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Draft Regulatory Support Document:

Control of Emissions from Unregulated Nonroad Engines

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

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Executive Summary

EPA is proposing new standards for emissions of oxides of nitrogen, hydrocarbons, and carbon monoxide from several categories of engines. This Draft Regulatory Support Document 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. Overall, the proposed requirements would dramatically reduce individual exposure to dangerous pollutants and 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 1 reviews information related to the health and welfare effects of the pollutants of concern. Chapter 2 contains an overview of the affected manufacturers, including some description of the range of engines involved and their place in the market. Chapter 3 covers a broad description of engine technologies, including a wide variety of approaches to reducing emissions. Chapter 4 summarizes the available information supporting the specific standards we are proposing, providing a technical justification for the feasibility of the standards. Chapter 5 applies cost estimates to the projected technologies. Chapter 6 presents the calculated contribution of these engines to the nationwide emission inventory with and without the proposed standards. Chapter 7 compares the costs and the emission reductions for an estimate of the cost-effectiveness of the rulemaking.

There are five sets of engines and vehicles that would be covered by the proposed standards. The following paragraphs describe the different types of engines and vehicles and the standards that apply.

Proposed Emission Standards

Large industrial spark-ignition engines

These are spark-ignition nonroad engines rated over 19 kW used in commercial applications. These include engines used in forklifts, electric generators, airport ground service equipment, and a variety of other construction, farm, and industrial equipment. Many Large SI engines, such as those used in farm and construction equipment, are operated outdoors, predominantly during warmer weather and often in or near heavily populated urban areas where they contribute to ozone formation and ambient CO and PM levels. These engines are also often operated in factories, warehouses, and large retail outlets throughout the year, where they contribute to high exposure levels to personnel who work with or near this equipment as well as to ozone formation and ambient CO and PM levels. For the purpose of this proposal, we are calling these “Large SI engines.” Table 1 shows the proposed emission standards for Large SI engines. This includes alternate emission standards for lower NOx emissions and higher CO emissions for engines that don’t operate in enclosed areas. The table also distinguishes between standards for duty-cycle testing and for field-testing.

Table 1
Proposed Emission Standards for Large SI Engines (g/kW-hr)

Model Year	Testing Type	Emission standards		Alternate emission standards	
		HC+NOx	CO	HC+NOx	CO
2004 - 2006	Duty-cycle testing	4.0	37.0	—	—
2007 and later	Duty-cycle testing	3.4	3.4	1.3	27
	Field-testing	4.7	5.0	1.8	41

Nonroad recreational engines and vehicles

These are spark-ignition nonroad engines used primarily in recreational applications. These include off-highway motorcycles, all-terrain-vehicles (ATVs), and snowmobiles. Some of these engines, particularly those used on ATVs, are increasingly used for commercial purposes within urban areas, especially for hauling loads and other utility purposes. These vehicles are typically used in suburban and rural areas, where they can contribute to ozone formation and ambient CO and PM levels. They can also contribute to regional haze problems in our national and state parks. Table 2 shows the proposed emission standards that apply to recreational vehicles.

Table 2
Recreational Vehicle Exhaust Emission Standards

Vehicle	Model Year	Emission standards		Phase-in
		HC g/kW-hr	CO g/kW-hr	
Snowmobile	2006	100	275	100%
	2010	75	200	100%
		HC+NOx g/km	CO g/km	
Off-highway Motorcycle	2006	2.0	25.0	50%
	2007 and later	2.0	25.0	100%
ATV	2006	2.0	25.0	50%
	2007 and 2008	2.0	25.0	100%
	2009	1.0	25.0	50%
	2010 and later	1.0	25.0	100%

Recreational marine diesel engines

These are marine diesel engines used on recreational vessels such as yachts, cruisers, and other types of pleasure craft. Recreational marine engines are primarily used in warm weather and therefore contribute to ozone formation PM levels, especially in marinas, which are often located in nonattainment areas.

Table 3
Proposed Recreational Marine Diesel Emission Limits and Implementation Dates

Subcategory	Implementation Date	HC+NOx g/kW-hr	PM g/kW-hr	CO g/kW-hr
power ≥ 37 kW 0.5 ≤ disp < 0.9	2007	7.5	0.40	5.0
0.9 ≤ disp < 1.2	2006	7.2	0.30	5.0
1.2 ≤ disp < 2.5	2006	7.2	0.20	5.0
2.5 ≤ disp	2009	7.2	0.20	5.0

Projected Impacts

The following paragraphs and tables summarize the projected emission reductions and costs associated with the proposed emission standards. See the detailed analysis later in this document for further discussion of these estimates.

Table 6 contains the projected emissions from the engines subject to this proposal. Projected figures compare the estimated emission levels with and without the proposed emission standards for 2020.

Table 6
2020 Projected Emissions Inventories (thousand short tons)

Category	Exhaust CO			Exhaust NOx			Exhaust HC**		
	base case	with proposed standards	percent reduction	base case	with proposed standards	percent reduction	base case	with proposed standards	percent reduction
Industrial SI >19kW	2,991	231	92	486	77	84	346	50	86
Snowmobiles	609	227	63	2	2	0	229	85	63
ATVs	4,589	3,041	34	25	25	0	1,301	205	84
Off-highway motorcycles	208	154	26	1	1	0	154	77	50
Recreational Marine diesel*	6	6	0	39	32	17	1.3	1.0	25
Total	8,404	3,658	56	552	137	75	2,032	418	79

* We also anticipate a 6 percent reduction in direct PM from a baseline of inventory of 1,470 tons in 2020 to a control inventory of 1,390 tons.
** The Industrial SI >19 kW estimate includes both exhaust and evaporative emissions.

Table 7 summarizes the projected costs to meet the proposed emission standards. This is our best estimate of the cost associated with adopting new technologies to meet the proposed emission standards. The analysis also considers total operating costs, including maintenance and fuel consumption. In many cases, the fuel savings from new technology are greater than the cost to upgrade the engines. All costs are presented in 2001 dollars.

Table 7
Estimated Average Cost Impacts of Proposed Emission Standards

Engine Type	Standard	Increased Production Cost per Engine*	Lifetime Operating Costs per Engine (NPV)
Large SI	2004	$600	$-3,985
Large SI	2007	$45	—
Snowmobiles	2006	$55	—
Snowmobiles	2010	$216	$-509
ATVs	2006	$60	$-102
ATVs	2009	$52	—
Off-highway motorcycles	2006	$151	$-98
Marine diesel	2006	$443	—

*The estimated long-term costs decrease by about 35 percent. Costs presented for second-phase standards for Large SI, and ATVs are incremental to the first-phase standards.

We also calculated the cost per ton of emission reductions for the proposed standards. For snowmobiles, this calculation is on the basis of CO emissions. For all other engines, we attributed the entire cost of the proposed program to the control of ozone precursor emissions (HC or NOx or both). A separate calculation could apply to reduced CO or PM emissions in some cases. Assigning the full compliance costs to a narrow emissions basis leads to cost-per-ton values that underestimate of the value of the proposed program.

Table 8 presents the discounted cost-per-ton estimates for the various engines (factoring in the effect of reduced operating costs). Reduced operating costs more than offset the increased cost of producing the cleaner engines for Large SI and ATV engines. The overall fuel savings associated with the proposal are greater than the total projected costs to comply with the proposed emission standards.

Table 8
Estimated Cost-per-Ton of the Proposed Emission Standards

Engine Type	Standard	Discounted Reductions per Engine (short tons)*	Discounted Cost per Ton of HC+NOx		Discounted Cost per Ton of CO	
			Without Fuel Savings	With Fuel Savings	Without Fuel Savings	With Fuel Savings
Large SI (Composite of all fuels)	2004	3.14	$220	$0	—	—
Large SI (Composite of all fuels)	2007	0.56	$80	$80	—	—
Snowmobiles	2006	1.18	—	—	$50	$50
Snowmobiles	2010	0.32	—	—	$670	$0
ATVs	2006	0.88	$70	$0	—	—
ATVs	2009	0.09	$550	$550	—	—
Off-highway motorcycles	2006	0.37	$310	$110	—	—
Marine diesel	2006	0.68	$580	$580	—	—
Aggregate	—	—	$140	$0	$100	$0

* HC+NOx reductions, except snowmobiles which are CO reductions.

CHAPTER 1: Health and Welfare Concerns

The engines and vehicles that would be subject to the proposed standards generate emissions of HC, CO, PM and air toxics that contribute to ozone and CO nonattainment as well as adverse health effects associated with ambient concentrations of PM and air toxics. Elevated emissions from those recreational vehicles that operate in national parks (e.g., snowmobiles) contribute to visibility impairment. This section summarizes the general health effects of these substances. In it, we present information about these health and environmental effects, air quality modeling results, and inventory estimates pre- and post-control.

1.1 Ozone

1.1.1 General Background

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and NOx in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. Volatile organic compounds are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. Volatile organic compounds also are emitted by natural sources such as vegetation. Oxides of nitrogen are emitted largely from motor vehicles, off-highway equipment, power plants, and other sources of combustion. Hydrocarbons (HC) are a large subset of VOC, and to reduce mobile source VOC levels we set maximum emissions limits for hydrocarbon as well as particulate matter emissions.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight.[1] As a result, differences in weather patterns, as well as NOx and VOC levels, contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up, resulting in higher ambient ozone levels than typically would occur on a single high temperature day. Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low local VOC or NOx emissions.

On the chemical level, NOx and VOC are the principal precursors to ozone formation. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities on clear summer days. Relatively small amounts of NOx enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NOx. Under these conditions, NOx reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NOx limited.” Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NOx limited.

When NOx levels are relatively high and VOC levels relatively low, NOx forms inorganic nitrates but relatively little ozone. Such conditions are called “VOC limited.” Under these conditions, VOC reductions are effective in reducing ozone, but NOx reductions can actually increase local ozone under certain circumstances. Even in VOC limited urban areas, NOx reductions are not expected to increase ozone levels if the NOx reductions are sufficiently large.

Rural areas are almost always NOx limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC or NOx limited, or a mixture of both.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NOx, VOC, and ozone, all of which change with time and location.

1.1.2 Health and Welfare Effects of Ozone and Its Precursors

Based on a large number of recent studies, EPA has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the country.[2, 3] Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. For example, studies conducted in the northeastern U.S. and Canada show that ozone air pollution is associated with 10-20 percent of all of the summertime respiratory-related hospital admissions. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma. Prolonged (6 to 8 hours), repeated exposure to ozone can cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

Children and outdoor workers are most at risk from ozone exposure because they typically are active outside during the summer when ozone levels are highest. For example, summer camp studies in the eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors. Further, children are more at risk than adults from ozone exposure because their respiratory systems are still developing. Adults who are outdoors and are moderately active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.

Evidence also exists of a possible relationship between daily increases in ozone levels and increases in daily mortality levels. While the magnitude of this relationship is too uncertain to allow for direct quantification, the full body of evidence indicates the possibility of a positive relationship between ozone exposure and premature mortality.

In addition to human health effects, ozone adversely affects crop yield, vegetation and forest growth, and the durability of materials. Because ground-level ozone interferes with the ability of a plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. Ozone causes noticeable foliage damage in many crops, trees, and ornamental plants (i.e., grass, flowers, shrubs) and causes reduced growth in plants. Studies indicate that current ambient levels of ozone are responsible for damage to forests and ecosystems (including habitat for native animal species). Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and, to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

Volatile organic compounds emissions are detrimental not only for their role in forming ozone, but also for their role as air toxics. Some VOCs emitted from motor vehicles are toxic compounds. At elevated concentrations and exposures, human health effects from air toxics can range from respiratory effects to cancer. Other health impacts include neurological developmental and reproductive effects. The toxicologically significant VOCs emitted in substantial quantities from the engines that are the subject of this proposal are discussed in more detail in Section 1.4, below.

1.1.3 Additional Health and Welfare Effects of NOx Emissions

In addition to their role as an ozone precursor, NOx emissions are associated with a wide variety of other health and welfare effects.[4] [5] Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NOx emissions are an important precursor to acid rain that may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems (“eutrophication”) in the Chesapeake Bay and several nationally important estuaries along the East and Gulf Coasts. Eutrophication can produce multiple adverse effects on water quality and the aquatic environment, including increased algal blooms, excessive phytoplankton growth, and low or no dissolved oxygen in bottom waters. Eutrophication also reduces sunlight, causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Deposition of nitrogen-containing compounds also affects terrestrial ecosystems. Nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of plants and microorganisms to utilize and retain the nitrogen. These environmental impacts are discussed further in Sections 1.6.4 and 1.6.5, below.

Elevated levels of nitrates in drinking water pose significant health risks, especially to infants. Studies have shown that a substantial rise in nitrogen levels in surface waters are highly correlated with human-generated inputs of nitrogen in those watersheds.[6] These nitrogen inputs are dominated by fertilizers and atmospheric deposition. Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and the value placed on scenic views.

1.1.4 Ozone Nonattainment

The current primary and secondary ozone National Ambient Air Quality Standard (NAAQS) is 0.12 ppm daily maximum 1-hour concentration, not to be exceeded more than once per year on average. The determination that an area is at risk of exceeding the ozone standard in the future was made for all areas with current design values grater than or equal to 0.125 ppm (or within a 10 percent margin) and with modeling evidence that exceedances will persist into the future.

