolers. Increased use of air-to-air aftercoolers is expected before any further change in emission standards as manufacturers attempt to improve the fuel efficiency and durability of their engines. Engines typically continue to use in-line fuel pumps with injection pressures around 1200 bar (18,000 psi). Manufacturers modified the shape of piston bowls and other components and significantly retarded injection timing. Engine acceleration is governed to limit smoke.

Engines rated over 560 kW must first comply with Tier 1 standards in the 2000 model year. By that time, these engines are expected to be turbocharged with a mix of air-to-air and air-to-water aftercooling. Fuel systems will use unit pumps or unit injectors. Engines rated over 560 kW are expected to fully utilize electronic controls, primarily for reasons independent of emission standards, prior to 2006, when the Tier 2 standards apply to those engines.

Engines rated between 37 and 130 kW have a mix of baseline technologies. Smaller engines in this range tend to be naturally aspirated, while larger engines tend to be turbocharged; a large degree of overlap prevents the use of a simple threshold for characterizing an engine's method of aspiration. Similarly, larger engines in this range typically use in-line fuel pumps, while the smaller engines are more likely to use lower-cost rotary fuel pumps. Engines certified to Tier 1 standards are showing increased use of turbocharging with air-to-water aftercooling. These engines will also see retarded injection timing. Engines that remain naturally aspirated are expected to raise injection pressures, increase swirl, and retard injection timing.

Engines rated under 37 kW are typically naturally aspirated and are fueled by distributor pumps. About two thirds of these engines use indirect injection technology according to the PSR OE Link database. This database includes imported models only if they are sold as loose engines. The missing captive engine imports may have a different distribution between direct injection and indirect injection engines, but neither the direction nor the magnitude of that change is clear.

2. Projected technologies for Tier 1

The proposed 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 proposed standards through retarded injection timing and other modifications to engine design, such as reentrant piston bowls, increased swirl, reduced crevice volume, and better ring packs for reduced oil consumption.

Indirect injection engines are already performing at levels that would comply with the proposed 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, 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 proposed Tier 2 standards, which apply to all power categories, will require a combination of engine technologies and design strategies. First, engine manufacturers are expected to use the Tier 2 standards to set the schedule for their product development cycles, conducting a broad 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. Such engine redesign is expected to be done with an eye toward compliance with the next tier of standards, so one major set of engine modifications could serve manufacturers for two tiers of emission standards. 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. Certification data from 1996 show that about 4 percent of engines rated between 130 and 560 kW include electronic controls.[5] 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 25 percent of engines rated between 37 and 75 kW will adopt electronic controls as a result of Tier 2 standards. Similarly, Tier 2 standards are expected to lead to a 50 percent increase in the use of electronic controls for engines rated between 75 and 560 kW.

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.

The result of engine modifications, new electronic controls, and improved fuel injection will be engines with better performance in addition to the enhanced emission control. To estimate the impact of the proposed 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 market- and EPA-driven improvements. This approach is described more completely in the Draft RIA for the proposed emission standards for 2004 model year heavy-duty highway engines.[6] In addition, several engine models will introduce or improve turbocharging and will incorporate air-to-air aftercooling. These changes can be used to improve emission control, but EPA believes that both of these technologies have sufficient benefits for engine performance and fuel consumption to project that market forces alone would account for their widespread use. EPA has therefore not estimated the costs of these technologies as an impact of the proposed standards.

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 proposed 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, proposed to take effect between 2006 and 2008 for engines rated between 37 and 560 kW, will also require multiple technological improvements.

Engines from all power categories subject to Tier 3 standards are estimated to increase their utilization of electronic controls by an additional 25 percent. Engines rated over 75 kW are also projected to adopt common rail fuel injection. Electronic controls and improved fuel injection provide benefits for controlling both NOx and PM emissions. Finally, EPA anticipates that all engines subject to Tier 3 standards will incorporate cooled EGR to control NOx emissions. Because EGR systems will be adopted exclusively for controlling emissions, EPA has considered the full cost of these systems as an impact of the proposed Tier 3 standards.

C. Cost of Engine Technologies

The analysis includes cost estimates for the six power categories listed in Table 4-1, which are based generally on the standards proposed 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 4-1 also lists the estimated annual sales for engine models in each of the power categories, as derived from the PSR OELink Database.[7]

Table 4-1
Power Categories and Sales Volumes
for Estimating Incremental Costs

Power Range	Nominal Engine Power	Annual Sales per Engine Model
0-37 kW (0-50 hp)	20 kW (25 hp)	3,500
37-75 kW (50-100 hp)	50 kW (75 hp)	7,500
75-130 kW (100-175 hp)	100 kW (150 hp)	2,750
130-450 kW (175-600 hp)	250 kW (300 hp)	3,000
450- 560 kW (600-750 hp)	500 kW (650 hp)	1,000
560+ kW (750+ hp)	750 kW (1000 hp)	600

EPA believes it is appropriate to use cost estimates for highway engines as the basis 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. R&D for engines rated under 19 kW is typically estimated to be two-thirds the level for highway engines, reflecting the greater price sensitivity and less rigorous demands of these less expensive engines. The analysis also decreases the highway R&D estimates by one-third for the largest engines, though for different reasons: manufacturers must design for a much less diverse market and the very small sales volumes of these engines makes it harder to pass on fixed costs. R&D expenditures for 50 and 500 kW engines "split the difference" by specifying 40 percent of that estimated for highway engines, based on the significant but incomplete potential for technology transfer from highway engines. Retooling costs are somewhat harder to predict, but would be likely follow a similar pattern; the analysis therefore extends the same methodology to retooling cost estimates.

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

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. The anticipated changes for engines rated under 37 kW include only modifications that have been thoroughly developed for other engines; the estimated R&D cost for these engines is therefore reduced to 40 percent of that previously estimated for highway engines, or $2 million dollars per engine family.

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 4-2). The low values of around $50 for engines rated at or below 250 kW reflects the effect of technology transfer and relatively high sales volume. The high value of $1500 for 750 kW engines shows that high per-engine costs result from amortizing large fixed costs over very small sales volumes. Amortizing costs over a longer period would allow manufacturers to soften this sharp effect of low sales volumes. An intermediate value of $500 is observed for 500 kW engines. The number of sales per engine model is an important parameter in calculating an amortized per-engine cost from the total fixed costs. Acurex derived these sales volume estimates from the PSR OE Link database by adding up average annual sales over a five-year period for those engine models that had sales in 1995 (see Table 4-1).[8]

The anticipated increase in operating costs for engines rated under 37 kW would be focused on the minority of engines that need design improvements, as described above, totaling about $220 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 under $75.

Table 4-2
Cost Calculation for Engine Modifications

	Tier 1	Tier 2				
	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	$50,000	$35,000	$200,000	$330,000
Fixed cost (per engine)	$153	$72	$49	$43	$537	$1476
Percentage applied	33%	100%	100%	100%	100%	100%
Composite engine cost	**$51**	**$72**	**$49**	**$43**	**$537**	**$1,476**
Operating cost	**$73**	**$0**	**$0**	**$0**	**$0**	**$0**

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.[9]

Acurex has prepared a memorandum to characterize the variable and fixed costs of adopting electronic controls for the various sizes of nonroad engines.[10] 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 in the rotary fuel pumps, while bigger engines would typically use electronically controlled fuel injectors. Finally, wiring harnesses and ECMs are needed to tie everything together.

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.

Table 4-3
Cost Calculation for Electronic Controls

	Tier 2/Tier 3			
	50 kW	100 kW	250 kW	500 kW
ECM	$125	$150	$175	$250
modified fuel injectors		$180	$180	$420
electronic fuel pump	$90			
sensors	$83	$104	$114	$120
wiring harness	$15	$20	$20	$25
assembly	$13	$16	$16	$20
markup @ 29%	$95	$136	$146	$242
warranty @ 10%	$33	$47	$51	$84
Total hardware RPE	$453	$653	$702	$1,161
R&D	$2,475,000	$2,400,000	$2,250,000	$1,800,000
tooling	$220,000	$150,000	$155,000	$105,000
Fixed cost (per engine)	$87	$224	$192	$454
Total engine cost	$540	$877	$894	$1,615
Percentage applied—Tier 2	25%	50%	50%	50%
Composite cost—Tier 2	**$135**	**$439**	**$447**	**$807**
Percentage applied—Tier 3	25%	25%	25%	25%
Composite cost—Tier 3	**$135**	**$219**	**$223**	**$404**

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. Total estimated costs for introducing electronic controls range from $500 for 50 kW engines to $1,600 for 500 kW engines.

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 between $120 and $140 as a result of these upgraded fuel pumps (see Table 4-4). Again, for engines rated under 37 kW, improved fuel pumps would only be applied to direct injection models.

Table 4-4
Cost Calculation for Improved Rotary Fuel Pumps

	Tier 2	Tier 2
	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
injectors per year	90,000	240,000
cylinders per engine	3	4
Fixed cost (per injector)	$9	$4
Fixed cost (per engine)	$28	$14
Total cost from supplier	$106	$92
Mfr. markup @ 29%	$31	$27
Total engine cost	$137	$118
Percentage applied	33%	100%
Composite cost	**$45**	**$118**

b. unit injection

Engines rated between 75 and 560 kW will need upgraded 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 nearly $400 (see Table 4-5).

Table 4-5
Cost Calculation for Improved Unit Injectors

	Tier 2		
	100 kW	250 kW	500 kW
incremental material	$18	$24	$40
improved solenoid	$45	$51	$80
markup @ 29%	$21	$25	$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)	$18	$15	$202
Total engine cost	**$113**	**$128**	**$377**

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 would 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. Resulting engine cost increases range from $140 to $350, except for 750 kW engines, which are anticipated to rise by almost $800 (see Table 4-6).

Table 4-6
Cost Calculation for Improved Common Rail Fuel Systems

	Tier 3			Tier 2
	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)	$19	$15	$185	$516
Total engine cost	**$135**	**$146**	**$354**	**$765**

4. Exhaust gas recirculation

The biggest technology change anticipated in response to the proposed 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 4-7, range from $250 to $1200.

Table 4-7
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	$40	$48	$53	$75
markup @ 29%	$24	$29	$31	$47
warranty @ 10%	$8	$10	$11	$16
Total hardware RPE	$116	$137	$151	$224
R&D	$4,000,000	$1,000,000	$1,000,000	$4,000,000
tooling	$40,000	$10,000	$10,000	$40,000
Fixed cost (per engine)	$131	$90	$82	$985
Total engine cost	**$247**	**$226**	**$233**	**$1,210**
rebuild cost impact	$43	$48	$58	$104
improved oil impact	$4	$7	$9	$26
Operating cost (NPV)	**$47**	**$55**	**$66**	**$130**

The EGR cooler goes a long way toward resolving the potential deleterious effects of EGR on fuel consumption and engine durability. Recirculating particulate matter through the engine remains as 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 $26 per engine.

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 $100 per engine.

5. Closed crankcase

Under the proposal, 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 4-8). Due to the small number of naturally aspirated engines with high power ratings, costs are estimated only for 20 and 50 kW engines.

Table 4-8
Cost Calculation for Closed Crankcases

	Tier 1	Tier 2
	20 kW	50 kW
PCV valve	$5	$5
tubing	$2	$2
assembly	$1	$1
markup @29%	$2	$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 the figure of $230,000 per engine family developed for highway diesel engines. 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 $20 or less 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 $95 per engine, as shown in Table 4-9.

The cost of combining the above technology elements to comply with the proposed standards is shown in Table 4-9 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 $75 per engine for both retail price and increased operating expenses.

Table 4-9
Incremental Unit Cost of Complying
with Proposed 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 purchase price operating cost (NPV)	75%	$38 $73	—	—	—	—	—
	Closed crankcase	100%	$10	—	—	—	—	—
	Certification	100%	$5	—	—	—	—	—
	Total first-year costs purchase price operating cost (NPV)	—	$53 $73	—	—	—	—	—
Tier 2	Engine modifications	50%	—	$36	$24	$22	$268	$738
	Closed crankcase	100%	—	$10	—	—	—	—
	Electronic controls	50%	—	$68	$219	$223	$404	—
	Improved rotary pumps	50%	$23	$59	—	—	—	—
	Improved unit injection	50%	—	—	$57	$64	$188	—
	Common rail systems	50%	—	—	—	—	—	$383
	Certification	100%	$5	$7	$20	$19	$56	$93
	Total first-year costs purchase price operating cost (NPV)	—	$28 $0	$180 $0	$321 $0	$328 $0	$916 $0	$1214 $0
Tier 3	Electronic controls	50%	—	$68	$110	$112	$202	—
	Common rail systems	50%	—	—	$68	$73	$177	—
	EGR purchase price operating cost (NPV)	100%	—	$247 $47	$226 $55	$233 $66	$1210 $130	—
	Certification	100%	—	$7	$20	$19	$56	—
	Total first-year costs purchase price operating cost (NPV)	—	—	$322 $47	$424 $55	$436 $66	$1645 $130	—

Tier 2 standards, while not expected to increase operating costs, involve generally higher estimated cost impacts. The price of engines rated 250 kW or less is expected to increase by $30 to $330, while bigger engines may face incremental costs of $900 to $1200. 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.

Characterizing these estimated costs in the context of their fraction of the total purchase price is helpful in gauging the economic impact of the proposed 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.[11] 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 4-10. 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 10 percent of actual sales prices. Moreover, the cost savings described below would further reduce the impact of the proposed emission standards; long-term cost increases are expected to be less than 5 percent of total engine price.

Table 4-10
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.[12][13] 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 would occur 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.

Insert Figure 4-1

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 4-11 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 $1000 to $1500 for the biggest engines are reduced to levels well below $300 per engine by the sixth year of production. The estimated impact on operating costs does not change over time and is therefore not shown in Table 4-11.

Table 4-11
Projected Long-Term Increase in Prices
Due to Proposed Tier 3 Standards—Engines

Years of Production*	Power (kW)			
	50	100	250	500
1-2	$322	$424	$436	$1645
3-5	$288	$369	$375	$1554
6+	$111	$177	$194	$291

*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 proposed 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. In addition, the proposal acknowledges that the period between the first and second tiers of standards (Tier 1 and Tier 2 standards for engines rated under 37 kW and Tier 2 and Tier 3 standards for larger engines) would be too short a time to reasonably recoup the investment needed to comply with the first tier of standards prior to imposing additional costs to comply with the second tier of standards. Thus, the second tier of standards are based on the premise that no significant equipment redesign beyond that required to accommodate engines meeting the first tier of standards would be required to accommodate engines meeting the second tier of standards. The following section presents EPA's analysis of the cost of the proposed engine standards to equipment manufacturers.

A. Methodology

Using the engine technology information provided in Chapter 3 and the engine cost information provided earlier in this chapter, EPA was generally able to determine changes equipment manufacturers would likely make to accommodate complying 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 proposed 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 would be reduced 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 proposed 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 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. EPA therefore believes that the cost of redesigning equipment with new engines should only be partially attributed to the new emission standards. As described for the engine cost projections above, the cost of anticipated equipment changes are discounted by one-half to estimate the impact of the proposed standards on equipment manufacturers. For equipment with engines rated under 37 kW, equipment changes related to Tier 1 engines are discounted by one-fourth, since this equipment category is being regulated for the first time and has a shorter lead time compared to the other equipment categories; emission controls could thus play a more prominent role for equipment manufacturers in this category.

The equipment changes resulting from the projected engine changes are expected to be similar across the power categories. For equipment with engines using air-to-water aftercooling, additional heat rejection may occur due to retarded injection timing, and thus some equipment manufacturers are expected to increase the size of their radiators to accommodate these engines. Using an alternative approach, some equipment manufacturers may increase the engine fan speed for additional airflow and cooling (increasing engine fan size can increase fan speed) to accommodate these engines. In many cases equipment manufacturers are expected to alter the engine compartment to accommodate these changes as well as making space for other changes such as added turbochargers and aftercoolers.

All engines rated under 560 kW face two tiers of proposed emission standards. Equipment manufacturers 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.

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 4-1. 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. Variable costs are also considered. The principal cost to equipment manufacturers resulting from the new standards will be related to a general redesign of the engine compartment and engine-related auxiliary devices.

Within the context of redesigning the engine compartment, a small percentage of the equipment is projected to need to modify the radiator and the engine fan to compensate for some additional heat rejection. Equipment with direct injection engines rated under 37 kW (about one-third of the equipment in that size range) are expected to meet the proposed Tier 1 standards through retarded injection timing, which is expected to lead to some additional heat rejection. In the case of engines using air-to-air aftercooling, no increase in heat rejection, and thus no increase in the size of the radiator and engine fan, is expected. Some equipment/engines introducing or improving air-to-water aftercooling may, however, still require more heat rejection and thus a somewhat larger radiator and fan, because the engine coolant would be routed (and thus heated up) through both the radiator and the aftercooler. Even with air-to-air aftercooling, some equipment may need a more effective engine fan (through increased engine fan size or speed), since there may be reduction in the airflow out of the engine compartment due to the aftercooler. In addition, EGR may lead to some additional heat load in the Tier 3 time frame.

For engine compartment modifications (engine panels, brackets, etc.), it is expected that many nonroad equipment models would need some additional steel to accommodate complying engines. EPA thus included a variable cost for additional steel for a large percentage of equipment models.

This section considers the costs associated with these changes to equipment, first for fixed costs, then for variable costs.

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 principally on engine packaging constraints of equipment. The space available for engine changes was thus used as an indicator of the difficulty in redesigning the equipment model's engine compartment. For example, some engine compartments have more space available for engine changes compared to other equipment and would therefore be less difficult to redesign. Generally, any changes to a models's heat rejection system or other internal equipment modifications for emissions control purposes are reflected in the fixed cost for making the needed packaging changes.

To calculate fixed costs for equipment applications, the following steps were taken. First, the applications are generally separated into the following two categories within the parameters of EPA's definition of nonroad engine (see 40 CFR 89.2): *motive* (i.e., agricultural tractors, excavators, forklifts, etc.) and *portable* (i.e., 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 derived in a separate memorandum and summarized in Table 4-12.[14] 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 (see Table 4-13).

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 would also have 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.

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. 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.[15]

Table 4-12
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= 60% moderate= 40%	extensive= 40% moderate= 60%
130-450 kW (175-600 hp)	extensive= 50% moderate= 50%	extensive= 30% moderate= 70%
450- 560 kW (600-750 hp)	extensive= 30% moderate= 70%	extensive= 20% moderate= 80%
560+ kW (750+ hp)	extensive= 10% moderate= 90%	extensive= 10% moderate= 90%

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. The effort needed for the total redesign of equipment, including improved performance, new features, and enhanced durability, was estimated to be about twice as much as that needed for emissions control alone. 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 would include the effort needed for testing, would be approximately 3,100 hours of effort. This includes 1,100 hours of junior engineers' time and 300 hours of senior engineers' time. In addition, 1,700 hours of technicians' time is included for testing, operating, repairing, and maintaining equipment, machines, and tools. This level of effort would be equivalent to about $210,000. 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 1,600 hours of effort distributed similarly, including the effort needed for testing, which would be equivalent to about $100,000.

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 would not include testing, would be approximately 500 hours of effort. This includes 300 hours of junior engineers' time, 80 hours of senior engineers' time, and 150 hours for technicians' time, which would be equivalent to about $40,000. 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 would include no testing, would be approximately 180 hours of effort distributed similarly, which would be equivalent to about $14,000.

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 would 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 would be 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 would be about 50 hours (distributed similarly), which would be 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 would be 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 $220,000 and $110,000 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 $45,000 and $15,000 for the extensive and moderately redesigned product lines, respectively. Using these figures, EPA calculated an amortized fixed cost per unit, as shown in Table 4-13.

Similar to costs described above in the engine cost section of this chapter, the widely varying cost estimates and sales volumes for different size equipment create broad diversities in the estimated unit costs. The low cost of about $15 for equipment utilizing engines rated under 37 kW is due primarily to the expectation that two-thirds of the engines already meet the proposed standards using indirect injection technology. 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 $190 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 less redesign effort. Also, the higher cost of $173 for equipment with engines rated between 75 and 130 kW results from amortizing fixed costs over a relatively small sales volume.

Table 4-13
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	Total Cost per Product Line*	First Year Unit Cost	Weighted First Year Unit Cost	
<37 kW (<50 hp)	Motive	140	500	Extensive	80%	$92,000	$26	$23	$15
				Moderate	20%	$46,000	$13		
	Portable	180	310	Extensive	50%	$19,000	$9	$6	
				Moderate	50%	$6,000	$3		
37-75 kW (50-100 hp)	Motive	210	265	Extensive	70%	$220,000	$119	$101	$66
				Moderate	30%	$110,000	$59		
	Portable	115	310	Extensive	50%	$45,000	$21	$14	
				Moderate	50%	$15,000	$7		
75-130 kW (100-175 hp)	Motive	170	105	Extensive	60%	$220,000	$302	$242	$173
				Moderate	40%	$110,000	$151		
	Portable	85	105	Extensive	40%	$45,000	$61	$37	
				Moderate	60%	$15,000	$20		
130-450 kW (175-600 hp)	Motive	310	150	Extensive	50%	$220,000	$212	$159	$132
				Moderate	50%	$110,000	$106		
	Portable	175	80	Extensive	30%	$45,000	$82	$44	
				Moderate	70%	$15,000	$27		
450-560 kW (600-750 hp)	Motive	30	30	Extensive	30%	$220,000	$1,050	$684	$190
				Moderate	70%	$110,000	$526		
	Portable	30	100	Extensive	20%	$45,000	$66	$31	
				Moderate	80%	$15,000	$22		
560+ kW (750+ hp)	Motive	20	90	Extensive	10%	$220,000	$334	$184	$112
				Moderate	90%	$110,000	$167		
	Portable	20	80	Extensive	10%	$45,000	$81	$33	
				Moderate	90%	$15,000	$27		

* 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.