Ground level ozone today remains a pervasive pollution problem in the United States. In 1999, 90.8 million people (1990 census) lived in 31 areas designated nonattainment under the 1-hour ozone NAAQS.[7] This sharp decline from the 101 nonattainment areas originally identified under the Clean Air Act Amendments of 1990 demonstrates the effectiveness of the last decade's worth of emission-control programs. However, elevated ozone concentrations remain a serious public health concern throughout the nation.

Over the last decade, declines in ozone levels were found mostly in urban areas, where emissions are heavily influenced by controls on mobile sources and their fuels. Twenty-three metropolitan areas have realized a decline in ozone levels since 1989, but at the same time ozone levels in 11 metropolitan areas with 7 million people have increased.[8] Regionally, California and the Northeast have recorded significant reductions in peak ozone levels, while four other regions (the Mid-Atlantic, the Southeast, the Central and Pacific Northwest) have seen ozone levels increase.

The highest ambient concentrations are currently found in suburban areas, consistent with downwind transport of emissions from urban centers. Concentrations in rural areas have risen to the levels previously found only in cities. Particularly relevant to this proposal, ozone levels at 17 of our National Parks have increased, and in 1998, ozone levels in two parks, Shenandoah National Park and the Great Smoky Mountains National Park, were 30 to 40 percent higher than the ozone NAAQS over the last decade.[9]

To estimate future ozone levels, we refer to the modeling performed in conjunction with the final rule for our most recent heavy-duty highway engine and fuel standards.[10] We performed a series of ozone air quality modeling simulations for nearly the entire Eastern U.S. covering metropolitan areas from Texas to the Northeast.[11] This ozone air quality model was based upon the same modeling system as was used in the Tier 2 air quality analysis, with the addition of updated inventory estimates for 2007 and 2030. The model simulations were performed for several emission scenarios, and the model outputs were combined with current air quality data to identify areas expected to exceed the ozone NAAQS in 2007, 2020, and 2030.[12] The results of this modeling are contained in Table 1.1-1. Areas presented in Table 1.1-1 have 1997-99 air quality data indicating violations of the 1-hour ozone NAAQS, or are within 10 percent of the standard, are predicted to have exceedance in 2007, 2020, or 2030. An area was considered likely to have future exceedances if exceedances were predicted by the model, and the area is currently violating the 1-hour standard, or is within 10 percent of violating the 1-hour standard. Table 1.1-1 shows that 37 areas with a 1999 population of 91 million people are at risk of exceeding the 1-hour ozone standard in 2007.

Table 1.1-1: Eastern Metropolitan Areas with Modeled Exceedances of the 1-Hour Ozone Standard in 2007, 2020, or 2030 (Includes all emission controls through HD07 standards)

MSA or CMSA / State	2007	2020	2030	pop (1999)
Atlanta, GA MSA	x	x	x	3.9
Barnstable-Yarmouth, MA MSA *	x			0.2
Baton Rouge, LA MSA	x	x	x	0.6
Beaumont-Port Arthur, TX MSA	x	x	x	0.4
Benton Harbor, MI MSA *	x	x	x	0.2
Biloxi-Gulfport-Pascagoula, MS MSA *	x	x	x	0.3
Birmingham, AL MSA	x	x	x	0.9
Boston-Worcester-Lawrence, MA CMSA	x	x	x	5.7
Charleston, WV MSA *	x	x		0.3
Charlotte-Gastonia-Rock Hill, NC MSA	x	x	x	1.4
Chicago-Gary-Kenosha, IL CMSA	x	x	x	8.9
Cincinnati-Hamilton, OH-KY-IN CMSA *	x	x	x	1.9
Cleveland-Akron, OH CMSA *	x	x	x	2.9
Detroit-Ann Arbor-Flint, MI CMSA	x	x	x	5.4
Grand Rapids-Muskegon-Holland, MI MSA*	x	x	x	1.1
Hartford, CT MSA	x	x	x	1.1
Houma, LA MSA *	x	x	x	0.2
Houston-Galveston-Brazoria, TX CMSA	x	x	x	4.5
Huntington-Ashland, WV-KY-OH MSA	x	x	x	0.3
Lake Charles, LA MSA *	x		x	0.2
Louisville, KY-IN MSA	x	x	x	1
Macon, GA MSA	x			0.3
Memphis, TN-AR-MS MSA	x	x	x	1.1
Milwaukee-Racine, WI CMSA	x	x	x	1.7
Nashville, TN MSA	x	x	x	1.2
New London-Norwich, CT-RI MSA	x	x	x	0.3
New Orleans, LA MSA *	x	x	x	1.3
New York-Northern NJ-Long Island, NY-NJ-CT-PA CMSA	x	x	x	20.2
Norfolk-Virginia Beach-Newport News, VA-NC MSA *	x		x	1.6
Orlando, FL MSA *	x	x	x	1.5
Pensacola, FL MSA	x			0.4
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	x	x	x	6
Providence-Fall River-Warwick,RI-MAMSA*	x	x	x	1.1
Richmond-Petersburg, VA MSA	x	x	x	1
St. Louis, MO-IL MSA	x	x	x	2.6
Tampa-St. Petersburg, FL MSA *	x	x		2.3
Washington-Baltimore	x	x	x	7.4
Total number of areas	37	32	32	
Population	91.2	88.5	87.8	91.4

* These areas have registered 1997-1999 ozone concentrations within 10 percent of standard.

With regard to future ozone levels, our photochemical ozone modeling for 2020 predicts exceedances of the 1-hour ozone standard in 32 areas with a total of 89 million people (1999 census; see Table 1.1-1). We expect that the control strategies contained in this proposal for nonroad engines will further assist state efforts already underway to attain and maintain the 1-hour ozone standard.

The inventories that underlie this predictive modeling for 2020 and 2030 include reductions from all current and committed to federal, state and local control programs, including the recently promulgated NOx and PM standards for heavy-duty vehicles and low sulfur diesel fuel. The geographic scope of these areas at risk of future exceedances underscores the need for additional, nationwide controls of ozone precursors.

It should be noted that this modeling did not attempt to examine the prospect of areas attaining or maintaining the ozone standard with possible future controls (i.e., controls beyond current or committed federal, State and local controls). Therefore, this information should be interpreted as indicating what areas are at risk of ozone violations in 2007, 2020 or 2030 without federal or state measures that may be adopted and implemented in the future. We expect many of these areas to adopt additional emission reduction programs, but we are unable to quantify or rely upon future reductions from additional State programs since they have not yet been adopted.

1.1.5 Public Health and Welfare Concerns from Prolonged and Repeated Exposures to Ozone

In addition to the health effects described above, there exists a large body of scientific literature that shows that harmful effects can occur from sustained levels of ozone exposure much lower than 0.125 ppm. Studies of prolonged exposures, those lasting about 7 hours, showed health effects from exposures to ozone concentrations as low as 0.08 ppm. Prolonged and repeated exposures to ozone at these levels are common in areas that do not attain the 1-hour NAAQS, and also occur in areas where ambient concentrations of ozone are in compliance with the 1-hour NAAQS.

Prolonged exposure to levels of ozone below the NAAQS have been reported to cause or be statistically associated with transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital and emergency room visits, and transient pulmonary respiratory inflamation. Such acute health effects have been observed following prolonged exposures at moderate levels of exertion at concentrations of ozone as low as 0.08 ppm, the lowest concentration tested. The effects are more pronounced as concentrations increase, affecting more subjects or having a greater effect on a given subject in terms of functional changes or symptoms. A detailed summary and discussion of the large body of ozone health effects research may be found in Chapters 6 through 9 (Volume 3) of the 1996 Criteria Document for ozone.[13] Monitoring data indicates that 333 counties in 33 states exceed these levels in 1997-99.[14]

To provide a quantitative estimate of the projected number of people anticipated to reside in areas in which ozone concentrations are predicted to exceed the 8-hour level of 0.08 to 0.12 ppm or higher for multiple days, we performed regional modeling using the variable-grid Urban Airshed Model (UAM-V).[15] UAM-V is a photochemical grid model that numerically simulates the effects of emissions, advection, diffusion, chemistry, and surface removal processes on pollutant concentrations within a 3-dimensional grid. As with the previous modeling analysis, the inventories that underlie this predictive modeling include reductions from all current and committed to federal, state and local control programs, including the recently promulgated NOx and PM standards for heavy-duty vehicles and low sulfur diesel fuel. This modeling forecast that 111 million people are predicted to live in areas that areas at risk of exceeding these moderate ozone levels for prolonged periods of time in 2020 after accounting for expected inventory reductions due to controls on light- and heavy-duty on-highway vehicles; that number is expected to increase to 125 million in 2030.[16] Prolonged and repeated ozone concentrations at these levels are common in areas throughout the country, and are found both in areas that are exceeding, and areas that are not exceeding, the 1-hour ozone standard. Areas with these high concentrations are more widespread than those in nonattainment for that 1-hour ozone standard.

Ozone at these levels can have other welfare effects, with damage to plants being of most concern. Plant damage affects crop yields, forestry production, and ornamentals. The adverse effect of ozone on forests and other natural vegetation can in turn cause damage to associated ecosystems, with additional resulting economic losses. Prolonged ozone concentrations of 0.10 ppm can be phytotoxic to a large number of plant species, and can produce acute injury and reduced crop yield and biomass production. Ozone concentrations within the range of 0.05 to 0.10 ppm have the potential over a longer duration of creating chronic stress on vegetation that can result in reduced plant growth and yield, shifts in competitive advantages in mixed populations, decreased vigor, and injury. Ozone effects on vegetation are presented in more detail in Chapter 5, Volume II of the 1996 Criteria Document.

1.2 Carbon Monoxide

1.2.1 General Background

Unlike many gases, CO is odorless, colorless, tasteless, and nonirritating. Carbon monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. These conditions are common during vehicle starting when air supply is restricted ("choked"), when cars are not tuned properly, and at high altitude, where "thin" air effectively reduces the amount of oxygen available for combustion (except in cars that are designed or adjusted to compensate for altitude). Carbon monoxide emissions increase dramatically in cold weather. This is because engines need more fuel to start at cold temperatures and because some emission control devices (such as oxygen sensors and catalytic converters) operate less efficiently when they are cold. Also, nighttime inversion conditions are more frequent in the colder months of the year. This is due to the enhanced stability in the atmospheric boundary layer, which inhibits vertical mixing of emissions from the surface.

1.2.2 Health Effects of CO

Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin, a compound that inhibits the blood's capacity to carry oxygen to organs and tissues. Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects. Persons with heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising. Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks. More importantly to many individuals is the frequent exposure of individuals to exhaust emissions from engines operating indoors. The Occupational Safety and Health Administration sets standards regulating the concentration of indoor pollutants, but high local CO levels are still commonplace.

Several recent epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases). Several studies in the United States and Canada have also reported an association of ambient CO exposures with frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association of ambient CO exposure with mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the Criteria Document review process. The CO Criteria Document (EPA 600/P-99/001F) contains additional information about the health effects of CO, human exposure, and air quality. It was published as a final document and made available to the public in August 2000 (www.epa.gov/ncea/co/).

1.2.3 CO Nonattaiment

The current primary NAAQS for CO are 35 parts per million for the one-hour average and 9 parts per million for the eight-hour average. These values are not to be exceeded more than once per year. Air quality carbon monoxide value is estimated using EPA guidance for calculating design values. In 1999, 30.5 million people (1990 census) lived in 17 areas designated nonattainment under the CO NAAQS.[17]

Snowmobiles, which have relatively high per engine CO emissions, can be a significant source of ambient CO levels in CO nonattainment areas. Several states that contain CO nonattainment areas also have large populations of registered snowmobiles. This is shown in Table 1.2-1. A review of snowmobile trail maps indicates that snowmobiles are used in these CO nonattainment areas or in adjoining counties.[18] These include the Mt. Spokane and Riverside trails near the Spokane Washington CO nonattainment area; the Larimer trails near the Fort Collins, Colorado CO nonattainment area; and the Hyatt Lake, Lake of the Woods, and Cold Springs trails near the Klamath Falls and Medford, Oregon CO nonattainment area. There are also trails in Missoula County, Montana that demonstrate snowmobile use in the Missoula, Montana CO nonattainment area. While Colorado has a large snowmobile population, the snowmobile trails are fairly distant from the Colorado Springs CO nonattainment area.[19]

Table 1.2-1
Snowmobile Use in Selected CO Nonattainment Areas

City and State	CO Nonattainment Classification	1998 State snowmobile population[a]
Fairbanks, AK	Serious	12,997
Spokane, WA	Serious	32,274
Colorado Springs, CO	Moderate	28,000
Fort Collins, CO	Moderate	
Klamath Falls, OR	Moderate	13,426
Medford, OR	Moderate	
Missoula, MT	Moderate	14,361

[a]Source: Letter from International Snowmobile Manufacturers Association to US-EPA, July 8, 1999, Docket A-2000-01, Document No. II-G-136

Exceedances of the 8-hour CO standard were recorded in three of these seven CO nonattainment areas located in the northern portion of the country over the five year period from 1994 to 1999: Fairbanks, AK; Medford, OR; and Spokane, WA.[20] Given the variability in CO ambient concentrations due to weather patterns such as inversions, the absence of recent exceedances for some of these nonattainment areas should not be viewed as eliminating the need for further reductions to consistently attain and maintain the standard. A review of CO monitor data in Fairbanks from 1986 to 1995 shows that while median concentrations have declined steadily, unusual combinations of weather and emissions have resulted in elevated ambient CO concentrations well above the 8-hour standard of 9 ppm. Specifically, a Fairbanks monitor recorded average 8-hour ambient concentrations at 16 ppm in 1988, around 9 ppm from 1990 to 1992, and then a steady increase in CO ambient concentrations at 12, 14 and 16 ppm during some extreme cases in 1993, 1994 and 1995, respectively.[21]

Nationally, significant progress has been made over the last decade to reduce CO emissions and ambient CO concentrations. Total CO emissions from all sources have decreased 16 percent from 1989 to 1998, and ambient CO concentrations decreased by 39 percent. During that time, while the mobile source CO contribution of the inventory remained steady at about 77 percent, the highway portion decreased from 62 percent of total CO emissions to 56 percent while the nonroad portion increased from 17 percent to 22 percent.[22] Over the next decade, we would expect there to be a minor decreasing trend from the highway segment due primarily to the more stringent standards for certain light-duty trucks (LDT2s).[23] CO standards for passenger cars and other light-duty trucks and heavy-duty vehicles did not change as a result of other recent rulemakings. As described in Section 1.5, below, the engines subject to this rule currently account for about 7 percent of the mobile source CO inventory; this is expected to increase to 10 percent by 2020 without the emission controls proposed in this action.

The state of Alaska recently submitted draft CO attainment SIPs to the Agency for the Fairbanks CO nonattainment area. Fairbanks is located in a mountain valley with a much higher potential for air stagnation than cities within the contiguous United States. Nocturnal inversions that give rise to elevated CO concentrations can persist 24-hours a day due to the low solar elevation, particularly in December and January. These inversions typically last from 2 to 4 days (Bradley et al., 1992), and thus inversions may continue during hours of maximum CO emissions from mobile sources. Despite the fact that snowmobiles are largely banned in CO nonattainment areas by the state, the state estimated that snowmobiles contributed 0.3 tons/day in 1995 to Fairbanks' CO nonattainment area or 1.2 percent of a total inventory of 23.3 tons per day in 2001.[24] While Fairbanks has made significant progress in reducing ambient CO concentrations, existing climate conditions make achieving and maintaining attainment challenging. Fairbanks failed to attain the CO NAAQS by the applicable deadline of December 21, 2000, and EPA approved a one-year extension in May of 2001.[25]

In addition to the health effects that can result from exposure to carbon monoxide, this pollutant also can contribute to ground level ozone formation.[26] Recent studies in atmospheric chemistry in urban environments suggest CO can react with hydrogen-containing radicals, leaving fewer of these to combine with non-methane hydrocarbons and thus leading to increased levels of ozone. Few analyses have been performed that estimate these effects, but a study of an ozone episode in Atlanta, GA in 1988 found that CO accounted for about 17.5 percent of the ozone formed (compared to 82.5 percent for volatile organic compounds). While different cities may have different results, the effects of CO emissions on ground level ozone are not insignificant. The engines that are the subject of the proposed standards are contributors to these effects in urban areas, particularly because their per engine emissions are so high. For example, CO emissions from a off-highway motorcycle are high relative to a passenger car, (32 g/mi compared to 4.2 g/mi).

1.3 Particulate Matter

1.3.1 General Background

Particulate pollution is a problem affecting urban and non-urban localities in all regions of the United States. Nonroad engines and vehicles that would be subject to the proposed standards contribute to ambient particulate matter (PM) levels in two ways. First, they contribute through direct emissions of particulate matter. Second, they contribute to indirect formation of PM through their emissions of organic carbon, especially HC. Organic carbon accounts for between 27 and 36 percent of fine particle mass depending on the area of the country.

Particulate matter represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. All particles equal to and less than 10 microns are called PM_{10}. Fine particles can be generally defined as those particles with an aerodynamic diameter of 2.5 microns or less (also known as $PM_{2.5}$), and coarse fraction particles are those particles with an aerodynamic diameter greater than 2.5 microns, but equal to or less than a nominal 10 microns.

Manmade emissions that contribute to airborne particulate matter result principally from combustion sources (stationary and mobile sources) and fugitive emissions from industrial processes and non-industrial processes (such as roadway dust from paved and unpaved roads, wind erosion from cropland, construction, etc.). Human-generated sources of particles include a variety of stationary sources (including power generating plants, industrial operations, manufacturing plants, waste disposal) and mobile sources (light- and heavy-duty on-road vehicles, and off-highway vehicles such as construction, farming, industrial, locomotives, marine vessels and other sources). Natural sources also contribute to particulate matter in the atmosphere and include sources such as wind erosion of geological material, sea spray, volcanic emissions, biogenic emanation (e.g., pollen from plants, fungal spores), and wild fires.

The chemical and physical properties of PM vary greatly with time, region, meteorology, and source category. Particles may be emitted directly to the atmosphere (primary particles) or may be formed by transformations of gaseous emissions of sulfur dioxide, nitrogen oxides or volatile organic compounds (secondary particles). Secondary PM is dominated by sulfate in the eastern U.S. and nitrate in the western U.S.[27] The vast majority (>90 percent) of the direct mobile source PM emissions and their secondary formation products are in the fine PM size range. Mobile sources can reasonably be estimated to contribute to ambient secondary nitrate and sulfate PM in proportion to their contribution to total NOx and SOx emissions.

Table 1.3-1: Percent Contribution to $PM_{2.5}$ by Component, 1998

	East	West
Sulfate	56	33
Elemental Carbon	5	6
Organic Carbon	27	36
Nitrate	5	8
Crustal Material	7	17

Source: National Air Quality and Emissions Trends Report, 1998, March, 2000, at 28. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

1.3.2 Health and Welfare Effects of PM

Particulate matter can adversely affect human health and welfare. Discussions of the health and welfare effects associated with ambient PM can be found in the Air Quality Criteria for Particulate Matter.[28]

Key EPA findings regarding the health risks posed by ambient PM are summarized as follows:

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

b. 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.

c. Published studies have found statistical associations between PM and several key health effects, including 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.

d. 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, we have concluded the following with respect to sensitive populations:

    1. 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.

    2. 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.

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

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

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

e. There are fundamental physical and chemical differences between fine and coarse fraction particles. The fine fraction contains acid aerosols, sulfates, nitrates, transition metals, diesel exhaust particles, and ultra fine particles; the coarse fraction typically contains high mineral concentrations, silica and resuspended dust. It is reasonable to expect that differences may exist in both the nature of potential effects elicited by coarse and fine PM and the relative concentrations required to produce such effects. Both fine and coarse particles can accumulate in the respiratory system. Exposure to coarse fraction particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles are closely associated with health effects such as premature death or hospital admissions, and for cardiopulmonary diseases.

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. Particles also contribute to soiling and materials damage. Components of particulate matter (e.g., sulfuric or nitric acid) also contribute to acid deposition, nitrification of surface soils and water eutrophication of surface water.

1.3.3 PM Nonattainment

The NAAQS for PM_{10} was established in 1987. According to these standards, the short term (24-hour) standard of 150 $\mu g/m^3$ is not to be exceeded more than once per year on average over three years. The long-term standard specifies an expected annual arithmetic mean not to exceed 50 $\mu g/m^3$ over three years.

The most recent PM_{10} monitoring data indicate that 14 designated PM_{10} nonattainment areas with a projected population of 23 million violated the PM_{10} NAAQS in the period 1997-1999. Table 1.3-2 lists the 14 areas, and also indicates the PM_{10} nonattainment classification, and 1999 projected population for each PM_{10} nonattainment area. The projected population in 1999 was based on 1990 population figures which were then increased by the amount of population growth in the county from 1990 to 1999.

Table 1.3-2: PM_{10} Nonattainment Areas Violating the PM_{10} NAAQS in 1997- 1999

Nonattainment Area or County	1999 Population (projected, in millions)
Anthony, NM (Moderate)[B]	0.003
Clark Co [Las Vegas], NV (Serious)	1.200
Coachella Valley, CA (Serious)	0.239
El Paso Co, TX (Moderate) [A]	0.611
Hayden/Miami, AZ (Moderate)	0.004
Imperial Valley, CA (Moderate)	0.122
Los Angeles South Coast Air Basin, CA (Serious)	14.352
Nogales, AZ (Moderate)	0.025
Owens Valley, CA (Serious)	0.018
Phoenix, AZ (Serious)	2.977
San Joaquin Valley, CA (Serious)	3.214
Searles Valley, CA (Moderate)	0.029
Wallula, WA (Moderate)[B]	0.052
Washoe Co [Reno], NV (Moderate)	0.320
Total Areas: 14	23.167

[A] EPA has determined that continuing PM_{10} nonattainment in El Paso, TX is attributable to transport under section 179(B).

[B] The violation in this area has been determined to be attributable to natural events under section 188(f) of the Act.

In addition to the 14 PM_{10} nonattainment areas that are currently violating the PM_{10} NAAQS listed in Table 1.3-2, there are 25 unclassifiable areas that have recently recorded ambient concentrations of PM_{10} above the PM_{10} NAAQS. EPA adopted a policy in 1996 that allows areas with PM_{10} exceedances that are attributable to natural events to retain their designation as unclassifiable if the State is taking all reasonable measures to safeguard public health regardless of the sources of PM_{10} emissions. Areas that remain unclassifiable areas are not required under the Clean Air Act to submit attainment plans, but we work with each of these areas to understand the nature of the PM_{10} problem and to determine what best can be done to reduce it. With respect to the monitored violations reported in 1997-99 in the 25 areas designated as unclassifiable, we have not yet excluded the possibility that factors such as a one-time monitoring upset or natural events, which ordinarily would not result in an area being designated as nonattainment for PM_{10}, may be responsible for the problem. Emission reductions from today's action will assist these currently unclassifiable areas to achieve ambient PM_{10} concentrations below the current PM_{10} NAAQS.

Current 1999 $PM_{2.5}$ monitored values, which cover about a third of the nation's counties, indicate that at least 40 million people live in areas where long-term ambient fine particulate matter levels are at or above 16 $\mu g/m^3$ (37 percent of the population in the areas with monitors).[29] This 16 $\mu g/m^3$ threshold is the low end of the range of long term average $PM_{2.5}$ concentrations in cities where statistically significant associations were found with serious health effects, including premature mortality.[30] To estimate the number of people who live in areas where long-term ambient fine particulate matter levels are at or above 16 $\mu g/m^3$ but for which there are no monitors, we can use modeling. According to our national modeled predictions, there were a total of 76 million people (1996 population) living in areas with modeled annual average $PM_{2.5}$ concentrations at or above 16 $\mu g/m^3$ (29 percent of the population).[31]

To estimate future $PM_{2.5}$ levels, we refer to the modeling performed in conjunction with the final rule for our most recent heavy-duty highway engine and fuel standards using EPA's Regulatory Model System for Aerosols and Deposition (REMSAD).[32] The most appropriate method of making these projections relies on the model to predict changes between current and future states. Thus, we have estimated future conditions only for the areas with current $PM_{2.5}$ monitored data (which covers about a third of the nation's counties). For these counties, REMSAD predicts the current level of 37 percent of the population living in areas where fine PM levels are at or above 16 μg/m3 to increase to 49 percent in 2030.[33]

Emissions of HCs from snowmobiles contribute to secondary formation of fine particulate matter which can cause a variety of adverse health and welfare effects, including regional haze discussed in Section 1.6 below. For 20 counties across nine states, snowmobile trails are found within or near counties that registered ambient PM 2.5 concentrations at or above 15 μg/m3, the level of the revised national ambient air quality standard for fine particles.[34] These counties are listed in Table 1.3.-3. To obtain the information about snowmobile trails contained in Table 1.3.-3, we consulted snowmobile trail maps that were supplied by various states.[35]

Table 1.3-3
Counties with Annual $PM_{2.5}$ Levels Above 16 μg/m3 and Snowmobile Trails

State	$PM_{2.5}$ Exceedance County	County with Snowmobile Trails	Proximity to $PM_{2.5}$ Exceedance County
Ohio	Mahoning	Mahoning	—
	Trumbull	Trumbull	—
	Summit	Summit	—
	Montgomery	Montgomery	—
	Portage	Portage	—
	Franklin	Delaware	Borders North
	Marshall/Ohio (WV)	Belmont	Borders West
Montana	Lincoln	Lincoln	—
California	Tulane	Tulane	—
	Butte	Butte	—
	Fresno	Fresno	—
	Kern	Kern	—
Minnesota	Washington	Washington	—
	Wright	Wright	—
Wisconsin	Waukesha	Waukesha	—
	Milwaukee	Milwaukee	—
Oregon	Jackson	Douglas	Borders NNE
	Klamath	Douglas	Borders North
Pennsylvania	Washington	Layette	Borders East
		Somerset	—
Illinois	Rock Island	Rock Island	—
		Henry	Borders East
Iowa	Rock Island (IL)	Dubuque	Borders West

1.4 Gaseous Air Toxics

In addition to the human health and welfare impacts described above, emissions from the engines covered by this proposal also contain several other substances that are known or suspected human or animal carcinogens, or have serious noncancer health effects. These include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. The health effects of these air toxics are described in more detail in Chapter 1 of the Draft Regulatory Support Document for this rule. Additional information can also be found in the Technical Support Document four our final Mobile Source Air Toxics rule.[36]