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 adding material and upgrading heat exchangers.

a. miscellaneous steel changes

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 $8 per unit for those units that need more steel (see Table 4-14), with $8 being estimated for the highest power ranges of equipment.

Table 4-14
Estimated Cost of Miscellaneous Steel Changes
First-Year 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

Markup @29%	$1	$1	$1	$1	$2	$2

Total hardware	**$3**	**$3**	**$4**	**$5**	**$8**	**$8**

b. heat exchange improvements

As discussed above, EPA estimates that a small percentage of equipment will experience some additional heat rejection. The heat exchange capacity for these engines would need to be increased by perhaps 20 percent. Equivalent cooling capacity modifications to both the radiator and engine fan would be expected to accommodate a 20 percent improvement.

To accommodate the additional heat rejection, EPA projected that for all power ranges 10 percent of nonroad equipment would need modified radiators. For these radiators, EPA estimated that about a 10 percent increase in their cooling capacity may be needed, either by increased volume or modified fin arrangement. Also, it may be necessary for equipment manufacturers to modify the brackets they use in assembling their radiators. These estimations of radiator changes and variable costs were made with the understanding that radiators in equipment with engines rated under 450 kW would in most cases be sensitive to the space available in the engine compartment; therefore, changes to the radiators would in some cases lead to the redesign of the engine compartment and steel changes, which are taken into account as discussed above. For the most part, the increase in the cost of a radiator is directly proportional to the change in the radiator's size or the fin arrangement for the purpose of additional cooling. Including assembly time and a markup for overhead and profits, the incremental retail price equivalent hardware costs range from approximately $15 to $130 for equipment with engines rated under 450 kW (see Table 4-15). Equipment with engines rated over 450 kW have estimated hardware costs ranging from $520 to $1,000.

For the many equipment types facing heavy and widely varying loads, EPA also believes that radiators may be over designed to account for fluctuations in heat rejection, and thus these equipment types may not need improvements to the radiator to accommodate the new engines. This radiator over design is generally found in equipment with engines rated at or above 450 kW. EPA projects, however, that even with this over design about 10 percent of equipment in this higher power range may still need to improve their heat exchange capacity due to the proposed standards. EPA expects this improvement would be generated by engine fan changes alone since as shown in Table 4-16, these modifications are more economical than radiator changes for equipment with larger engines.

Table 4-15
Estimated Cost of Radiator Changes: 10% increase in size or cooling capacity
First-Year Incremental Variable Costs

	0-37 kW	37-75 kW	75-130 kW	130-450 kW	450-560 kW	560+ kW

radiator fins	$10	$15	$30	$100	$400	$800

radiator brackets	$0.05	$0.25	$0.50	$1	$2	$2

assembly	$2	$2	$2	$2	$2	$2

Total variable cost	$12	$17	$33	$103	$404	$804

Markup @29%	$3	$5	$9	$30	$117	$233

Total hardware	**$16**	**$22**	**$42**	**$133**	**$521**	**$1,037**

Percent increase in	10%	10%	10%	10%	10%	10%

Percent of fleet	10%	10%	10%	10%	0%	0%

To compensate for the additional heat load, EPA also estimated that either in conjunction with or instead of radiator modifications, 10 percent of nonroad equipment in all power ranges would need modified engine fans. Improvements to the cooling capacity of the engine fan can be achieved through increasing the fan size or speed. For equipment with engines rated under 450 kW, EPA estimated that about a 10 percent increase in cooling capacity of the engine fan may be necessary. For equipment with engines rated over 450 kW, EPA projected that about a 20 percent increase in cooling capacity of the engine fan may be needed since as discussed above for this power range, modifying the engine fan alone to achieve the expected 20 percent improvement in heat exchange capacity is estimated to be more economical than changing both the radiator and engine fan by an equivalent amount. Also, it may be necessary for equipment manufacturers to modify the engine fan brackets or mounts utilized in assembling engine fans. Generally, a modification in engine fan size for additional cooling needs leads to an increase in the engine fan cost (total RPE) that is about 20 to 30 percent more than the percentage increase in the engine fan size. For example, a 10 percent increase in the engine fan size generally leads to about a 30 to 40 percent increase in the engine fan price. Based on this methodology, including assembly time and a markup for overhead and profits, the incremental retail price equivalent hardware costs range from approximately $20 to $40 for equipment with engines rated under 130 kW (see Table 4-16). Equipment with engines rated over 130 kW have estimated hardware costs ranging from $90 to $200. The incremental variable costs for engine fan changes are directly proportional to the size and price of the base-case engine fans found in equipment.

Table 4-16
Estimated Cost of Engine Fan Changes: 10-20% increase in size or cooling capacity
First-Year Incremental Variable Costs

	0-37 kW	37-75 kW	75-130 kW	130-450 kW	450-560 kW	560+ kW

fan blade	$12	$24	$30	$70	$135	$150

fan	$0.05	$0.25	$0.50	$1	$2	$2

assembly	$2	$2	$2	$2	$2	$2

Total variable cost	$14	$26	$33	$73	$139	$154

Markup @29%	$4	$8	$9	$21	$40	$45

Total hardware	**$18**	**$34**	**$42**	**$94**	**$179**	**$199**

Percent increase in	10%	10%	10%	10%	20%	20%

Percent of fleet	10%	10%	10%	10%	20%	20%

D. Summary of Total Projected Cost

1. First-year costs

Fixed and variable costs are combined in Table 4-17 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 tier of proposed standards for these engines. The costs shown in Table 4-17 reflect this breakdown between the two tiers. For example, for the equipment between 130 and 450 kW, three-fourths of the $157 total cost ($118) would be the Tier 2 cost per unit, and one-fourth, $39, would be the Tier 3 cost per unit.

The breakdown for the fractions of the total equipment fleet that EPA projects would be impacted by the different variable costs (miscellaneous steel changes, radiator improvements, and engine fan improvements) is also shown in Table 4-17. Prior to allocating the variable costs by the fractions described above for first and second tiers of standards, EPA discounted the variable costs by the fractions of the equipment fleet not expected to need hardware changes. Since miscellaneous steel changes were projected to be needed for only 50 percent of the equipment, 50 percent of the variable costs for miscellaneous steel changes would be added to the unit fixed cost for all power ranges. In addition, the radiator and engine fan changes (heat exchange improvements) were projected to be needed for only 20 percent of the equipment, and thus, 10 or 20 percent of the variable costs for radiator and engine fan changes would be added to the unit fixed cost (these variable costs for equipment with engines rated over 450 kW were projected to be from engine fan changes alone). For example, in the 130 to 450 kW range one-half of the $5 variable cost ($2.5) for miscellaneous steel changes was added to one-tenth of the $133 variable cost ($13) for radiator changes, one-tenth of the $94 variable cost ($9) for engine fan changes, and the $132 fixed cost per unit for a total cost of $157 per unit. In addition, for equipment with engines rated under 37 kW, EPA discounted the variable costs by two-thirds to account for indirect injection engines with emission levels already below the proposed Tier 1 standards. For two-thirds of the engines and equipment in this power category, EPA therefore expects no change resulting from the proposed emission standards.

In summary, for the proposed Tier 1 standards that only apply to equipment with engines rated under 37 kW, EPA projected the incremental cost on this equipment to be just over $10. In addition, EPA estimated that for the proposed Tier 2 standards the incremental cost for equipment in this same power range is even lower at $5. For these proposed Tier 2 standards, equipment with engines rated between 37 and 75 kW are expected to have incremental costs below $60, and the equipment with larger engines may incur incremental costs up to $160. The incremental costs of the proposed Tier 3 standards are expected to range from $20 to $50 for equipment with engines rated over 37 kW.

Table 4-17 also shows the total projected unit costs for new equipment by adding the estimated incremental costs for new engines.

Table 4-17
Incremental Unit Cost of Complying
with Proposed Emission Standards—Equipment

Equipment Modification	Percent of Fleet Affected	Weighted Unit Cost					
		0-37 kW	37-75 kW	75-130 kW	130-450 kW	450-560 kW	560+ kW
Tier 1							
Miscellaneous steel changes	17%	$0.4	—	—	—	—	—
Heat exchange improvements	7%	$1	—	—	—	—	—
Total first-year costs equipment changes engine changes total	—	 $12 $53 $65	—	—	—	—	—
Tier 2							
Miscellaneous steel changes	50%	$0.4	$1	$2	$2	$3	$4
Heat exchange improvements	20%	$1	$4	$6	$17	$13	$20
Total first-year costs equipment changes engine changes total	—	 $5 $28 $33	 $55 $180 $235	 $138 $321 $459	 $118 $328 $446	 $159 $916 $1,075	 $136 $1,214 $1,350
Tier 3							
Miscellaneous steel changes	50%	—	$0.5	$1	$1	$1	—
Heat exchange improvements	20%	—	$1	$2	$5	$5	—
Total first-year costs equipment changes engine changes total	—	—	 $18 $322 $340	 $46 $424 $470	 $39 $436 $475	 $53 $1,645 $1,698	—

To better understand the economic impact of the proposed 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 4-18).[16] 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 prices. Some very small equipment, such as a 3 kW (4 hp) centrifugal pump in the portable equipment category, may have a relatively low purchase price, resulting in an estimated price increase of up to 4 percent.

Table 4-18
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 would 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 proposed standards would require manufacture of new components and assemblies, which would 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 4-19. 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 proposed standards.

Table 4-19
Projected Long-Term Increase in Prices Due to Proposed Tier 3 Standards

Scenario	Years of Production*	Power (kW)			
		37-75	75-130	130-450	450-560
Equipment	1-2	$18	$46	$39	$53
	3-5	$18	$45	$38	$52
	6-10	$18	$45	$37	$51
	11+	$1	$2	$4	$4
Engine and Equipment	1-2	$340	$470	$475	$1,698
	3-5	$306	$414	$413	$1,606
	6-10	$129	$222	$231	$342
	11+	$112	$179	$198	$295

*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 proposed emission standards in any year.[17] Increased purchase prices and operating costs lead to aggregate costs of about $3 million in the first year, increasing to a peak of $320 million in 2008 as increasing numbers of engines become subject to the proposed standards (Figure 4-2). The following years show declining aggregate costs as the per-unit cost of compliance decreases, as described above, to a low pont of about $190 million in 2014. After 2014, stable engine costs applied to a slowly growing market lead to slowly increasing aggregate costs.