1.4.1 Benzene

Benzene is an aromatic hydrocarbon which is present as a gas in both exhaust and evaporative emissions from motor vehicles. Benzene in the exhaust, expressed as a percentage of total organic gases (TOG), varies depending on control technology (e.g., type of catalyst) and the levels of benzene and other aromatics in the fuel, but is generally about three to five percent. The benzene fraction of evaporative emissions depends on control technology and fuel composition and characteristics (e.g., benzene level and the evaporation rate), and is generally about one percent.[37]

EPA has recently reconfirmed that benzene is a known human carcinogen by all routes of exposure.[38] Respiration is the major source of human exposure. Long-term respiratory exposure to high levels of ambient benzene concentrations has been shown to cause cancer of the tissues that form white blood cells. Among these are acute nonlymphocytic leukemia,[39] chronic lymphocytic leukemia and possibly multiple myeloma (primary malignant tumors in the bone marrow), although the evidence for the latter has decreased with more recent studies.[40,41] Leukemias, lymphomas, and other tumor types have been observed in experimental animals exposed to benzene by inhalation or oral administration. Exposure to benzene and/or its metabolites has also been linked with genetic changes in humans and animals[42] and increased proliferation of mouse bone marrow cells.[43] The occurrence of certain chromosomal changes in individuals with known exposure to benzene may serve as a marker for those at risk for contracting leukemia.[44]

A number of adverse noncancer health effects, blood disorders such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene.[45] People with long-term exposure to benzene may experience harmful effects on the blood-forming tissues, especially the bone marrow. These effects can disrupt normal blood production and cause a decrease in important blood components, such as red blood cells and blood platelets, leading to anemia (a reduction in the number of red blood cells), leukopenia (a reduction in the number of white blood cells), or thrombocytopenia (a reduction in the number of blood platelets, thus reducing the ability for blood to clot). Chronic inhalation exposure to benzene in humans and animals results in pancytopenia,[46] a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[47,48] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,[49] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[50] [51] The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood.[52]

1.4.2 1,3-Butadiene

1,3-Butadiene is formed in vehicle exhaust by the incomplete combustion of fuel. It is not present in vehicle evaporative emissions, because it is not present in any appreciable amount in fuel. 1,3-Butadiene accounts for 0.4 to 1.0 percent of total organic gas exhaust, depending on control technology and fuel composition.[53]

1,3-Butadiene was classified by EPA as a Group B2 (probable human) carcinogen in 1985.[54] This classification was based on evidence from two species of rodents and epidemiologic data. In the EPA1998 draft Health Risk Assessment of 1,3-Butadiene, that was reviewed by the Science Advisory Board (SAB), the EPA proposed that 1,3-butadiene is a known human carcinogen based on human epidemiologic, laboratory animal data, and supporting data such as the genotoxicity of 1,3-butadiene metabolites.[55] The Environmental Health Committee of EPA's Scientific Advisory Board (SAB) reviewed the draft document in August 1998 and recommended that 1,3-butadiene be classified as a probable human carcinogen, stating that designation of 1,3-butadiene as a known human carcinogen should be based on observational studies in humans, without regard to mechanistic or other information.[56] In applying the 1996 proposed Guidelines for Carcinogen Risk Assessment, the Agency relies on both observational studies in humans as well as experimental evidence demonstrating causality, and therefore the designation of 1,3-butadiene as a known human carcinogen remains applicable.[57] The Agency has revised the draft Health Risk Assessment of 1,3-Butadiene based on the SAB and public comments. The draft Health Risk Assessment of 1,3-Butadiene will undergo the Agency consensus review, during which time additional changes may be made prior to its public release and placement on the Integrated Risk Information System (IRIS).

1,3-Butadiene also causes a variety of noncancer reproductive and developmental effects in mice and rats (no human data) when exposed to long-term, low doses of butadiene.[58] The most sensitive effect was reduced litter size at birth and at weaning. These effects were observed in studies in which male mice exposed to 1,3-butadiene were mated with unexposed females. In humans, such an effect might manifest itself as an increased risk of spontaneous abortions, miscarriages, still births, or very early deaths. Long-term exposures to 1,3-butadiene should be kept below its reference concentration of 4.0 microgram/m^3 to avoid appreciable risks of these reproductive and developmental effects.[59] EPA has developed a draft chronic, subchronic, and acute RfC values for 1,3-butadiene exposure as part of the draft risk characterization mentioned above. The RfC values will be reported on IRIS.

1.4.3 Formaldehyde

Formaldehyde is the most prevalent aldehyde in vehicle exhaust. It is formed from incomplete combustion of both gasoline and diesel fuel and accounts for one to four percent of total organic gaseous emissions, depending on control technology and fuel composition. It is not found in evaporative emissions.

Formaldehyde exhibits extremely complex atmospheric behavior.[60] It is formed by the atmospheric oxidation of virtually all organic species, including biogenic (produced by a living organism) hydrocarbons. Mobile sources contribute both primary formaldehyde (emitted directly from motor vehicles) and secondary formaldehyde (formed from photooxidation of other VOCs emitted from vehicles).

EPA has classified formaldehyde as a probable human carcinogen based on limited evidence for carcinogenicity in humans and sufficient evidence of carcinogenicity in animal studies, rats, mice, hamsters, and monkeys.[61] Epidemiological studies in occupationally exposed workers suggest that long-term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity (generally the area at the back of the mouth near the nose), nasal cavity, and sinus. Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to formaldehyde causes an increase in the incidence of squamous (epithelial) cell carcinomas (tumors) of the nasal cavity. The distribution of nasal tumors in rats suggests that not only regional exposure but also local tissue susceptibility may be important for the distribution of formaldehyde-induced tumors.[62] Research has demonstrated that formaldehyde produces mutagenic activity in cell cultures.[63]

Formaldehyde exposure also causes a range of noncancer health effects. At low concentrations (0.05-2.0 ppm), irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes is the principal effect observed in humans. At exposure to 1-11 ppm, other human upper respiratory effects associated with acute formaldehyde exposure include a dry or sore throat, and a tingling sensation of the nose. Sensitive individuals may experience these effects at lower concentrations. Forty percent of formaldehyde-producing factory workers reported nasal symptoms such as rhinitis (inflammation of the nasal membrane), nasal obstruction, and nasal discharge following chronic exposure.[64] In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm.[65] Formaldehyde exposure may also cause bronchial asthma-like symptoms in non-asthmatics.[66] [67]

Immune stimulation may occur following formaldehyde exposure, although conclusive evidence is not available. Also, little is known about formaldehyde's effect on the central nervous system. Several animal inhalation studies have been conducted to assess the developmental toxicity of formaldehyde. The only exposure-related effect noted in these studies was decreased maternal body weight gain at the high-exposure level. No adverse effects on reproductive outcome of the fetuses that could be attributed to treatment were noted. An inhalation reference concentration (RfC), below which long-term exposures would not pose appreciable noncancer health risks, is not available for formaldehyde at this time.

1.4.4 Acetaldehyde

Acetaldehyde is a saturated aldehyde that is found in vehicle exhaust and is formed as a result of incomplete combustion of both gasoline and diesel fuel. It is not a component of evaporative emissions. Acetaldehyde comprises 0.4 to 1.0 percent of total organic gas exhaust, depending on control technology and fuel composition.[68]

The atmospheric chemistry of acetaldehyde is similar in many respects to that of formaldehyde.[69] Like formaldehyde, it is produced and destroyed by atmospheric chemical transformation. Mobile sources contribute to ambient acetaldehyde levels both by their primary emissions and by secondary formation resulting from their VOC emissions. Acetaldehyde emissions are classified as a probable human carcinogen. Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to acetaldehyde causes an increase in the incidence of nasal squamous cell carcinomas (epithelial tissue) and adenocarcinomas (glandular tissue).[70] [71]

Noncancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes.[72] [73] [74] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract. At high concentrations, irritation and pulmonary effects can occur, which could facilitate the uptake of other contaminants. Little research exists that addresses the effects of inhalation of acetaldehyde on reproductive and developmental effects. The *in vitro* and *in vivo* studies provide evidence to suggest that acetaldehyde may be the causative factor in birth defects observed in fetal alcohol syndrome, though evidence is very limited linking these effects to inhalation exposure. Long-term exposures should be kept below the reference concentration of 9 $\mu g/m^3$ to avoid appreciable risk of these noncancer health effects.[75]

1.4.5 Acrolein

Acrolein is extremely toxic to humans from the inhalation route of exposure, with acute exposure resulting in upper respiratory tract irritation and congestion. Although no information is available on its carcinogenic effects in humans, based on laboratory animal data, EPA considers acrolein a possible human carcinogen.[76]

1.5 Inventory Contributions

1.5.1 Inventory Contribution

The contribution of emissions from the nonroad engines and vehicles that would be subject to the proposed standards to the national inventories of pollutants that are associated with the health and public welfare effects described in this chapter are considerable. To estimate nonroad engine and vehicle emission contributions, we used the latest version of our NONROAD emissions model. This model computes nationwide, state, and county emission levels for a wide variety of nonroad engines, and uses information on emission rates, operating data, and population to determine annual emission levels of various pollutants. A more detailed description of the model and our estimation methodology can be found in the Chapter 6 of this document.

Baseline emission inventory estimates for the year 2000 for the categories of engines and vehicles covered by this proposal are summarized in Table 1.5-1. This table show the relative contributions of the different mobile-source categories to the overall national mobile-source inventory. Of the total emissions from mobile sources, the categories of engines and vehicles covered by this proposal contribute about 13 percent, 3 percent, 6 percent, and 1 percent of HC, NOx, CO, and PM emissions, respectively, in the year 2000. The results for large SI engines indicate they contribute approximately 3 percent to HC, NOx, and CO emissions from mobile sources. The results for land-based recreational engines reflect the impact of the significantly different emissions characteristics of two-stroke engines. These engines are estimated to contribute 10 percent of HC emissions and 3 percent of CO from mobile sources. Recreational CI marine contribute less than 1 percent to NOx mobile source inventories. When only nonroad emissions are considered, the engines and vehicles that would be subject to the proposed standards would account for a larger share.

Our draft emission projections for 2020 for the nonroad engines and vehicles subject to this proposal show that emissions from these categories are expected to increase over time if left uncontrolled. The projections for 2020 are summarized in Table 1.5-2 and indicate that the categories of engines and vehicles covered by this proposal are expected to contribute 33 percent, 9 percent, 9 percent, and 2 percent of HC, NOx, CO, and PM emissions in the year 2020. Population growth and the effects of other regulatory control programs are factored into these projections. The relative importance of uncontrolled nonroad engines is higher than the projections for 2000 because there are already emission control programs in place for the other categories of mobile sources which are expected to reduce their emission levels. The effectiveness of all control programs is offset by the anticipated growth in engine populations.

Table 1.5-1
Modeled Annual Emission Levels for Mobile-Source Categories in 2000 (thousand short tons)

Category	NOx		HC		CO		PM	
	tons	percent of mobile source	tons	percent of mobile source	tons	percent of mobile source	tons	percent of mobile source
Total for engines subject to proposed standards	**343**	**3%**	**985**	**13%**	**4,870**	**6%**	**8.3**	**1.2%**
Nonroad Large SI > 19 kW	306	2%	247	3%	2,294	3%	1.6	0.2%
Recreational SI	13.0	0.10%	737	10%	2,572	3%	5.7	0.9%
Recreation Marine CI	24	0.2%	1	0%	4	0%	1	0%
Highway Motorcycles	8	0%	84	1%	329	0%	0.4	0.1%
Marine SI Evap	0	0.0%	89	1%	0	0%	0	0%
Marine SI Exhaust	32	0.2%	708	9%	2,144	3%	38	5%
Nonroad SI < 19 kW	106	0.8%	1,460	19%	18,359	24%	50	7%
Nonroad CI	2,625	20%	316	4%	1,217	2%	253	36%
Commercial Marine CI	977	7%	30	0%	129	0.2%	41	6%
Locomotive	1,192	9%	47	1%	119	0.2%	30	4%
Total Nonroad	5,275	39%	3,635	48%	26,838	35%	420	60%
Total Highway	7,981	59%	3,811	50%	49,811	64%	240	36%
Aircraft	178	1%	183	2%	1,017	1%	39	6%
Total Mobile Sources	13,434	100%	7,629	100%	77,666	100%	660	100%
Total Man-Made Sources	24,538	--	18,575	--	99,745	--	3,095	--
Mobile Source percent of Total Man-Made Sources	55%	--	41%	--	78%	--	23%	–

Table 1.5-2
Modeled Annual Emission Levels for Mobile-Source Categories in 2020 (thousand short tons)

Category	NOx		HC		CO		PM	
	tons	percent of mobile source	tons	percent of mobile source	tons	percent of mobile source	tons	percent of mobile source
Total for engines subject to proposed standards	**552**	**9%**	**2,055**	**33%**	**8,404**	**9%**	**11.9**	**1.9%**
Nonroad Large SI >19 kW	486	8%	348	6%	2,991	3%	2.4	0.4%
Recreational SI	27.0	0.40%	1,706	28%	5,407	3%	7.5	1.2%
Recreation Marine CI	39	0.6%	1	0%	6	0%	2	0%
Highway Motorcycles	14	0%	144	2%	569	1%	0.8	0.1%
Marine SI Evap	0	0.0%	102	1%	0	0%	0	0%
Marine SI Exhaust	58	0.9%	284	5%	1,985	2%	28	4%
Nonroad SI < 19 kW	106	1.7%	986	16%	27,352	31%	77	12%
Nonroad CI	1,791	29%	142	2%	1,462	2%	261	41%
Commercial Marine CI	819	13%	35	1%	160	0.2%	46	7%
Locomotive	611	10%	35	1%	119	0.1%	21	3%
Total Nonroad	3,937	63%	3,639	59%	39,482	44%	444	70%
Total Highway	2,050	33%	2,278	37%	48,903	54%	145	23%
Aircraft	232	4%	238	4%	1,387	2%	43	7%
Total Mobile Sources	6,219	100%	6,155	100%	89,772	100%	632	100%
Total Man-Made Sources	16,195	--	16,215	--	113,440	--	3,016	--
Mobile Source percent of Total Man-Made Sources	38%	--	38%	--	79%	--	21%	–

1.5.2 Inventory Impacts on a Per Vehicle Basis

In addition to the general inventory contributions described above, the engines that would be subject to the proposed standards are more potent polluters than their highway counterparts in that they have much higher emissions on a per vehicle basis. This is illustrated in Table 1.5-3, which equates the emissions produced in one hour of operation from the different categories of equipment covered by the proposal to the equivalent miles of operation it would take for a car produced today to emit the same amount of emissions.

Table 1.5-3: Per-Vehicle Emissions Comparison

Equipment Category	Emission Comparison	Miles a Current Passenger Car Would Need to Drive to Emit the Same Amount of Pollution as the Equipment Category Emits in One Hour of Operation
Recreational Marine CI	HC+NOx	2,400
Large SI	HC+NOx	1,470
Snowmobiles	HC	24,300
Snowmobiles	CO	1,520
2-Stroke ATVs & off-road motorcycles	HC	14,850
4-Stroke ATVs & off-road motorcycles	HC	590

The per engine emissions are important because they mean that operators of these engines and vehicles, as well as those who work in their vicinity, are exposed to high levels of emissions, many of which are air toxics. These effects are of particular concern for people who operate forklifts in enclosed areas and for snowmobile riders. These effects are described in more detail in the next section.

1.6 Other Adverse Public Health and Welfare Effects Associated with Nonroad Engines and Vehicles

The previous section describes national-scale adverse public health effects associated with the nonroad engines and vehicles covered by this proposal. This section describes significant adverse health and welfare effects arising from the usage patterns of snowmobiles, large SI engines, and gasoline marine engines on the regional and local scale. Studies suggest that emissions from these engines can be concentrated in specific areas, leading to elevated ambient concentrations of particular pollutants and associated elevated personal exposures to operators and by-standers. Recreational vehicles, and particularly snowmobiles, are typically operating in rural areas such as national parks and wilderness areas, and emissions from these vehicles contribute to ambient particulate matter which is a leading component of visibility impairment. This section describes these effects. We end this section by describing two other environmental effects of nonroad emissions: acid deposition and water eutrophication and nitrification

1.6.1 Snowmobiles

In this section, we describe more localized human health and welfare effects associated with snowmobile emissions: visibility impairment and personal exposure to air toxics and CO. We describe the contribution of snowmobile HC emissions to secondary formation of fine particles, which are the leading component of visibility impairment and adverse health effects related to ambient PM2.5 concentrations greater than 16 μg/m3. We also discuss personal exposure to CO emissions and air toxics. Gaseous air toxics are components of hydrocarbons, and CO personal exposure measurements suggest that snowmobile riders and bystanders are exposed to unhealthy levels of gaseous air toxics (e.g., benzene) and CO.

1.6.1.1 Nonroad Engines and Regional Haze

The Clean Air Act established special goals for improving visibility in many national parks, wilderness areas, and international parks. In the 1977 amendments to the Clean Air Act, Congress set as a national goal for visibility the "prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution" (CAA section 169A(a)(1)). The Amendments called for EPA to issue regulations requiring States to develop implementation plans that assure "reasonable progress" toward meeting the national goal (CAA Section 169A(a)(4)). EPA issued regulations in 1980 to address visibility problems that are "reasonably attributable" to a single source or small group of sources, but deferred action on regulations related to regional haze, a type of visibility impairment that is caused by the emission of air pollutants by numerous emission sources located across a broad geographic region. At that time, EPA acknowledged that the regulations were only the first phase for addressing visibility impairment. Regulations dealing with regional haze were deferred until improved techniques were developed for monitoring, for air quality modeling, and for understanding the specific pollutants contributing to regional haze.

In the 1990 Clean Air Act amendments, Congress provided additional emphasis on regional haze issues (see CAA section 169B). In 1999 EPA finalized a rule that calls for States to establish goals and emission reduction strategies for improving visibility in all 156 mandatory Class I national parks and wilderness areas. In that rule, EPA also encouraged the States to work together in developing and implementing their air quality plans. The regional haze program is designed to improve visibility and air quality in our most treasured natural areas. At the same time, control strategies designed to improve visibility in the national parks and wilderness areas will improve visibility over broad geographic areas.

Regional haze is caused by the emission from numerous sources located over a wide geographic area. Such sources include, but are not limited to, major and minor stationary sources, mobile sources, and area sources. Visibility impairment is caused by pollutants (mostly fine particles and precursor gases) directly emitted to the atmosphere by a number of activities (such as electric power generation, various industry and manufacturing processes, truck and auto emissions, construction activities, etc.). These gases and particles scatter and absorb light, removing it from the sight path and creating a hazy condition.

Some fine particles are formed when gases emitted to the air form particles as they are carried downwind (examples include sulfates, formed from sulfur dioxide, and nitrates, formed from nitrogen oxides). These activities generally span broad geographic areas and fine particles can be transported great distances, sometimes hundreds or thousands of miles. Consequently, visibility impairment is a national problem. Without the effects of pollution a natural visual range is approximately 140 miles in the West and 90 miles in the East. However, fine particles have significantly reduced the range that people can see and in the West the current range is 33-90 miles and in the East it is only 14-24 miles.

Because of evidence that fine particles are frequently transported hundreds of miles, all 50 states, including those that do not have Class I areas, will have to participate in planning, analysis and, in many cases, emission control programs under the regional haze regulations. Even though a given State may not have any Class I areas, pollution that occurs in that State may contribute to impairment in Class I areas elsewhere. The rule encourages states to work together to determine whether or how much emissions from sources in a given state affect visibility in a downwind Class I area.

The regional haze program calls for states to establish goals for improving visibility in national parks and wilderness areas to improve visibility on the haziest 20 percent of days and to ensure that no degradation occurs on the clearest 20 percent of days. The rule requires states to develop long-term strategies including enforceable measures designed to meet reasonable progress goals. Under the regional haze program, States can take credit for improvements in air quality achieved as a result of other Clean Air Act programs, including national mobile-source programs.

Nonroad engines (including construction equipment, farm tractors, boats, planes, locomotives, recreational vehicles, and marine engines) contribute significantly to regional haze. This is because there are nonroad engines in all of the states, and their emissions contain precursors of fine PM and organic carbon that are transported and contribute to the formation of regional haze throughout the country and in Class I areas specifically. As illustrated in Table 1.6-1, nonroad engines are expected to contribute 15 percent of national VOC emissions, 23 percent of national NOx emissions, 6 percent of national SOx emissions, and 14 percent of national PM10 emissions. Snowmobiles alone are estimated to emit 208,926 tons of total hydrocarbons (THC), 1,461 tons of NOx, 2,145 tons of SOx, and 5,082 tons of PM in 2007.

Table 1.6-1
National Emissions of Various Pollutants - 2007
(Thousands Short Tons)

Source	VOC		NOx		SOx		PM_{10}	
	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
Heavy-Duty Highway	413	3%	2,969	14%	24	0	115	4%
Light-Duty Highway	2,596	18%	2,948	14%	24	0	82	3%
Nonroad	2,115	15%	4,710	23%	1,027	6%	407	14%
Electric Gen.	35	0	4,254	21%	10,780	63%	328	12%
Point	1,639	11%	3,147	15%	3,796	22%	1,007	36 %
Area	7,466	52%	2,487	12%	1,368	8%	874	31%
TOTAL	14,265		20,516		17,019		2,814	

1.6.1.2 Snowmobiles and Visibility Impairment

As noted above, EPA issued regulations in 1980 to address Class I area visibility impairment that is “reasonably attributable” to a single source or small group of sources. In 40 CFR Part 51.301 of the visibility regulations, visibility impairment is defined as “any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.” States are required to develop implementation plans that include long-term strategies for improving visibility in each class I area. The long-term strategies under the 1980 regulations should consist of measures to reduce impacts from local sources and groups of sources that contribute to poor air quality days in the class I area. Types of impairment covered by these regulations includes layered hazes and visible plumes. While these kinds of visibility impairment can be caused by the same pollutants and processes as those that cause regional haze, they generally are attributed to a smaller number of sources located across a smaller area. The Clean Air Act and associated regulations call for protection of visibility impairment in class I areas from localized impacts as well as broader impacts associated with regional haze.

Visibility and particle monitoring data are available for 8 Class I areas where snowmobiles are commonly used. These are: Acadia, Boundary Waters, Denali, Mount Rainier, Rocky Mountain, Sequoia and Kings Canyon, Voyageurs, and Yellowstone.[77] Visibility and fine particle data for these parks are set out in Table 1.6-2. This table shows the number of monitored days in the winter that fell within the 20-percent haziest days for each of these eight parks.

Monitors collect data two days a week for a total of about 104 days of monitored values. Thus, for a particular site, a maximum of 21 worst possible days of these 104 days with monitored values constitute the set of 20-percent haziest days during a year which are tracked as the primary focus of regulatory efforts.[78] With the exception of Denali in Alaska, we defined the snowmobile season as January 1 through March 15 and December 15 through December 31 of the same calendar year, consistent with the methodology used in the Regional Haze Rule, which is calendar-year based. For Denali in Alaska, the snowmobile season is October 1 to April 30.

Table 1.6-2
Winter Days That Fall Within the 20 Percent Haziest Days
At National Parks Used by Snowmobiles

NPS Unit	State(s)	Number of Sampled Wintertime Days Within 20 Percent Haziest Days (maximum of 21 sampled days)			
		1996	1997	1998	1999
Acadia NP	ME	4	4	2	1
Denali NP and Preserve	AK	10	10	12	9
Mount Rainier NP	WA	1	3	1	1
Rocky Mountain NP	CO	2	1	2	1
Sequoia and Kings Canyon NP	CA	4	9	1	8
Voyageurs NP (1989-1992)	MN	1989 3	1990 4	1991 6	1992 8
-- Boundary Waters USFS Wilderness Area (close to Voyaguers with recent data)	MN	2	5	1	5
Yellowstone NP	ID, MT, WY	0	2	0	0

Source: Letter from Debra C. Miller, Data Analyst, National Park Service, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01, Document Number. II-B-28.

The information presented in Table 1.6-2 shows that visibility data supports a conclusion that there are at least eight Class I Areas (7 in National Parks and one in a Wilderness Area) frequented by snowmobiles with one or more wintertime days within the 20-percent haziest days of the year. For example, Rocky Mountain National Park in Colorado was frequented by about 27,000 snowmobiles during the 1998-1999 winter. Of the monitored days characterized as within the 20-percent haziest monitored days, two (2) of those days occurred during the wintertime when snowmobile emissions such as hydrocarbons contributed to visibility impairment. According to the National Park Service, "[s]ignificant differences in haziness occur at all eight sites between the averages of the clearest and haziest days. Differences in mean standard visual range on the clearest and haziest days fall in the approximate range of 115-170 km."[79]

Ambient concentrations of fine particles are the primary pollutant responsible for visibility impairment. Five pollutants are largely responsible for the chemical composition of fine particles: sulfates, nitrates, organic carbon particles, elemental carbon, and crustal material. Hydrocarbon emissions from automobiles, trucks, snowmobiles, and other industrial processes are common sources of organic carbon. The organic carbon fraction of fine particles ranges from 47 percent in Western areas such as Denali National Park, to 28 percent in Rocky Mountain National Park, to 13 percent in Acadia National Park.[80]

The contribution of snowmobiles to elemental carbon and nitrates is small. Their contribution to sulfates is a function of fuel sulfur and is small and will decrease even more as the sulfur content of their fuel decreases due to our recently finalized fuel sulfur requirements. In the winter months, however, hydrocarbon emissions from snowmobiles can be significant, as indicated in Table 1.6-3, and these HC emissions can contribute significantly to the organic carbon fraction of fine particles which are largely responsible for visibility impairment. This is because they are typically powered by two-stroke engines that emit large amounts of hydrocarbons. In Yellowstone, a park with high snowmobile usage during the winter months, snowmobile hydrocarbon emissions can exceed 500 tons per year, as much as several large stationary sources. Other parks with less snowmobile traffic are less impacted by these hydrocarbon emissions.[81]

Table 1.6-3 shows modeled tons of four pollutants during the winter season in five Class I national parks for which we have estimates of snowmobile use. The national park areas outside of Denali in Alaska are open to snowmobile operation in accordance with special regulations (36 CFR Part 7). Denali National Park permits snowmobile operation by local rural residents engaged in subsistence uses (36 CFR Part 13). Emission calculations are based on an assumed 2 hours of use per snowmobile visit at 16 hp with the exception of Yellowstone where 4 hours of use at 16 hp was assumed. The emission factors used to estimate these emissions are identical to those used by the NONROAD model. Two-stroke snowmobile emission factors are: 111 g/hp-hr HC, 296 g/hp-hr CO, 0.86 g/hp-hr NOx, and 2.7 g/hp-hr PM. These emission factors are based on a number of engine tests performed by the International Snowmobile Manufacturers Association (ISMA) and the Southwest Research Institute (SwRI). These emission factors are still under review, and the emissions estimates may change pending the outcome of that review.