Insert Figure 4-2

IV. Initial Regulatory Flexibility Analysis

This section presents the results of the initial regulatory flexibility analysis, which evaluates the impacts on small businesses resulting from the proposed emission standards. To quantify these impacts, EPA relied extensively on the contracted study conducted by ICF, Incorporated.[18] The analysis had the following objectives: (1) to evaluate what a small business is for nonroad equipment manufacturers affected by the proposed standards compared with the Small Business Administration's (SBA) definitions of small businesses for the many lines of business within this industry,[c] **(2) to characterize the small equipment manufacturers, (3) to assess the impact of the proposed standards on small equipment manufacturers, and (4) to evaluate the relief provided by regulatory alternatives.**

A. Requirements of SBREFA and RFA

When proposing 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 response to provisions of SBREFA, EPA uses an economic measure known as the "sales test" to evaluate the impacts on small businesses. 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 recognizes that the PSR database is not comprehensive of the entire universe of equipment manufacturers, but EPA does not have another consistent source for finding information on additional equipment manufacturers. Dun and Bradstreet (D& B)

---

[c] The Regulatory Flexibility Act specifies that SBA definitions should be used as the initial determination of a small entity but an agency may use an alternative definition if it better captures the point at which entities are affected simply because of their size.

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. Since 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 proposed rule.

2. Definition of small equipment manufacturer

This analysis used the threshold of 500 or fewer employees to characterize small nonroad diesel equipment manufacturers. Since equipment manufacturers are included in several lines of business (with differing SBA definitions for small manufacturer), the most common definition of 500 employees for small businesses was selected for all companies in the analysis. The analysis examined companies classified as small based on the number of employees under the SBA definitions for all the lines of business associated with the 334 nonroad diesel equipment manufacturers. The general threshold definition of 500 employees established by SBA and referenced by the RFA for manufacturing companies was also applied to the data. 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. In addition, the 286 small equipment manufacturers identified based on the specific lines 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. Since 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 used. Thus, the analysis focuses on the impacts of the proposed rule for 283 small businesses.

C. Characterization of Small Equipment Manufacturers

1. Generating model companies

The equipment industry was characterized 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 representing 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 4-20 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 considered to be 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 4-20
Characteristics of Model Company Groups

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

ICF 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 the proposed rule. 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 proposed standards

As discussed in Section II. of this chapter, the projected fixed costs to equipment manufacturers include research and development and tooling costs needed to accommodate new engines. Table 4-13 describes the fixed cost for a whole product line for each power category and calculates an amortized cost per unit. For purposes of the small business analysis, these fixed costs per product line were distributed over a ten year period to determine an annual fixed cost per product line as shown in Table 4-21. These fixed costs are combined for the two tiers of standards. Since variable costs would be the same for all equipment companies and the change in total sales would generally be small in response to industry-wide price changes, manufacturers are expected to be successful in passing the variable costs along as price increases. Manufacturers may also be successful in passing on fixed costs to the final consumer. Because fixed costs require manufacturers to generate capital and amortize the expenses over several years, the analysis considers the fixed costs to equipment manufacturers to be the measure for assessing the impact on small businesses. To the extent that manufacturers are able to recover their fixed costs, the impacts estimated here would be mitigated.

Table 4-21
Compliance Cost by Engine Power Range

Power Range	Fixed Cost per Product Line
0-37 kW (0-50 hp)	$6,000
37-75 kW (50-100 hp)	$18,800
75-130 kW (100-175 hp)	$18,000
130-450 kW (175-600 hp)	$16,200
450- 560 kW (600-750 hp)	$11,800
560+ kW (750+ hp)	$9,600

This analysis evaluates the economic impacts under two scenarios, the "flexibility case" and "base case." The flexibility case is based on implementing the new standards as proposed, including the provisions that provide flexibility to equipment manufacturers in meeting the new standards by allowing them to exempt certain percentages of equipment they sell for the first seven years after the proposed standards are implemented. To provide extra flexibility to small companies, small equipment manufacturers may exempt up to one hundred pieces of equipment for each power category regardless of the number of product lines making up those one hundred units. The base case provides a measure of the effectiveness of these provisions by analyzing the impacts of the proposed rule without flexibilities.

2. Sales test

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 4-22 for the ratio ranges of less than one percent, one to three percent, and more than three percent. The results of Table 4-22 show that the impact of the proposed rule without flexibility provisions would be that more than 20 percent of small businesses would be economically impacted by greater than or equal to 1 percent.

Table 4-22
Compliance Cost Impacts as a Percentage of Sales Revenue by Company Size

Company Type	Number of Companies	< 1%	1-3%	>3%
Small	283	211	43	29
		75%	15%	10%
Large	51	51	0	0
		100%	0%	0%
Total	**334**	**262**	**43**	**29**

As demonstrated in Table 4-23, the flexibility provisions downgrade the impact of the proposed rule such that only 9 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 72 to 27, approximately a 60 percent decrease. Thus, the flexibility provisions that permit small companies to exempt up to 100 units from each power category dramatically reduce the impacts of the proposed standards.

Table 4-23
Compliance Cost Impacts with Flexibility Provisions
as a Percentage of Sales Revenue by Company Size

Company Type	Total	< 1%	1-3%	>3%
Small	283	256	12	15
		90%	4%	5%
Large	51	51	0	0
		100%	0%	0%
Total	**334**	**307**	**12**	**15**

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 proposed 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 proposed regulations on small equipment manufacturers, decreasing the percentage of small equipment manufacturers that would experience a 1 percent or greater impact from 25 to 9 percent of small companies. EPA considers the flexibility provisions to be a significant regulatory alternative since they enable the Agency to accomplish the objectives of the proposed 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 proposed 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, since they have a low revenue based on total power production. The proposed 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 is to collect the advice and recommendations of representatives of small entities that will be affected by the proposed 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 is provided to the agency issuing the proposed rule and included in the rulemaking record. In light of the Panel report, the agency is to make changes to the proposed rule or the initial regulatory flexibility analysis for the proposed rule, where appropriate. 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 this proposal, EPA and the SBREFA Panel have been in contact with representatives of four separate but related industries that will be subject to this proposed 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-manufacture marinizing of diesel engines. 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:

- Manufacturers of engines (includes 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

(The definition of small manufacturer of nonroad diesel equipment is discussed further in Section IV.B.2. of this RIA.) 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 affected by the proposed rule. The SBREFA panel encouraged EPA to continue to seek additional information on the number of small entities affected by the proposed standards. The Agency continues to be interested in the potential impacts of the proposed rule on small entities and welcomes additional information and comments during the rulemaking process on the number of small entities.

Regarding the projected 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 proposed for 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 specified in the proposed rule, EPA proposes to 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 would be 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. EPA will consider during the rulemaking process any comments on these reporting and record keeping requirements.

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 proposed. No other potential overlaps with other federal rules were noted. The panel encouraged EPA to consider this potential overlap with OSHA CO limits. EPA will consider any suggestions and comments for addressing this overlap for equipment manufacturers and purchasers.

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 this proposal. It is important to note that the Panel's findings are based on the information available at the time the Panel report was drafted. The Panel makes its report at an early stage of the process of promulgating a rule and its report should be considered in that light. These five regulatory alternatives are as follows:

- Instead of a fixed exemption allowance in each year under the flexibility provisions, provide equipment manufacturers an equivalent "lump sum" of exemptions, to be spread over the same years as manufacturers see fit.

- Extend the period of flexibility provisions for manufacturers of small engines. The proposal from the Supplemental ANPRM limits flexibilities for equipment manufacturers using engines rated under 37 kW to 4 years, in contrast to 7 or 8 years for those equipment manufacturers using engines rated over 37 kW. This regulatory alternative would expand the former to match the provisions specified for the large engines.

- Allow equipment manufacturers to purchase credits earned by engine manufacturers in the Averaging, Banking, and Trading (ABT) program to offset the sale of additional equipment built with noncomplying engines (beyond that allowed under other flexibility provisions).

- Expand the exemptions for small manufacturers. The proposal from the Supplemental ANPRM allowed equipment manufacturers to exempt up to 100 machines of a single model annually, in recognition of the fact that exempting a certain percentage of production does not help small equipment manufacturers with very limited product offerings. This regulatory alternative would drop the model restriction, allowing the combined annual production of more than one model to be exempted, up to the combined total of 100 machines annually in each regulated power band.

- Provide a last resort opportunity for small equipment manufacturers, after exhausting all other flexibilities, to be relieved of the prohibition on using an earlier model engine. Small equipment manufacturers have stated that they are sometimes at the mercy of engine suppliers who are not responsive to the major disruptions caused by last-minute changes or delays. EPA would evaluate these requests on a case-by-case basis.

EPA is proposing or soliciting comment in the proposed rule on the five regulatory alternatives, based on EPA's analysis and agreement with the Panel's findings. These alternatives are expected to maximize the compliance flexibility for small manufacturers of nonroad equipment and small marinizers while achieving the Agency's air quality objectives.

Chapter 4 References

.“Estimated Economic Impact of New Emission Standards for Heavy-Duty On-Highway Engines,” Acurex Environmental Corporation Final Report (FR 97-103), March 31, 1997.

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

."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.See reference 4

.“Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines,” June 6, 1996.

7.“Nonroad Engine Sales Data,” Memorandum from Lou Browning, Acurex Environmental, to Alan Stout, EPA, March 14, 1997.

.See reference 7.

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

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

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

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

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

.“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.

.“Methodology to Determine Number of Product Lines and their Sales Volume for Nonroad Diesel Equipment Cost Analysis,” EPA memorandum from Bryan J. Manning to Public Docket

A-96-40.

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

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

18.“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.

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, a computer model for projecting nonroad emissions inventories, the Nonroad Emissions Model (NEM), has been developed. 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 Nonroad Emissions Model (NEM) to understand the impact that the proposed emission standards are expected 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 results 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 he 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 proposed rule, EPA is proposing 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. Nonroad Emissions 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 developed a computer model called the Nonroad Emissions Model (NEM). For a complete description of NEM, the reader is referred to two memorandums to the docket. The first memorandum, entitled "Nonroad CI Modeling Methodology and Request for Comment", explains how NEM works physically and contains a listing of the program. The second memorandum, entitled "Operation of the Nonroad Emissions Model" explains the method of running the model.

III. Activity Growth Estimates

Essential to the determination of future emissions is the ability to accurately estimate the growth in nonroad equipment activity. NEM employs activity growth numbers as a yearly percentage increase or decrease in the equipment population.