Table 1.6-3
Winter Season Snowmobile Emissions (tons; 1999 Winter Season)

NPS Unit	HC	CO	NOx	PM
Denali NP and Preserve	>9.8	>26.1	>0.08	>0.24
Grand Teton NP	13.7	36.6	0.1	0.3
Rocky Mountain NP	106.7	284.7	0.8	2.6
Voyageurs NP	138.5	369.4	1.1	3.4
Yellowstone NP	492.0	1,311.9	3.8	12.0

Source: Letter from Aaron J. Worstell, Environmental Engineer, National Park Service, Air Resources Division, to Drew Kodjak, August 21, 2001, particularly Table 1. Docket No. A-2000-01, Document No. II-G-178.

Inventory analysis performed by the National Park Service for Yellowstone National Park suggests that snowmobile emissions can be a significant source of total annual mobile source emissions for the park year round. Table 1.6-4 shows that in the 1998 winter season snowmobiles contributed 64 percent, 39 percent, and 30 percent of HC, CO, and PM emissions.[82] It should be noted that the snowmobile emission factors used to estimate these contributions are currently under review, and the snowmobile emissions may be revised down. However, when the emission factors used by EPA in its NONROAD model are used, the contribution of snowmobiles to total emissions in Yellowstone is still high: 59 percent, 33 percent, and 45 percent of HC, CO and PM emissions. The University of Denver used remote-sensing equipment to estimate snowmobile HC emissions at Yellowstone during the winter of 1998-1999, and estimated that snowmobiles contribute 77% of annual hydrocarbon emissions at the park.[83] The portion of wintertime emissions attributable to snowmobiles is even higher, since all snowmobile emissions occur during the winter months.

Table 1.6-4
1998 Annual HC Emissions (tpy), Yellowstone National Park

Source	HC		CO		NOx		PM	
Coaches	2.69	0%	24.29	1%	0.42	0%	0.01	0%
Autos	307.17	33%	2,242.12	54%	285.51	88%	12.20	60%
RVs	15.37	2%	269.61	6%	24.33	7%	0.90	4%
Snowmobiles	596.22	64%	1,636.44	39%	1.79	1%	6.07	30%
Buses	4.96	1%	18.00	0%	13.03	4%	1.07	5%
TOTAL	926.4		4190.46		325.08		20.25	

Source: National Park Service, February 2000. Air Quality Concerns Related to Snowmobile Usage in National Parks. Air Docket A-2000-01, Document No. II-A-44.

The information presented in this discussion indicates that snowmobiles are significant emitters of pollutants that are known to contribute to visibility impairment in some Class I areas. Annual and particularly wintertime hydrocarbon emissions from snowmobiles are high in the five parks considered in Table 1.6-4, with two parks having HC emissions nearly as high as Yellowstone (Rocky Mountain and Voyageurs). The proportion of snowmobile emissions to emissions from other sources affecting air quality in these parks is likely to be similar to that in Yellowstone.

1.6.1.3 Individual Air Toxics and CO Exposure

In addition to their contribution to ozone formation and CO concentrations generally, snowmobile emissions are of concern because of their potential impacts on riders and on park attendants, as well as other groups of people who are in contact with these vehicles for extended periods of time.

Snowmobile users can be exposed to high air toxic and CO emissions, both because they sit very close to the vehicle's exhaust port and because it is common for them to ride their vehicles on groomed trails where they travel fairly close behind other snowmobiles. Because of these riding patterns, snowmobilers breathe exhaust emissions from their own vehicle, the vehicle directly in front as well as those farther up the trail. This can lead to relatively high personal exposure levels of harmful pollutants. A study of snowmobile rider CO exposure conducted at Grand Teton National Park showed that a snowmobiler riding at distances of 25 to 125 feet behind another snowmobiler and traveling at speeds from 10 to 40 mph can be exposed to average CO levels ranging from 0.5 to 23 ppm, depending on speed and distance. The highest CO level measured in this study was 45 ppm, as compared to the current 1-hour NAAQS for CO of 35 ppm.[84] While exposure levels can be less if a snowmobile drives 15 feet off the centerline of the lead snowmobile, the exposure levels are still of concern. This study led to the development of an empirical model for predicting CO exposures from riding behind snowmobiles.

Hydrocarbon speciation for snowmobile emissions was performed for the State of Montana in a 1997 report.[85] Using the empirical model for CO from the Grand Teton exposure study with benzene emission rates from the State of Montana's emission study, benzene exposures for riders driving behind a single snowmobile were predicted to range from 1.2E+02 to 1.4E+03 μg/m3. Using the same model to predict exposures when riding at the end of a line of six snowmobiles spaced 25 feet apart yielded exposure predictions of 3.5E+03, 1.9E+03, 1.3E+03, and 1.2E+03 μg/m3 benzene. at 10, 20, 30, and 40 mph, respectively.

The cancer risk posed to those exposed to benzene emissions from snowmobiles must be viewed within the broader context of expected lifetime benzene exposure. Observed monitoring data and predicted modeled values demonstrate that a significant cancer risk already exists from ambient concentrations of benzene for a large portion of the US population. The Agency's 1996 National-Scale Air Toxics Assessment of personal exposure to ambient concentrations of air toxic compounds emitted by outside sources (e.g. cars and trucks, power plants) found that benzene was among the five air toxics appear to pose the greatest risk to people nationwide. This national assessment found that for approximately 50% of the US population in 1996, the inhalation cancer risks associated with benzene exceeded 10 in one million. Modeled predictions for ambient benzene from this assessment correlated well with observed monitored concentrations of benzene ambient concentrations.

Specifically, the draft National-Scale Assessment predicted nationwide annual average benzene exposures from outdoor sources to be 1.4 μg/m3.[86] In comparison, snowmobile riders and those directly exposed to snowmobile exhaust emissions had predicted benzene levels two to three orders of magnitude greater than the 1996 national average benzene concentrations.[87] These elevated levels are also known as air toxic "hot spots," which are of particular concern to the Agency. Thus, total annual average exposures to typical ambient benzene concentrations combined with elevated short-term exposures to benzene from snowmobiles may pose a significant risk of adverse public health effects to snowmobile riders and those exposed to exhaust benzene emissions from snowmobiles.

Since snowmobile riders often travel in large groups, the riders towards the back of the group are exposed to the accumulated exhaust of those riding ahead. These exposure levels can continue for hours at a time. An additional consideration is that the risk to health from CO exposure increases with altitude, especially for unacclimated individuals. Therefore, a park visitor who lives at sea level and then rides his or her snowmobile on trails at high-altitude is more susceptible to the effects of CO than local residents.

In addition to snowmobilers themselves, people who are active in proximity to the areas where snowmobilers congregate may also be exposed to high CO levels. An OSHA industrial hygiene survey reported a peak CO exposure of 268 ppm for a Yellowstone employee working at an entrance kiosk where snowmobiles enter the park. This level is greater than the NIOSH peak recommended exposure limit of 200 ppm. OSHA's survey also measured employees' exposures to several air toxics. Benzene exposures in Yellowstone employees ranged from 67-600 μg/m3, with the same individual experiencing highest CO and benzene exposures. The highest benzene exposure concentrations exceeded the NIOSH Recommended Exposure Limit of 0.1 ppm for 8-hour exposures.[88]

1.6.2 Large SI Engines

Exhaust emissions from applications with significant indoor use can expose individual operators or bystanders to dangerous levels of pollution. Forklifts, ice-surfacing machines, sweepers, and carpet cleaning equipment are examples of large industrial spark-ignition engines that often operate indoors or in other confined spaces. Forklifts alone account for over half of the engines in this category. Indoor use may include extensive operation in a temperature-controlled environment where ventilation is kept to a minimum (for example, for storing, processing, and shipping produce).

The principal concern for human exposure relates to CO emissions. One study showed several forklifts with measured CO emissions ranging from 10,000 to 90,000 ppm (1 to 9 percent).[89] The threshold limit value for a time-weighted average 8-hour workplace exposure set by the American Conference of Governmental Industrial Hygienists is 25 ppm.

One example of a facility that addressed exposure problems with new technology is in the apple-processing field.[90] Trout Apples in Washington added three-way catalysts to about 60 LPG-fueled forklifts to address multiple reports of employee health complaints related to CO exposure. The emission standards proposed in this document are based on the same technologies installed on these in-use engines.

Additional exposure concerns occur at ice rinks. Numerous papers have identified ice-surfacing machines with spark-ignition engines as the source of dangerous levels of CO and NO_2, both for skaters and for spectators.[91] This is especially problematic for skaters, who breathe air in the area where pollutant concentration is highest, with higher respiration rates resulting from their high level of physical activity. This problem has received significant attention from the medical community.

In addition to CO emissions, HC emissions from these engines can also lead to increased exposure to harmful pollutants, particularly air toxics. Since many gasoline or dual-fuel engines are in forklifts that operate indoors, reducing evaporative emissions could have direct health benefits to operators and other personnel. Fuel vapors can also cause odor problems.

1.6.3 Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when SO_2 and NOx react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles.[92] It contributes to damage of trees at high elevations and in extreme cases may cause lakes and streams to become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. To reduce damage to automotive paint caused by acid rain and acidic dry deposition, some manufacturers use acid-resistant paints, at an average cost of $5 per vehicle--a total of $61 million per year if applied to all new cars and trucks sold in the U.S.

Acid deposition primarily affects bodies of water that rest atop soil with a limited ability to neutralize acidic compounds. The National Surface Water Survey (NSWS) investigated the effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams. It found that acid deposition was the primary cause of acidity in 75 percent of the acidic lakes and about 50 percent of the acidic streams, and that the areas most sensitive to acid rain were the Adirondacks, the mid-Appalachian highlands, the upper Midwest and the high elevation West. The NSWS found that approximately 580 streams in the Mid-Atlantic Coastal Plain are acidic primarily due to acidic deposition. Hundreds of the lakes in the Adirondacks surveyed in the NSWS have acidity levels incompatible with the survival of sensitive fish species. Many of the over 1,350 acidic streams in the Mid-Atlantic Highlands (mid-Appalachia) region have already experienced trout losses due to increased stream acidity. Emissions from U.S. sources contribute to acidic deposition in eastern Canada, where the Canadian government has estimated that 14,000 lakes are acidic. Acid deposition also has been implicated in contributing to degradation of high-elevation spruce forests that populate the ridges of the Appalachian Mountains from Maine to Georgia. This area includes national parks such as the Shenandoah and Great Smoky Mountain National Parks.

1.6.4 Eutrophication and Nitrification

Nitrogen deposition into bodies of water can cause problems beyond those associated with acid rain. The Ecological Society of America has included discussion of the contribution of air emissions to increasing nitrogen levels in surface waters in a recent major review of causes and consequences of human alteration of the global nitrogen cycle in its Issues in Ecology series.[93] Long-term monitoring in the United States, Europe, and other developed regions of the world shows a substantial rise of nitrogen levels in surface waters, which are highly correlated with human-generated inputs of nitrogen to their watersheds. These nitrogen inputs are dominated by fertilizers and atmospheric deposition.

Human activity can increase the flow of nutrients into those waters and result in excess algae and plant growth. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration, and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can also adversely affect fish and shellfish populations. This problem is of particular concern in coastal areas with poor or stratified circulation patterns, such as the Chesapeake Bay, Long Island Sound, or the Gulf of Mexico. In such areas, the "overproduced" algae tends to sink to the bottom and decay, using all or most of the available oxygen and thereby reducing or eliminating populations of bottom-feeder fish and shellfish, distorting the normal population balance between different aquatic organisms, and in extreme cases causing dramatic fish kills.

Collectively, these effects are referred to as eutrophication, which the National Research Council recently identified as the most serious pollution problem facing the estuarine waters of the United States (NRC, 1993). Nitrogen is the primary cause of eutrophication in most coastal waters and estuaries.[94] On the New England coast, for example, the number of red and browntides and shellfish problems from nuisance and toxic plankton blooms have increased over the past two decades, a development thought to be linked to increased nitrogen loadings in coastal waters. We believe that airborne NOx contributes from 12 to 44 percent of the total nitrogen loadings to United States coastal water bodies. For example, some estimates assert that approximately one-quarter of the nitrogen in the Chesapeake Bay comes from atmospheric deposition.

Excessive fertilization with nitrogen-containing compounds can also affect terrestrial ecosystems.[95] Research suggests that nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem, providing beneficial nutrients to plant growth in areas that do not suffer from nitrogen over-saturation. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of the plants and microorganisms to utilize and retain the nitrogen. This phenomenon has already occurred in some areas of the U.S.

Notes to Chapter 1

1.Carbon monoxide also participates in the production of ozone, albeit at a much slower rate than most VOC and NOx compounds.

2.U.S. EPA, 1996, Review of National Ambient Air Quality Standards for Ozone, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-96-007. A copy of this document can be obtained from Air Docket A-99-06, Document No. II-A-22.

3.U.S. EPA, 1996, Air Quality Criteria for Ozone and Related Photochemical Oxidants, EPA/600/P-93/004aF. The document is available on the internet at http://www.epa.gov/ncea/ozone.htm. A copy can also be obtained from Air Docket No. A-99-06, Documents Nos. II-A-15, II-A-16, II-A-17.

4.U.S. EPA, 1995, Review of National Ambient Air Quality Standards for Nitrogen Dioxide, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-95-005.

5.U.S.EPA, 1993, Air Quality Criteria for Oxides of Nitrogen, EPA/600/8-91/049aF.

6.Vitousek, Pert M., John Aber, Robert W. Howarth, Gene E. Likens, et al. 1997. Human Alteration of the Global Nitrogen Cycle: Causes and Consequences. *Issues in Ecology*. Published by Ecological Society of America, Number 1, Spring 1997.

7.National Air Quality and Emissions Trends Report, 1999, EPA, 2001, at Table A-19. This document is available at http://www.epa.gov/oar/aqtrnd99/. The data from the Trends report are the most recent EPA air quality data that has been quality assured. A copy of this table can also be found in Docket No. A-2000-01, Document No. II-A-64.

8.National Air Quality and Emissions Trends Report, 1998, March, 2000, at 28. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

9.National Air Quality and Emissions Trends Report, 1998, March, 2000, at 32. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

10.Additional information about this modeling can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. 1-2000-01, Document No. II-A-13. This document is also available at http://www.epa.gov/otaq/diesel.htm#documents.

11.We also performed ozone air quality modeling for the western United States but, as described further in the air quality technical support document, model predictions were well below corresponding ambient concentrations for out heavy-duty engine standards and fuel sulfur control rulemaking. Because of poor model performance for this region of the country, the results of the Western ozone modeling were not relied on for that rule.

12.Additional information about these studies can be found in Chapter 2 of "Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements," December 2000, EPA420-R-00-026. Docket No. A-2000-01, Document Number II-A-13. This document is also available at http://www.epa.gov/otaq/diesel.htm#documents.

13.Air Quality Criteria Document for Ozone and Related Photochemical Oxidants, EPA National Center for Environmental Assessment, July 1996, Report No. EPA/600/P-93/004cF. The document is available on the internet at http://www.epa.gov/ncea/ozone.htm. A copy can also be obtained from Air Docket No. A-99-06, Documents Nos. II-A-15, II-A-16, II-A-17.

14.A copy of this data can be found in Air Docket A-2000-01, Document No.II-A-80.

15.Memorandum to Docket A-99-06 from Eric Ginsburg, EPA, "Summary of Model-Adjusted Ambient Concentrations for Certain Levels of Ground-Level Ozone over Prolonged Periods," November 22, 2000. Docket A-2000-01, Document Number II-B-13.

16.Memorandum to Docket A-99-06 from Eric Ginsburg, EPA, "Summary of Model-Adjusted Ambient Concentrations for Certain Levels of Ground-Level Ozone over Prolonged Periods," November 22, 2000, at Table C, Control Scenario – 2020 Populations in Eastern Metropolitan Counties with Predicted Daily 8-Hour Ozone greater than or equal to 0.080 ppm. Docket A-2000-01, Document Number II-B-13.

17.National Air Quality and Emissions Trends Report, 1999, EPA, 2001, at Table A-19. This document is available at http://www.epa.gov/oar/aqtrnd99/. The data from the Trends report are the most recent EPA air quality data that has been quality assured. A copy of this table can also be found in Docket No. A-2000-01, Document No. II-A-64.

18.St. Paul, Minnesota was recently reclassified as being in attainment but is still considered a maintenance area. There is also a significant population of snowmobiles in Minnesota, with snowmobile trails in Washington County.

19.The trail maps consulted for this proposal can be found in Docket No. A-2000-01, Document No. II-A-65.

20. Technical Memorandum to Docket A-2000-01 from Drew Kodjak, Attorney-Advisor, Office of Transportation and Air Quality, "Air Quality Information for Selected CO Nonattainment Areas," July 27, 2001, Docket Number A-2000-01, Document Number II-B-18.

21. Air Quality Criteria for Carbon Monoxide, US EPA, EPA 600/P-99/001F, June 2000, at 3-38, Figure 3-32 (Federal Bldg, AIRS Site 020900002). Air Docket A-2000-01, Document Number II-A-29. This document is also available at http://www.epa.gov/ncea/coabstract.htm.

22. National Air Quality and Emissions Trends Report, 1998, March, 2000; this document is available at http://www.epa.gov/oar/aqtrnd98/. National Air Pollutant Emission Trends, 1900-1998 (EPA-454/R-00-002), March, 2000. These documents are available at Docket No. A-2000-01, Document No. II-A-72. See also Air Quality Criteria for Carbon Monoxide, US EPA, EPA 600/P-99/001F, June 2000, at 3-10. Air Docket A-2000-01, Document Number II-A-29. This document is also available at http://www.epa.gov/ncea/coabstract.htm.

23. LDTs are light-duty trucks greater than 3750 lbs. loaded vehicle weight, up through 6000 gross vehicle weight rating.

24. Draft Anchorage Carbon Monoxide Emission Inventory and Year 2000 Attainment Projections, Air Quality Program, May 2001, Docket Number A-2000-01, Document II-A-40; Draft Fairbanks 1995-2001 Carbon Monoxide Emissions Inventory, June 1, 2001, Docket Number A-2000-01, Document II-A-39.

25.66 FR 28836, May 25, 2001. Clean Air Act Promulgation of Attainment Date Extension for the Fairbanks North Star Borough Carbon Monoxide Nonattainment Area, AK, Direct Final Rule.

26.U.S. EPA, Air Quality Criteria for Carbon Monoxide, EPA 600/P-99.001F, June 2000, Section 3.2.3. Air Docket A-2000-01, Document Number II-A-29. This document is also available at http://www.epa.gov/ncea/coabstract.htm.

27. Air Quality and Emissions Trends Report, 1998, March, 2000. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

28.EPA (1996) Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information OAQPS Staff Paper. EPA-452/R-96-013. Docket Number A-99-06, Documents Nos. II-A-18, 19, 20, and 23. The particulate matter air quality criteria documents are also available at http://www.epa.gov/ncea/partmatt.htm.

29.Memorandum to Docket A-99-06 from Eric O. Ginsburg, Senior Program Advisor, “Summary of 1999 Ambient Concentrations of Fine Particulate Matter,” November 15, 2000. This memo is also available in the docket for this rule. Docket A-2000-01, Document Number II-B-12.

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31.Memorandum to Docket A-99-06 from Eric O. Ginsburg, Senior Program Advisor, "Summary of Absolute Modeled and Model-Adjusted Estimates of Fine Particulate Matter for Selected Years," December 6, 2000. This memo is also available in the docket for this rule. Docket A-2000-01, Document Number II-B-14.

32.Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents.

33. Technical Memorandum, EPA Air Docket A-99-06, Eric O. Ginsburg, Senior Program Advisor, Emissions Monitoring and Analysis Division, OAQPS, Summary of Absolute Modeled and Model-Adjusted Estimates of Fine Particulate Matter for Selected Years, December 6, 2000, Table P-2. Docket Number 2000-01, Document Number II-B-14.

34. Memo to file from Terence Fitz-Simons, OAQPS, Scott Mathias, OAQPS, Mike Rizzo, Region 5, "Analyses of 1999 PM Data for the PM NAAQS Review," November 17, 2000, with attachment B, 1999 PM2.5 Annual Mean and 98th Percentile 24-Hour Average Concentrations. Docket No. A-2000-01, Document No. II-B-17.

35. The trail maps consulted for this proposal can be found in Docket No. A-2000-01, Document No. II-A-65.

36.See our Mobile Source Air Toxics final rulemaking, 66 FR 17230, March 29, 2001, and the Technical Support Document for that rulemaking. Docket No. A-2000-01, Documents Nos. II-A-42 and II-A-30.

37.U.S. EPA. (1999) Analysis of the Impacts of Control Programs on Motor Vehicle Toxic Emissions and Exposure in Urban Areas and Nationwide: Volume I. Prepared for EPA by Sierra Research, Inc. and Radian International Corporation/Eastern Research Group, November 30, 1999. Report No. EPA420-R-99-029. http://www.epa.gov/otaq/toxics.htm.

38.U.S. EPA (1998) Environmental Protection Agency, Carcinogenic Effects of Benzene: An Update, National Center for Environmental Assessment, Washington, DC. 1998. EPA/600/P-97/001F. http://www.epa.gov/ncepihom/Catalog/EPA600P97001F.html.

39.Leukemia is a blood disease in which the white blood cells are abnormal in type or number. Leukemia may be divided into nonlymphocytic (granulocytic) leukemias and lymphocytic leukemias. Nonlymphocytic leukemia generally involves the types of white blood cells (leukocytes) that are involved in engulfing, killing, and digesting bacteria and other parasites (phagocytosis) as well as releasing chemicals involved in allergic and immune responses. This type of leukemia may also involve erythroblastic cell types (immature red blood cells). Lymphocytic leukemia involves the lymphocyte type of white bloods cell that are responsible for the immune responses. Both nonlymphocytic and lymphocytic leukemia may, in turn, be separated into acute (rapid and fatal) and chronic (lingering, lasting) forms. For example; in acute myeloid leukemia (AML) there is diminished production of normal red blood cells (erythrocytes), granulocytes, and platelets (control clotting) which leads to death by anemia, infection, or hemorrhage. These events can be rapid. In chronic myeloid leukemia (CML) the leukemic cells retain the ability to differentiate (i.e., be responsive to stimulatory factors) and perform function; later there is a loss of the ability to respond.

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41.Clement Associates, Inc. (1991) Motor vehicle air toxics health information, for U.S. EPA Office of Mobile Sources, Ann Arbor, MI, September 1991. Air Docket A-2000-01, Document No. II-A-49.

42.International Agency for Research on Cancer (IARC) (1982) IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France, p. 345-389.

43.Irons, R.D., W.S. Stillman, D.B. Colagiovanni, and V.A. Henry (1992) Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor *in vitro*, Proc. Natl. Acad. Sci. 89:3691-3695.

44.Lumley, M., H. Barker, and J.A. Murray (1990) Benzene in petrol, *Lancet* 336:1318-1319.

45.U.S. EPA (1993) Motor Vehicle-Related Air Toxics Study, U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, EPA Report No. EPA 420-R-93-005, April 1993.

46.Pancytopenia is the reduction in the number of all three major types of blood cells (erythrocytes, or red blood cells, thrombocytes, or platelets, and leukocytes, or white blood cells). In adults, all three major types of blood cells are produced in the bone marrow of the vertebra, sternum, ribs, and pelvis. The bone marrow contains immature cells, known as multipotent myeloid stem cells, that later differentiate into the various mature blood cells. Pancytopenia results from a reduction in the ability of the red bone marrow to produce adequate numbers of these mature blood cells.

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49.Aplastic anemia is a more severe blood disease and occurs when the bone marrow ceases to function, i.e.,these stem cells never reach maturity. The depression in bone marrow function occurs in two stages - hyperplasia, or increased synthesis of blood cell elements, followed by hypoplasia, or decreased synthesis. As the disease progresses, the bone marrow decreases functioning. This myeloplastic dysplasia (formation of abnormal tissue) without acute leukemiais known as preleukemia. The aplastic anemia can progress to AML (acute mylogenous leukemia).

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79.Letter from Debra C. Miller, Data Analyst, National Park Service, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01, Document. Number. II-B-28.

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81.Technical Memorandum, Aaron Worstell, Environmental Engineer, National Park Service, Air Resources Division, Denver, Colorado, particularly Table 1. Docket No. A-2000-01, Document Number II-G-178.

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83.G. Bishop, et al., Snowmobile Contributions to Mobile Source Emissions in Yellowstone National Park, Environmental Science and Technology, Vol. 35, No. 14, at 2873. Docket No. A-2000-01, Document No. II-A-47.

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86. National-Scale Air Toxics Assessment for 1996, EPA-453/R-01-003, Draft, January 2001.

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89."Warehouse Workers' Headache, Carbon Monoxide Poisoning from Propane-Fueled Forklifts," Thomas A. Fawcett, et al, *Journal of Occupational Medicine*, January 1992, p. 12. Docket A-2000-01, Document No. II-A-36.

90."Terminox System Reduces Emissions from LPG Lift Trucks," Material Handling Product News. Docket A-2000-01, Document No. II-A-14.

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92.Much of the information in this subsection was excerpted from the EPA document, *Human Health Benefits from Sulfate Reduction*, written under Title IV of the 1990 Clean Air Act Amendments, U.S. EPA, Office of Air and Radiation, Acid Rain Division, Washington, DC 20460, November 1995. Air Docket A-2000-01, Document No. II-A-32.

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94.Much of this information was taken from the following EPA document: *Deposition of Air Pollutants to the Great Waters-Second Report to Congress*, Office of Air Quality Planning and Standards, June 1997, EPA-453/R-97-011.

95.Terrestrial nitrogen deposition can act as a fertilizer. In some agricultural areas, this effect can be beneficial.

CHAPTER 2: Industry Characterization

To accurately assess the potential impact of this emission control program, it is important to understand the nature of the affected industries. This chapter describes relevant background information related to each of the categories of engines subject to this proposal.