Total emissions in the nonroad emissions inventory is a function of the specific emission factor (in grams per unit of work) and the amount of work per year that these engines do. The emission factor is related in part to the type of engine and its typical use. The amount of work that nonroad engines produce is related to the demand for them and is generally called "activity". When determining future emissions, both the future emission factors and the activity growth must be estimated.[d]

Growth predictions are more specifically related to activity in work per year units. This is analogous to the number of miles traveled per year by highway vehicles. For this analysis, EPA looked at growth factors developed from two different sources: economic projections from the Department of Commerce's Bureau of Economic Analysis (BEA) and historical trends in growth in nonroad engine sales from the Power Systems Research (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) to determine the growth in demand for given emission sectors. 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 are also the basis for EPA's Trends Report and are contemplated for use in EPA's upcoming guidance for estimating nonroad emissions, although states may choose to use other growth estimates if better local sources of information are available . 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. In most cases the national average is close to the aggregate GSP, but some differences may occur. For purposes of this work, the aggregate GSP estimates were used. The application category specific BEA growth estimates used in this analysis are shown in Table 5-1. These growth projections are from most recent BEA estimates (July 1995) and are related to a 1995 base year.

---

[d] Activity growth and population growth, as far as the Nonroad Equipment Model is concerned, are synonymous. The Nonroad Equipment Model keeps other factors, such as load factor and annual use, constant so the only way that growth can be expressed is through a percentage increase in equipment population.

Table 5-1
Growth Factors for Application Categories

Engine Category	BEA Category	Average Annual BEA Predicted Activity Growth Through 2010 (%)
Agricultural	Farm	1.6
Construction	Construction	1.1
General Industrial	Total Manufacturing	1.7
Lawn and Garden	Farm	1.6
Marine <37 kW	Population	0.9
Material Handling	Total Manufacturing	1.7
Pumps and Compressors	Total Manufacturing	1.7
Welders and Generators	Total Manufacturing	1.7

Of course, BEA projections are for economic growth in broad sectors of the economy (such as farm, construction, or total manufacturing), and may not correlate completely with the growth in nonroad equipment used by those sectors. For the equipment categories covered by this proposal, 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 annual sales from PSR's EngineData Database[1] indicates that overall historical growth in sales may be higher than BEA projections of future growth. Information from the Department of Energy's Energy Information Administration[2] indicates that diesel fuel sales in the "Off-highway" sector, which consists predominantly of construction and road building equipment, grew by an average rate of 3.8% per year between 1985 and 1995, which is higher than the BEA projection for future years of 1.1%. On the other hand, historical diesel fuel sales in the "Farm" category for the same period were only 1.3%, less than the BEA projection of 1.6%. Of course, past historical trends are not perfect predictors of future trends. In addition, EPA has not developed application category specific growth factors based on these sources. However, given the information derived from these sources and the uncertainties inherent in projecting future growth rates, EPA believes that it is reasonable to include in this analysis a scenario based on the assumption of a 3% annual growth rate for all categories for comparison with the more conservative BEA projections in order to better inform the public of the effects of higher growth rates.

IV. Emission Inventory Estimates

A. Emission Standards

In 1994, EPA set new emission standards for nonroad diesel engines rated under 37 kW. Table 5-2 lists the applicable Tier 1 standards.

Table 5-2
Tier 1 Nonroad Diesel Engine Standards, g/kW-hr (g/hp-hr)

Power Range (kW)	Effective Year	THC	CO	NOx	PM
37 to < 75	1998	—	—	9.2 (6.9)	—
75 to < 130	1997	—	—	9.2 (6.9)	—
130 to < 560	1996	1.3 (1.0)	11.4 (8.5)	9.2 (6.9)	0.54 (0.4)
560 +	2000	1.3 (1.0)	11.4 (8.5)	9.2 (6.9)	0.54 (0.4)

This proposal contains additional standards that include Tier 1 and Tier 2 standards for engines rated under 37 kW and Tier 2 and Tier 3 standards for larger engines. Table 5-3 contains the proposed standards for NMHC + NOx, CO, and PM.

Table 5-3
Proposed Standards, g/kW-hr (g/hp-hr)

Power Range (kW)	Effective Year	NMHC + NOx	CO	PM
Tier 1				
0 to < 8	2000	10.5 (7.8)	8.0 (6.0)	1.0 (0.75)
8 to < 19	2000	9.5 (7.1)	6.6 (4.9)	0.8 (0.6)
19 to < 37	1999	9.5 (7.1)	5.5 (4.1)	0.8 (0.6)
Tier 2				
0 to < 8	2005	7.5 (5.6)	8.0 (6.0)	0.8 (0.6)
8 to < 19	2005	7.5 (5.6)	6.6 (4.9)	0.8 (0.6)
19 to < 37	2004	7.5 (5.6)	5.5 (4.1)	0.6 (0.45)
37 to < 75	2004	7.5 (5.6)	5.0 (3.7)	0.4 (0.3)
75 to < 130	2003	6.6 (4.9)	5.0 (3.7)	0.3 (0.22)
130 to < 225	2003	6.6 (4.9)	3.5 (2.6)	0.2 (0.15)
225 to < 450	2001	6.6 (4.8)	3.5 (2.6)	0.2 (0.15)
450 to < 560	2002	6.4 (4.8)	3.5 (2.6)	0.2 (0.15)
560 +	2006	6.4 (4.8)	3.5 (2.6)	0.2 (0.15)
Tier 3				
37 to < 75	2008	4.7 (3.5)	5.0 (3.7)	—
75 to < 130	2007	4.0 (3.0)	5.0 (3.7)	—
130 to < 225	2006	4.0 (3.0)	3.5 (2.6)	—
225 to < 450	2006	4.0 (3.0)	3.5 (2.6)	—
450 to < 560	2006	4.0 (3.0)	3.5 (2.6)	—

B. NMHC vs. THC in Diesel Emissions

For hydrocarbon determinations, NEM uses the Total Hydrocarbon (THC) figures from EPA's nonroad emissions study (NEVES).[3] The Tier 1 standards are based on THC measurement. Because the proposed standards include an NMHC-based standard, it is important to determine how much of a contribution methane makes to THC. Table 5-4 contains the results of some hydrocarbon speciation tests done by EPA on diesel highway vehicles, both light-duty and heavy-duty. It shows the percentage of methane as a total of all hydrocarbons collected for several test vehicles. As can be seen from the table, the percent of methane emissions in exhaust from diesel vehicles is quite low, averaging from 2% to 5%. For the purposes of this analysis, EPA considers NMHC to be the same as THC.

Table 5-4
Methane Fraction of Diesel Exhaust Emissions[4]

Vehicle	Methane (g/mi)	Total HC (g/mi)	Methane (% of THC)
Light-Duty			
1	0.032	0.19	16.7%
2	0.009	0.30	2.9%
3	0.006	0.17	3.8%
4	0.015	1.16	1.3%
5	0.039	0.76	5.2%
6	0.020	0.80	2.6%
7	0.011	0.39	2.8%
Average	0.019	0.54	5.2%
Heavy-Duty			
1	0.007	0.66	1.0%
2	0.040	1.61	2.5%
Average	0.024	1.14	1.8%

C. Determination of NMHC and NOx Contributions

Because the proposed standards are in the form of NMHC + NOx, it is essential to develop an understanding of what level of contribution each pollutant is expected to have. Tables 5-5 and 5-6 present the NMHC and NOx certification levels assumed by EPA under the Tier 1, Tier 2 and Tier 3 standards. The estimated certification levels were used to develop the emission inventories and emission reductions due to the proposed standards.

Table 5-5
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 5-6
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

For Tier 1 engines rated at 37 kW and above, EPA has assumed those engines are emitting at the Tier 1 NOx standard of 9.2 g/kW-hr (6.9 g/hp-hr). The NOx certification levels for Tier 1 engines show that, though there are engines with NOx levels 1.0 g/kW-hr or more below the standard, there are a significant number of engines with NOx levels essentially at the standard. With regard to HC levels from

Tier 1 engines rated at 37 kW and above, EPA has assumed such engines are emitting at the sales-weighted average HC certification levels of Tier 1 engines. An analysis of 1996 certification data from Tier 1 engines (130 to 560 kW) reveals that the sales-weighted average HC emissions from were 0.4 g/kW-hr (0.3 g/hp-hr), significantly below the standard of 1.3 g/kW-hr (1.0 g/hp-hr).

For Tier 1 engines rated under 37 kW, which are currently unregulated by EPA, EPA estimated the NOx and HC levels using information from the NEVES report and certification information from the California ARB, which regulates engines rated under 19 kW. For precontrol engines, EPA used the emission factors contained in the NEVES report.[5] For post-control engines, EPA used the California ARB certification information. Engines in the under 37 kW category employ a large percent of two different diesel technologies termed simply as Indirect Injection (IDI) and Direct Injection (DI). Based on an analysis of the California ARB certification data for engines rated under 19 kW and equipment populations taken from the PSR database, the information in Table 5-7 was compiled. To estimate the average certification levels for engines rated under 19 kW, EPA weighted the average HC and NOx California ARB certification levels by the appropriate IDI and DI engine market share. For engines rated between 19 and 37 kW, currently unregulated by both EPA and the California ARB, EPA used the average California ARB certification levels for engines rated between 8 and 19 kW, weighted by the appropriate IDI and DI weightings. The weighted NOx and NMHC emission results are presented in the last two columns of Table 5-7.

Table 5-7
Determination of NMHC and NOx Levels
for Engines Rated Under 37 kW, g/kW-hr (g/hp-hr)

Power Range (kW)	Average NMHC		Average NOx		Market Share		Weighted Emissions	
	IDI	DI	IDI	DI	IDI	DI	NMHC	NOx
0-8	0.8 (0.6)	2.4 (1.8)	6.7 (5.0)	8.0 (6.0)	15%	85%	2.1 (1.6)	7.9 (5.9)
8-19	0.8 (0.6)	1.5 (1.1)	6.7 (5.0)	8.0 (6.0)	80%	20%	0.9 (0.7)	7.0 (5.2)
19- 37	0.8 (0.6)	1.5 (1.1)	6.7 (5.0)	8.0 (6.0)	55%	45%	1.1 (0.8)	7.4 (5.5)

For Tier 2 engines rated at 37 kW and above, EPA assumed that NOx emissions would be at the levels of the standards proposed by the European Union. EPA's proposed standards are intended to be equivalent in stringency to the proposed European standards, except that the EPA's proposed standards are in the form of NMHC + NOx, whereas the proposed European standards have separate NMHC and NOx standards. EPA assumed the NMHC level of engines rated over 37 kW would be equal to the difference between the EPA's proposed NMHC + NOx standards and the European Union's proposed NOx standards. For Tier 2 engines rated under 37 kW, EPA assumed a reasonable lower limit for NMHC would be 0.8 g/kW-hr, based on the current California ARB certification data for IDI engines rated under 19 kW. EPA assumed the NOx levels for Tier 2 engines rated under 37 kW would be the proposed NMHC + NOx standards minus the 0.8 g/kW-hr NMHC level.

For Tier 3 engines rated at 37 kW and above, EPA assumed a reasonable lower limit for NMHC would be 0.3 g/kW-hr. EPA assumed the NOx levels for Tier 3 engines rated at 37 kW and above would be the proposed NMHC + NOx standards minus the 0.3 g/kW-hr NMHC level.

D. Treatment of Particulate Matter in Modeling

Although the Tier 1 rule established new standards for PM, no PM benefits were claimed in that rule. This was due to 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. 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 proposed standards will be completely accurate. Nevertheless, EPA has attempted to make a reasonable estimate of these reductions.

EPA believes that the best treatment of this PM issue is to set the baseline at the pre-Tier 1 levels and to establish a level of control that is 0.34 g/kW-hr (0.25 g/hp-hr) below the uncontrolled levels for each application. (As noted earlier, the uncontrolled levels for engines are taken from the NEVES report.) This offset is derived from taking the difference between the proposed standards and the existing Tier 1 standards. The Tier 1 rule established PM standards only for those pieces of equipment above 175 horsepower. Thus, for those pieces of equipment below 175 horsepower, EPA simply employed that same 0.34 g/kW-hr offset in modeling the effects of the proposed PM standards. EPA has chosen to also apply this same offset to equipment below 175 horsepower, which is not subject to a Tier 1 PM standard. EPA believes this approach provides a reasonable estimate of PM benefits from the proposed standards but actual benefits could vary significantly from these levels.

E. Equipment Manufacturer Allowance Scenarios

Along with the new proposed engine standards, EPA is proposing some flexibility allowances for equipment manufacturers. These allowances were enumerated in the Supplemental Advance Notice of Proposed Rulemaking (Supplemental ANPRM), which formed the basis for this proposal.

There are two flexibility provisions in the proposal with the potential to have significant impacts on emissions projections. They are the Percentage Phase-in Allowance (PPA) and the Small Volume Allowance (SVA). Equipment manufacturers are allowed under the terms of the proposal to take advantage of one, but not both, of these provisions in any year in any power category. The PPA is broken up into two separate parts. One section deals with the treatment of equipment with engines rated under 37 kW and the other deals with equipment at 37 kW and above. Also, under the PPA provisions, there are separate provisions for agricultural equipment. Table 5-8 illustrates the provisions of the PPA scenario. During the first year of implementation of the proposed Tier 1 standards for engines rated below 37 kW, or the proposed Tier 2 standards for larger engines, not all pieces of equipment are required to meet the new standard. A certain fraction of them, either 15% or 30% depending upon the usage classification, will only have to meet the previous standard which is either the Tier 1 standard in the case of equipment at 37 kW and above, or unregulated in the case of equipment under 37 kW. In any subsequent year, up to the limit noted in the last column of Table 5-8, these exemptions drop to 15% or 5%. 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 Tier 3 standard is in place, however, the standard for the exempted equipment continues to be the Tier 1 standard.

Table 5-8
Equipment Manufacturer Flexibility Under the PPA Scenario

Power Range (kW)	First Year Phase-in Percent Exempted	Subsequent Year Phase-in Percent Exempted	Total length of Phase-in (years)
Nonagricultural			
0 < 37	15% (Unregulated)	5% (Unregulated)	4
37+	15% (Tier 1)	5% (Tier 1)	7
Agricultural			
0 < 37	30% (Unregulated)	15% (Unregulated)	4
37+	30% (Tier 1)	15% (Tier 1)	8

Modeling the PPA scenario with NEM involves a couple of steps. The first step is a simple determination of what is termed the Base emissions case. This step is described in Table 5-9. It is an example of how the emission inputs under the PPA base case would be modeled with NEM if all equipment manufacturers were assumed to be taking full advantage of this allowance. NEM receives its input describing a certain scenario in the form of the emission standard and the year that the standard takes effect.[e] **These scenarios can be entered into NEM, as illustrated in Table 5-9, for an example case for NOx emissions from nonagricultural equipment from 130 to less than 225 kW.**

Table 5-9
Calculation of NOx Emission Inputs
for Nonagricultural Equipment 130 to < 225 kW, g/kW-hr (g/hp-hr)

Timeframe	**Tier 1**	**Tier 2 First Year, 2003 (15% Tier 1 + 85% Tier 2)**	**Tier 2 for years 2004, 2005 (5% Tier 1 + 95% Tier 2)**	**Tier 3 for years 2006 - 2009 (5% Tier 1 + 95% Tier 3)**	**Tier 3 for years 2010+ (100% Tier 3)**
Calculation	**9.2 (6.9)**	**15% x 9.2 + 85% x 6.0**	**5% x 9.2 + 95% x 6.0**	**5% x 9.2 + 95% x 3.8**	**3.8 (2.8)**
NEM Entry Year/Standard	***1996/ 9.2 (6.9)***	***2003/6.5 (4.9)***	***2004/6.2 (4.6)***	***2006/4.0 (3.0)***	***2010/3.8 (2.8)***

This same general methodology is used for all power ranges and for both NOx and NMHC emissions. As noted earlier, for the equipment under 37 kW, a certain percent of the equipment will be allowed to be unregulated because the original Tier 1 diesel rule excluded engines rated under 37 kW. Tables 5-14 and 5-15, presented later in this chapter, indicate the precontrol levels that were used for each pollutant in determining the appropriate emission inputs for the NEM runs.[f]

Realistically, all manufacturers will not opt into the PPA scenario. Some will opt into the SVA option, while others will not opt into either of

---

[e] The reader is directed to examine the memorandum to the docket describing the operation of NEM.

[f] The precontrol levels presented in Tables 5-14 and 5-15 represent population-weighted averages and were derived from the NEVES emission factors for the top ten equipment applications below 37 kW.

these programs.[g] However, for the purposes of emissions modeling, and thus to determine potential benefits from this proposal, EPA modeled only the PPA allowance assuming all manufacturers take full advantage of this scenario. This results in the most conservative estimate (i.e., yields the lowest benefits) for the benefits of the proposed standards.

F. Emission Model Results

Because this proposed 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 NEM modeling performed in support of this proposal. The following section presents the inventories for each of the three pollutants, the total reductions expected under this proposal, and the relative contribution of each power range and market segment to the 1995 baseline inventories. A memo containing all of the modeling results has been placed in the public docket for the rulemaking.[6]

1. Projected emission inventories and reductions

Table 5-10 presents the NOx inventory under the current Tier 1 standards and the emission reductions expected from the proposed standards for future years in five year increments using both the BEA and 3% growth assumptions. It is evident from the table that the BEA figures yield lower reduction estimates than the 3% growth assumptions, as would be expected. Based on EPA's use of these two different growth factors it is reasonable to assume that the actual emission reductions are located somewhere between these two sets of numbers.

---

[g] The reader is referred to the preamble for the proposal for a better understanding of the SVA scenarios. Briefly, the SVA scenario allows any manufacturer, regardless of size, to exceed the percentage phase-in allowance provided they limit the installation of Tier 1 engines (uncontrolled engines for ratings under 37 kW) to a single equipment model with an annual production of 100 pieces or less in U.S. sales.

Table 5-10
NOx Inventories and Reductions (Short tons/Year)

Calendar Year	NOx Emission Inventories Under the Current Standards		NOx Reductions Due to the Proposed Standards	
	Assuming BEA Growth	Assuming 3% Growth	Assuming BEA Growth (% Reduction)	Assuming 3% Growth (% Reduction)
1995	3,140,000	3,140,000	0	0
2000	2,920,000	3,150,000	31,300 (1.1%)	33,700 (1.1%)
2005	2,730,000	3,180,000	302,500 (11.1%)	352,900 (11.1%)
2010	2,740,000	3,450,000	885,100 (32.3%)	1,120,100 (32.5%)
2015	2,880,000	3,920,000	1,344,900 (46.7%)	1,840,900 (46.9%)
2020	3,070,000	4,520,000	1,609,900 (52.4%)	2,375,200 (52.5%)

Based on the information in Table 5-10, the proposed rule 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 current Tier 1 standards and the proposed standards for the BEA and 3% growth assumptions, respectively. Note that with the 3% growth assumption, under the Tier 1 rule there is a net increase in emissions from 1995 to 2020, whereas with the BEA growth assumptions, there is a net decrease in emissions. Under both growth scenarios, the proposed 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 under the terms of this proposal. Table 5-11 presents the baseline HC inventory and the emission reductions expected from the proposed standards for future years in five year increments using both the BEA and 3% growth assumptions. This analysis assumes that the Tier 1 rule achieved no reductions in hydrocarbons, an assumption stated in that rule. Thus, the baseline inventory is based on uncontrolled emission levels. The reductions due to the proposed standards were modeled based on the difference between the current NMHC levels (precontrol levels for engines rated under 37 kW and Tier 1 certification levels for engines rated at or above 37 kW) and the NMHC levels expected under the proposed standards (presented earlier in Table 5-5).

Insert Figures 5-1 and 5-2

Table 5-11
Hydrocarbon Inventories and Reductions (Short tons/year)

Calendar Year	Baseline HC Emission Inventories		HC Reductions Due to the Proposed Standards	
	Assuming BEA Growth	Assuming 3% Growth	Assuming BEA Growth (% Reduction)	Assuming 3% Growth (% Reduction)
1995	467,500	467,500	0	0
2000	503,300	542,600	6000 (1.2%)	6500 (1.2%)
2005	541,300	629,200	28,300 (5.2%)	32,800 (5.2%)
2010	581,900	729,500	72,900 (12.5%)	91,500 (12.5%)
2015	625,600	845,700	109,700 (17.6%)	148,600 (17.6%)
2020	672,600	980,400	131,600 (19.6%)	191,900 (19.6%)

By the year 2010, a decrease of about 13% in hydrocarbon is projected under this proposed rule regardless of the growth scenario. By the year 2020 approximately a 20% reduction in hydrocarbons can be expected. Figures 5-3 and 5-4 illustrate the relationship between the baseline HC inventories and the HC inventories under the proposed standards for the BEA and 3% growth assumptions, respectively.

PM emissions are examined in the same way that HC emissions were. The Tier 1 rule is assumed to offer no reductions and thus, the baseline is equivalent to the uncontrolled levels. Section IV.D. of this chapter described the assumptions used in modeling PM inventory reductions. Table 5-12 presents the baseline PM inventory and the emission reductions expected from the proposed standards for future years in five year increments using both the BEA and 3% growth assumptions.

Insert Figures 5-3 and 5-4

Table 5-12
PM Inventories and Reductions (Short tons/year)

Calendar Year	Baseline PM Emission Inventories		PM Reductions Due to the Proposed Standards	
	Assuming BEA Growth	Assuming 3% Growth	Assuming BEA Growth (% Reduction)	Assuming 3% Growth (% Reduction)
1995	443,800	443,800	0	0
2000	478,000	515,200	2,100 (0.4%)	2,200 (0.4%)
2005	514,100	597,600	30,500 (5.9%)	35,400 (5.9%)
2010	552,700	692,800	69,500 (12.6%)	87,100 (12.6%)
2015	594,200	803,100	92,300 (15.5%)	124,800 (15.5%)
2020	638,800	931,000	104,800 (16.4%)	152,800 (16.4%)

Figures 5-5 and 5-6 illustrate the relationship between the baseline PM inventories and the PM inventories under the proposed standards for the BEA and 3% growth assumptions, respectively. In each case there is a net decrease in PM emissions from the baseline of about 13% in the year 2010 and over 16% 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 proposed standards will be completely accurate.

It should be noted that the emissions inventories contained in the above tables are significantly higher than inventories for corresponding applications in EPA's NEVES report and in the Tier 1 rulemaking analyses. The differences are largely due to improvements made in the accuracy of the nonroad equipment population database used in these analyses, population growth since the 1990 NEVES report base year, and a re-assessment of the portion of semi-mobile equipment such as generator sets that are assumed to be regulated as mobile sources.[7]

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

Insert Figures 5-5 and 5-6

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.[8] SAI used a combination of ambient concentration data and computer modeling that simulates atmospheric conditions to estimate the 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 NOMC 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 NPRM[9]. 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 5-13.

Table 5-13
Estimated Secondary PM Reductions (Short tons/year)

Calendar Year	Total NOx Emission Reductions		Equivalent Secondary PM Emission Reductions	
	BEA Growth	3% Growth	BEA Growth	3% Growth
2005	302,500	352,900	12,100	14,100
2010	885,100	1,120,100	35,400	44,800
2015	1,344,900	1,840,900	53,800	73,600
2020	1,609,900	2,375,200	64,400	95,000

3. Equipment/power emission breakdown

To more fully understand the relationship between the nonroad emissions based on power rating and market segment, Figures 5-7, 5-8, and 5-9 have been prepared. They reveal the different market segments and horsepower ranges and the relative contribution that each has to the 1995 baseline nonroad inventories of HC, NOx, and PM. It is evident that the construction and agriculture segments contribute the most emissions, by far, with the 37 kW to 375 kW (50 to 500 horsepower) range being the area where these emissions are most concentrated.

4. Nonroad emission comparison with other sources

Figure 5-10 provides a general comparison of the relationship between the various sources of NOx. These sources include other mobile sources not included in this rule (nonroad spark-ignition engines, highway engines, aircraft, marine engines, and locomotives), and stationary sources. The projected levels for nonroad diesel engines include the Tier 1 standards and show that nonroad diesels remain a very significant contributor to overall NOx emissions. As the figure shows, additional controls will be necessary if the current downward trend in NOx emissions from these engines is to continue.

Figure 5-11 presents the Agency’s current projections for PM emissions from diesel engines. (Diesel engines contribute most of the direct PM emissions from mobile sources; mobile source emissions in turn are roughly the same magnitude as PM from stationary-source fuel combustion and from industrial sources.) As the figure shows, PM controls on highway diesels are projected to reduce direct PM emissions well into the future; however, this progress is expected to be more than offset by growth in nonroad diesel PM emissions in the absence of further controls.

Insert Figure 5-7

Insert Figure 5-8

Insert Figure 5-9

Insert Figures 5-10 and 5-11

Currently, PM emissions from nonroad diesel equipment covered by this proposal (440,000 tons per year) account for about two thirds of total diesel PM emissions. In 2010, the fraction of total diesel PM emissions from nonroad diesel equipment (550,000 tons per year) is projected to exceed 80 percent of total diesel PM emissions in the absence of further controls.[10]

V. Per-Piece of Equipment Emission Reductions

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 proposed 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 how much reductions will be achieved from a typical piece of nonroad equipment. As noted earlier in this chapter, the equation used to calculate emissions from a piece of nonroad equipment (equation 1 of the NEM Methodology memorandum in the docket) requires 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. The values used in this analysis and the methodology for determining the values are presented below.

A. Per-Engine Emission Levels

To project the impact of the proposed standards, EPA must estimate the emission levels of engines prior to the time the proposed standards take effect and the emission levels once the proposed standards go into effect. Tables 5-14 and 5-15 contain the estimated NMHC + NOx certification emission levels and PM certification emission levels assumed by EPA in projecting the impact of the proposed standards, respectively. (For the 0 to 37 kW category and the 175 to 600 kW category, where more than one power subcategory was combined, EPA weighted the appropriate subcategory emissions levels by population to determine the emission level for the overall power category.) For an explanation of the assumptions behind the emission levels, the reader is directed to Section IV.C. of this chapter.

Table 5-14
Estimated NMHC + NOx Certification Emission Levels, g/kW-hr (g/hp-hr)

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol	14.5 (10.8)	—	—	—	—	—
Tier 1	8.3 (6.2)	10.2 (7.6)	9.8 (7.3)	9.7 (7.2)	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 5-15
Estimated PM Certification Emission Levels, g/kW-hr (g/hp-hr)

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol	1.9 (1.4)	—	—	—	—	—
Tier 1	0.82 (0.61)	0.67 (0.50)	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	—	—	—	—	—	—

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. 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. Table 5-16 presents the resulting population-weighted average power for the different power categories.

Table 5-16
Average Power

Power Range (kW)	Average Power, kW (hp)
0-37	20.5 (27.5)
37-75	52.2 (68.7)
75-130	95.6 (128.1)
130-450	178.7 (239.6)
450-560	473.3 (634.5)
>560	628.5 (842.5)

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. 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. Table 5-17 presents the resulting population-weighted average load factors for the different power ranges.

Table 5-17
Average Load Factor

Power Range (kW)	Average Load Factor
0-37	0.57
37-75	0.55
75-130	0.64
130-450	0.65
450-560	0.72
>560	0.68

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. 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. Table 5-18 presents the resulting population-weighted average load factors for the different power ranges.

Table 5-18
Average Annual Hours of Operation

Power Range (kW)	Average Annual Hours
0-37	691
37-75	803
75-130	598
130-450	550
450-560	514
>560	737

E. Projected Annual Emissions Levels and Emission Reductions

Using the information presented in Tables 5-14 through 5-18 and the emissions calculation equation (equation 1 of the NEM Methodology memorandum in the docket), 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-controlled levels for engines <37 kW) and engines designed to meet the proposed standards. Tables 5-19 and 5-20 contain the annual NMHC + NOx emissions estimates and annual PM emissions estimates, respectively.

Table 5-19
Annual NMHC + NOx Emissions, short tons

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol	0.13	—	—	—	—	—
Tier 1	0.07	0.25	0.39	0.68	1.85	3.35
Tier 2	0.07	0.19	0.26	0.46	1.24	2.23
Tier 3	—	0.12	0.16	0.28	0.77	—

Table 5-20
Annual PM Emissions, short tons

Control Level	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol	0.02	—	—	—	—	—
Tier 1	0.01	0.02	0.02	0.04	0.10	0.19
Tier 2	0.01	0.01	0.01	0.01	0.04	0.07

Table 5-21 and Table 5-22 contain the annual NMHC + NOx emission reductions and annual PM emission reductions resulting from the proposed standards, respectively.

Table 5-21
Annual NMHC + NOx Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.055	—	—	—	—	—
Tier 1 to Tier 2	0.007	0.066	0.129	0.220	0.618	1.116
Tier 2 to Tier 3	—	0.070	0.102	0.178	0.464	—

Table 5-22
Annual PM Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.009	—	—	—	—	—
Tier 1 to Tier 2	0.001	0.007	0.010	0.024	0.064	0.116

F. Average Lifetime

To calculate the emission reductions that will occur over the lifetime of nonroad equipment due to the proposed standards, it is necessary to know the lifetime of nonroad equipment. The equation that is used to calculate average lifetime of nonroad equipment (presented as equation 2 of the NEM Methodology memorandum in the docket) 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 5-17 and 5-18, respectively, and the engine life at full load information (presented in Table 3 of the NEM methodology memorandum to the docket), the average lifetime of nonroad equipment was calculated by power range and is presented in Table 5-23. As noted in the NEM methodology memorandum, the average lifetime for lawn and garden equipment is not calculated in the same manner, but is specified in Table 4 of that same NEM methodology memorandum.

For nonroad equipment under 37 kW, where diesel lawn and garden applications exist, the average lifetime results presented in Table 5-23 are a population-weighted value of the lawn and garden application results, as presented in Table 4 of the NEM Methodology memorandum to the docket, and the results of the remaining applications (other than lawn and garden equipment) using equation 2 of the NEM Methodology memorandum and information presented in Table 3 of that same memorandum, and Tables 5-17 and 5-18 above.

Table 5-23
Average Lifetime (years)

Power Range (kW)	Average Lifetime
0-37	6.2
37-75	9.1
75-130	10.5
130-450	11.1
450-560	16.3
>560	12.0

G. Lifetime Emission Reductions

The lifetime emission reductions due to the proposed standards were calculated based on the annual emission reductions contained in Table 5-21 and Table 5-22 and the average lifetimes contained in Table 5-23. Table 5-24 and Table 5-25 contain the lifetime NMHC + NOx emission reductions and PM emission reductions, respectively, on a nondiscounted basis. Table 5-26 and Table 5-27 contain the lifetime NMHC + NOx emission reductions and PM emission reductions, respectively on a discounted basis, assuming a 3% discount rate.

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

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.34	—	—	—	—	—
Tier 1 to Tier 2	0.04	0.61	1.35	2.45	10.06	13.36
Tier 2 to Tier 3	—	0.64	1.07	1.99	7.55	—

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

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.059	—	—	—	—	—
Tier 1 to Tier 2	0.007	0.061	0.102	0.264	1.048	1.392

Table 5-26
Discounted Lifetime NMHC + NOx Emission Reductions, short tons

Control Increment	Power Range (kW					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.32	—	—	—	—	—
Tier 1 to Tier 2	0.04	0.59	1.19	2.11	8.11	11.44
Tier 2 to Tier 3	—	0.62	0.94	1.71	6.08	—

Table 5-27
Discounted Lifetime PM Emission Reductions, short tons

Control Increment	Power Range (kW)					
	0-37	37-75	75-130	130-450	450-560	>560
Precontrol to Tier 1	0.055	—	—	—	—	—
Tier 1 to Tier 2	0.006	0.059	0.089	0.227	0.845	1.192

VI. Conclusions

The amount of emission reductions that can be achieved with the implementation of the proposed standards is quite substantial. The chief pollutant, NOx, will 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 proposed standards will increase to over 50% in the year 2020. Under the proposed standards, HC and PM are expected to show reductions of about 20% and 15%, 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 65,000 tons/year nationwide by the year 2020 (assuming BEA 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 proposed standards, however, the projected levels of inventories continue to decrease well into the 21st century.

Based on a comparison of the results obtained for nonroad diesel equipment from NEM with emission projections for other emission sources, nonroad NOx emissions are a significant portion of overall NOx emissions, and the projected reductions of this proposal will make significant reductions in the overall levels of NOx in the atmosphere. According to this analysis nonroad sources amount to about 27% of all NOx emissions from mobile sources in 1996, after the proposal has been implemented this share of the NOx from all mobile sources can be expected to drop to about 18% in 2010 and 13% in 2020. Since NOx is a precursor to ozone formation, this proposal, in concert with other regional-scale NOx control programs, should result in lower levels of ambient ozone in most areas of the country.

Chapter 5 References

1.Power Systems Research, EngineData Database, 1996.

2.Energy Information Administration Report EIA-821, "Annual Fuel Oil and Kerosene Sales Report, 1995".

3.Nonroad Engine and Vehicle Emission Study Report and Appendices (EPA-21A-2001), November 1991. See also Nonroad Emission Inventory Tables: Inventories A and B, available in EPA Public Docket #A-96-40.

4.Southwest Research Institute, prepared for U.S. Environmental Protection Agency, "Characterization of Sulfates, Odor, Smoke, POM and Particulates from Light and Heavy Duty Engines - Part IX," June 1979, EPA-460/3-79-007, EPA Contract No. 68-03-2417.

5.Nonroad Engine and Vehicle Emission Study Report and Appendices (EPA-21A-2001), November 1991.

6."Results of the Emissions Modeling in Support of the Nonroad Diesel Engine NPRM," EPA memorandum from Phil Carlson to Public Docket A-96-40, August 8, 1997.

7.EPA memorandum from Mike Samulski and Pete Caffrey to Don Kopinski, July 11, 1997.

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

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

10.Figures 5-10 and 5-11 are based on EPA data described in an August 1997 memo from Joe Somers to the docket for this rule, titled "Emission Inventories Used in the Nonroad Diesel Proposed Rule."

CHAPTER 6: COST-EFFECTIVENESS

This chapter assesses the cost-effectiveness of the proposed 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 proposed standards in terms of dollars per ton of total NMHC + NOx emission reductions. This chapter also examines the cost-effectiveness of the proposed PM standards. Finally, the chapter compares the cost-effectiveness of the proposed 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 three percent to the beginning of the equipment's life. An estimate of the fleet-wide cost-effectiveness of the proposed standards, combining all of the power categories, is also presented. EPA has analyzed the cost-effectiveness of each new proposed 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 of the proposed provisions 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 proposed 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 Proposed Emission Standards

A. NMHC + NOx

The following section describes the cost-effectiveness of the proposed NMHC + NOx standards for the various power categories of nonroad equipment. As discussed in Chapter 4, the estimated cost of complying with the proposed standards varies depending on the model year under consideration. The following section therefore 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 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 proposed 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 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.

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

Power Category	1995 Population
0-37 kW	2,368,000
37-75 kW	1,977,000
75-130 kW	1,410,000
130-450 kW	1,184,000
450-560 kW	38,000
>560 kW	30,000

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

Tables 6-3 through 6-8 contain the total net present value costs based on the information presented in Chapter 4, the lifetime NMHC + NOx emission reductions as presented in Chapter 5, and the resulting discounted cost-effectiveness values for the individual power categories of nonroad equipment. Table 6-9 contains the fleet-wide, discounted cost-effectiveness of the proposed Tier 2 NMHC + NOx emission standards and the proposed Tier 3 NMHC + NOx emission standards.

Table 6-3
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for 0-37 kW Engines

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	$138	0.32	$440
	3 to 5	$136		$430
Tier 2	1 to 2	$33	0.04	$790
	3 to 5	$29		$700
	6 to 10	$15		$360
	11+	$11		$270

Table 6-4
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for 37-75 kW Engines

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	$235	0.59	$400
	3 to 5	$211		$360
Tier 3	1 to 2	$430	0.62	$700
	3 to 5	$395		$640
	6 to 10	$217		$350
	11+	$201		$330

Table 6-5
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for 75-130 kW Engines

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	$458	1.19	$390
	3 to 5	$414		$350
Tier 3	1 to 2	$573	0.94	$610
	3 to 5	$517		$550
	6 to 10	$325		$350
	11+	$281		$300

Table 6-6
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for 130-450 kW Engines

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	$446	2.11	$210
	3 to 5	$396		$190
Tier 3	1 to 2	$601	1.71	$350
	3 to 5	$539		$310
	6 to 10	$356		$210
	11+	$323		$190

Table 6-7
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for 450-560 kW Engines

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	$1,075	8.11	$130
	3 to 5	$996		$120
Tier 3	1 to 2	$1,878	6.08	$310
	3 to 5	$1,786		$290
	6 to 10	$522		$90
	11+	$475		$80

Table 6-8
Discounted Cost-effectiveness of the
Proposed NMHC + NOx Standards for Greater than 560 kW Engines

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	$1,350	11.44	$120
	3 to 5	$1,320		$120
	6 to 10	$207		$20
	11+	$95		$10

Table 6-9
Discounted Fleet-wide Cost-effectiveness
of the Proposed NMHC + NOx Standards

Level of Standard	Model Year Grouping	Discounted Cost-effectiveness ($/ton)
Tier 2	1 to 2	$300
	3 to 5	$270
Tier 3	1 to 2	$400
	3 to 5	$370
	6 to 10	$180
	11+	$160

B. PM

EPA also estimated the cost-effectiveness of the proposed 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 costs projected in Chapter 4 were allocated for PM control. EPA believes this is a conservative assumption given the stringency of the proposed NMHC + NOx standards and results in an upper end estimate of the cost-effectiveness for PM control. Table 6-10 contains the resulting fleet-wide cost-effectiveness of the proposed PM standards. For this estimate, the proposed Tier 1 standards for engines rated under 37 kW were combined with the proposed Tier 2 standards for all power categories.

Table 6-10
Discounted Fleet-wide Cost-effectiveness
of the Proposed PM Standards

Level of Standard	Model Year Grouping	Discounted Cost-effectiveness ($/ton)
Tier 1 and Tier 2 combined	1 to 2	$1,470
	3 to 5	$1,340
	6 to 10	$840
	11+	$530

II. Comparison with Cost-Effectiveness of Other Control Programs

In an effort to evaluate the cost-effectiveness of the proposed controls, 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 proposed standards. Table 6-11 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 standards for highway heavy-duty diesel engines.

Table 6-11
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 for Highway Heavy-Duty Engines	NMHC + NOx	$100 - $600

A comparison of the cost-effectiveness numbers in Table 6-11 with the cost-effectiveness results presented throughout this chapter for nonroad diesel engines shows that the cost-effectiveness of the proposed NMHC + NOx standards are more favorable than the cost-effectiveness of both the clean fuel fleet vehicle program and reformulated gasoline. The cost-effectiveness of the proposed NMHC + NOx standards for nonroad diesel engines are comparable to the cost-effectiveness of the most recent highway heavy-duty NMHC + 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 6-12 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 presented earlier in Table 6-10 are more favorable than either of the urban bus programs.

Table 6-12
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.

Appendix to the Regulatory Impact Analysis

Table A-1 contains the year by year fleetwide costs and emission benefits associated with the proposed diesel nonroad engine standards for the 20-year period from 1999 to 2018. (The numbers presented in Table A-1 are <u>not</u> discounted.)

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

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons)		
		NOx	HC	PM
1999	$3,500,000	12,700	2,500	800
2000	$15,500,000	31,300	6,000	2,100
2001	$29,900,000	54,700	9,600	3,800
2002	$40,200,000	79,600	13,200	5,700
2003	$118,400,000	145,400	16,700	12,500
2004	$168,400,000	224,000	20,300	21,500
2005	$162,700,000	302,500	28,300	30,500
2006	$244,100,000	419,000	37,200	38,300
2007	$288,200,000	535,500	46,200	46,100
2008	$320,400,000	652,100	55,100	53,900
2009	$306,400,000	768,600	64,000	61,700
2010	$317,500,000	885,100	72,900	69,500
2011	$277,400,000	977,100	80,300	74,100
2012	$260,500,000	1,069,000	87,700	78,600
2013	$199,100,000	1,161,000	95,000	83,200
2014	$191,000,000	1,252,900	102,400	87,700
2015	$204,900,000	1,344,900	109,700	92,300
2016	$207,000,000	1,397,900	114,100	94,800
2017	$216,400,000	1,450,900	118,500	97,300
2018	$215,800,000	1,503,900	122,900	99,800

Table A-2 contains the discounted year by year fleetwide costs and emission benefits associated with the proposed 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.

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

Calendar Year	Discounted Fleetwide Costs	Discounted Fleetwide Reductions (short tons)		
		NOx	HC	PM
1999	$3,500,000	12,700	2,500	800
2000	$14,500,000	29,300	5,700	1,900
2001	$26,100,000	47,800	8,400	3,300
2002	$32,900,000	65,000	10,700	4,700
2003	$90,300,000	110,900	12,800	9,600
2004	$120,100,000	159,700	14,500	15,300
2005	$108,400,000	201,500	18,900	20,300
2006	$152,000,000	260,900	23,200	23,800
2007	$167,800,000	311,700	26,900	26,800
2008	$174,300,000	354,700	30,000	29,300
2009	$155,700,000	390,700	32,500	31,400
2010	$150,800,000	420,500	34,700	33,000
2011	$123,200,000	433,800	35,700	32,900
2012	$108,100,000	443,600	36,400	32,600
2013	$77,200,000	450,200	36,800	32,300
2014	$69,200,000	454,100	37,100	31,800
2015	$69,400,000	455,600	37,200	31,300
2016	$65,500,000	442,500	36,100	30,000
2017	$64,000,000	429,300	35,100	28,800
2018	$59,700,000	415,800	34,000	27,600

Summing the discounted annual costs and discounted emission reductions over the twenty year period yields a 20-year fleetwide cost of $1.83 billion and 20-year emission reductions of 5.9 million tons of NOx, 0.5 million tons of HC, and 0.4 million tons of PM. The resulting 20-year annualized fleetwide costs and emission reductions are $173 million per year and 556,000 tons per year of NOx, 48,000 tons per year of HC, and 42,000 tons per year of PM, respectively. A copy of the spreadsheet prepared for this 20-year cost and benefit analysis has been placed in the public docket for the notice of proposed rulemaking. The reader is directed to the spreadsheets for a complete version of the analysis.