2.1 Marine

This section gives a general characterization of the segments of the marine industry that may be impacted by the proposed regulations. For this discussion, we divide the recreational marine industry into twi segments: compression-ignition (CI) diesel engine manufacturers and boat builders. This industry characterization was developed in part under contract with ICF Consulting[1] as well as independent analyses conducted by EPA through interaction with the industry and other sources.[2,3,4]

2.1.1 Marine Diesel Engine Manufacturers

2.1.1.1 Identification of Diesel Engine Manufacturers

We have determined that there are at least 16 companies that manufacture CI marine engines for recreational vessels. Nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to three large companies. Six of the identified companies are considered small businesses as defined by the Small Business Administration SIC code 3519 (less than 1000 employees). Based on sales estimates for 2000, these six companies represent approximately 4 percent of recreational marine diesel engine sales. The remaining companies each comprise between two and seven percent of sales for 2000. Table 2.1-1 provides a list of the diesel engine manufacturers identified to date by EPA.

Table 2.1-1 List of CI Marine Engine Manufacturers Identified by EPA

Greater than 1000 employees	*Less than 1000 employees*
Caterpillar	Alaska Diesel/Lugger
Cummins	American Diesel
Detroit Diesel	Daytona Marine
Isotta Fraschini	Marine Power
John Deere	Peninsular Diesel
Marine Corporation of America	Westerbeke
Mercruiser	
MTU	
Volvo Penta	
Yanmar	

2.1.1.2 Use of Diesel Engines

Diesel engines are primarily available in inboard marine configurations, but may also be available in sterndrive and outboard marine configurations. Inboard diesel engines are the primary choice for many larger recreational boats.

Larger boats are powered exclusively by diesel inboard engines. These boats are generally 40 feet or greater in length. Recreational boats in ports with access to the ocean (e.g. Seattle) can be 80 to 100 feet or longer. The larger boats typically require twin inboard diesel engines with 2,000 total horsepower or more. Recreational diesel marine engines are generally produced by domestic companies that have been long-standing players in the marine diesel engine market. The three companies that tend to dominate the market are Caterpillar, Cummins, and Detroit Diesel. As mentioned above, nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to these three companies.

Sterndrive diesel engines account for less than 1 or 2 percent of the market. A minority of mid-sized boat owners insist on diesel powered sterndrive engines for their boats. Diesel marine sterndrive systems generally power the same types of boats as their gasoline counterparts, which tend to be 15 to 30 feet in length. Customers that choose a diesel sterndrive marine engine are generally seeking three main advantages over gasoline sterndrive marine engines. First, diesel fumes are much less ignitable and explosive that gasoline fumes. Second, diesel powered craft have a greater range than gasoline powered craft with similar fuel capacity. Lastly, diesel engines tend to be more reliable and tend to run more hours between major overhauls than gasoline engines. This last point is particularly important to boat owners who operate their boats higher than the average.

One major disadvantage of diesel sterndrive engines is their cost relative to comparably powered gasoline sterndrive engines. For example, a 40 foot twin cabin cruiser with twin gasoline sterndrive engines costs $238,000. For twin diesel sterndrive engines, the price increases approximately $50,000. The fact that the diesel engine is more expensive, coupled with the fact that diesel fuel is often less available than gasoline in the U.S., has resulted in limited domestic demand for recreational diesel sterndrive marine engines.

2.1.1.3 Current Trends

The strong economy of the mid-1990's, the rapid growth of the stock market, and the gains in personal disposable personal income have combined to accelerate big ticket purchases, including the purchases of large boats. For example, from 1995 to 1997, inboard cruiser diesel marine sales have increased by 15 percent according to data collected by ICF. In addition to positive economic conditions, favorable financing, low fuel costs, product advancement and recent model design changes have also lead to increased sales of larger boats.

2.1.2 Recreational Boat Builders

2.1.2.1 Identification of Boat Builders

We have less precise information about recreational boat builders than is available about engine manufacturers. We used several sources, including trade associations and Internet sites when identifying entities that build and/or sell recreational boats. We have also worked with an independent contractor to assist in the characterization of this segment of the industry. Finally, we have obtained a list of nearly 1,700 boat builders known to the U.S. Coast Guard to produce boats using recreational gasoline and diesel engines. At least 1,200 of these companies install gasoline-fueled engines and would therefore be subject to the proposed evaporative emission standards. More that 90 percent of the companies identified so far would be considered small businesses as defined by SBA SIC code 3732.

Based on information supplied by a variety of recreational boat builders, fuel tanks for recreational boats are usually purchased from fuel tank manufacturers. However, some boat builders construct their own fuel tanks. The boat builder provides the specifications to the fuel tank manufacturer who helps match the fuel tank for a particular application. It is the boat builder’s responsibility to install the fuel tank and connections into their vessel design. For vessels designed to be used with small outboard engines, the boat builder may not install a fuel tank; therefore, the end user would use a portable fuel tank with a connection to the engine.

2.1.2.2 Current Trends

Additional information provided by NMMA indicate that an estimated 72 million people participated in recreational boating in 2000, which is down slightly from 77 million in 1995. In 2000, nearly 17 million boats were in use in the United States.

2.1.2.3 Production Practices

Based on information supplied by a variety of recreational boat builders, the following discussion provides a description of the general production practices used in this sector of the marine industry.

Engines are usually purchased from factory authorized distribution centers. The boat builder provides the specifications to the distributor who helps match an engine for a particular application. It is the boat builders responsibility to fit the engine into their vessel design. The reason for this is that sales directly to boat builders are a very small part of engine manufacturers’ total engine sales. These engines are not generally interchangeable from one design to the next. Each recreational boat builder has their own designs. In general, a boat builder will design one or two molds that are intended to last 5-8 years. Very few changes are tolerated in the molds because of the costs of building and retooling these molds.

Recreational vessels are designed for speed and therefore typically operate in a planing mode. To enable the vessel to be pushed onto the surface of the water where it will subsequently operate, recreational vessels are constructed of lighter materials and use engines with high power density (power/weight). The tradeoff on the engine side is less durability, and these engines are typically warranted for fewer hours of operation. Fortunately, this limitation typically corresponds with actual recreational vessel use. With regard to design, these vessels are more likely to be serially produced. They are generally made out of light-weight fiberglass. This material, however, minimizes the ability to incorporate purchaser preferences, not only because many features are designed into the fiberglass molds, but also because these vessels are very sensitive to any changes in their vertical or horizontal centers of gravity. Consequently, optional features are generally confined to details in the living quarters, and engine choice is very limited or is not offered at all.

2.2 Large Industrial SI Equipment

Large SI engines are those spark-ignition nonroad engines that have rated power higher than 25 horsepower, that are not recreational engines or marine engines. They are typically derivatives of automotive engines, but use less advanced technology. The most common application of these engines is in forklifts. Other applications include generators, pumps, compressors, and a wide variety of other applications.

2.2.1 Manufacturers

There are seven principal manufacturers of Large SI engines. Table 2.2-1 shows that sales volumes are relatively evenly distributed among these seven manufacturers. This sales information is based on average annual volumes for the period from 1994 through 1996. Where marketing data from individual companies did not agree with the published figures, the analysis adjusts the estimated figures to improve the accuracy of historical sales volumes. The figures for "other" manufacturers presents aggregated data from four additional companies—Volkswagen, Westerbeke, Hercules, and Chrysler. While these and other numbers in this chapter may be changing somewhat over the recent and coming years, they provide a good indication of the nature of this industry segment.

The degree to which engine manufacturers offer integrated engine and equipment models is an important factor in determining how companies address the need to redesign their products. Companies that use their own engine models to produce equipment have the advantage of coordinating the engine design changes with the appropriate changes in their equipment models. The principal integrated manufacturers (Nissan, Mitsubishi, and Toyota) all produce forklifts. About 30 percent of Large SI equipment sales are from integrated manufacturers.

Other forklift manufacturers have also been responsible for varying degrees of engine design. Engine design expertise among these companies is so prevalent that some forklift manufacturers may assume responsibility for certifying their engines, even though they buy the engines mostly assembled from other manufacturers.

Table 2.2.-1
Engine Sales by Manufacturer

Manufacturer	Average Annual Sales	Distribution
General Motors	19,500	19%
Mitsubishi Motors	15,600	15%
Ford Power Products	14,000	14%
Nissan Industrial Engines	13,800	13%
Wis-Con Total Power	12,100	12%
Toyota	11,800	12%
Mazda	8,200	8%
Other	7,200	6%
Total	102,300	100%

2.2.2 Applications

We have also estimated populations of engine and equipment models using historical sales information adjusted according to survival and scrappage rates. Table 2-2 presents the estimated U.S. population of the various Large SI equipment applications. A recent, commercial study of the forklift market showed the need to adjust forklift population estimates.[5] That study identified a 1996 population of 491,321 engine-powered forklifts (Classes 4, 5, and 6), estimating that 80 percent of all forklifts operate on liquefied petroleum gas (LPG), with the rest running on either gasoline or diesel fuel.[a] With an estimated even split between gasoline and diesel for these remaining forklifts, we estimate a total population of spark-ignition forklifts of 442,000. This spark-ignition population includes all units operating on gasoline and LPG; a small number of spark-ignition forklifts are fueled by natural gas.

For other applications, the split between LPG and gasoline also warrants further attention. Large SI engines today are typically sold without fuel systems, which makes it difficult to assess the distribution of engine sales by fuel type. Also, engines are often retrofitted for a different fuel after the initial sale, making it still more difficult to estimate the prevalence of the different fuels. The high percentage of propane systems for forklifts can be largely attributed to expenses related to maintaining fuel supplies. LPG cylinders can be readily exchanged with minimal infrastructure cost. Installing and maintaining underground tanks for storing gasoline has always been a significant expense, which has become increasingly costly due to the new requirements for replacing underground tanks.

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[a] Molecular propane (C_3H_8) is the most common constituent in LPG. LPG is therefore commonly referred to as propane.

Natural gas is a third fuel option. While natural gas and LPG fuel systems are very similar, natural gas installations are much less common in Large SI engines. Natural gas supply systems typically offer the advantage of pipeline service, but the cost of installing high-pressure refueling equipment is an obstacle to increased use of natural gas.

Some applications of nonroad SI equipment face much different refueling situations. Lawn and garden equipment is usually not centrally fueled and therefore operates almost exclusively on gasoline, which is more readily available. Agriculture equipment is predominantly powered by diesel engines. Most agriculture operators have storage tanks for diesel fuel. Those who use spark-ignition engines in addition to, or instead of, the diesel models, would likely invest in gasoline storage tanks as well, resulting in little or no use of LPG or natural gas for those applications. For construction, general industrial, and other nonroad equipment, there may be a mix of central and noncentral fueling, and motive and portable equipment; we therefore believe that estimating an even mix of LPG and gasoline for these engines is most appropriate. The estimated distribution of fuel types for the individual applications are listed in Table 2-2.

An additional issue related to population figures is the level of growth factored into emission estimates for the future. EPA's Nonroad Emission Model incorporates application-specific growth figures. The projected growth is reflected in the population estimates included in Table 2.2-2.

Table 2.2-2
Operating Parameters and Population Estimates for Various Applications of Engines Rated above 19 kW

Application*	Load Factor	Usage Rate (hours/yr)	1996 Population	Projected 2010 Population	Percent LPG/CNG
Forklift	0.30	1500	442,000	547,063	95
Generator	0.68	115	205,990	202,177	50
Welder	0.51	208	55,495	67,872	50
Commercial turf	0.60	733	41,440	55,074	0
Pump	0.69	221	41,104	44,830	50
Air compressor	0.56	484	24,182	28,633	50
Baler	0.62	68	21,937	27,597	0
Irrigation set	0.60	716	17,800	9,724	50
Aerial lift	0.46	361	15,734	15,555	50
Scrubber/sweeper	0.71	516	14,154	13,955	50
Chipper/grinder	0.78	488	12,218	16,262	50
Leaf blower/vacuum	0.75	56	10,823	14,384	0

Application*	Load Factor	Usage Rate (hours/yr)	1996 Population	Projected 2010 Population	Percent LPG/CNG
Oil field equipment	0.90	1104	8,792	8,924	100
Sprayer	0.65	80	8,635	10,863	0
Trencher	0.66	402	8,168	9,604	50
Specialty vehicle/cart	0.58	65	7,833	8,726	50
Skid/steer loader	0.58	310	7,795	9,164	50
Other general industrial	0.54	713	3,987	3,942	50
Rubber-tired loader	0.71	512	3,476	4,088	50
Gas compressor	0.60	8500	3,023	1,620	100
Paving equipment	0.59	175	2,996	3,524	50
Terminal tractor	0.78	827	2,905	2,872	50
Bore/drill rig	0.79	107	2,618	3,080	50
Ag. tractor	0.62	550	2,152	2,707	0
Concrete/industrial saw	0.78	610	2,133	2,509	50
Rough terrain forklift	0.63	413	1,933	2,273	50
Roller	0.62	621	1,596	1,878	50
Crane	0.47	415	1,584	1,864	50
Other material handling	0.53	386	1,535	1,518	50
Paver	0.66	392	1,337	1,573	50
Other agriculture equipment	0.55	124	1,234	1,552	0
Other construction	0.48	371	1,222	1,436	50
Pressure washer	0.85	115	1,207	2,271	50
Aircraft support	0.56	681	840	1,238	50
Crushing/processing equip	0.85	241	532	628	50
Surfacing equipment	0.49	488	481	567	50
Tractor/loader/backhoe	0.48	870	416	489	50
Hydraulic power unit	0.56	450	339	384	50
Other lawn & garden	0.58	61	333	443	0
Refrigeration/AC	0.46	605	163	226	100

*The list of applications and the associated load factors and usage rates are from PSR. The population figures and the distribution of fuel types are from the EPA's Nonroad Model.

2.2.3 Engine Design and Operation

Most engines operate at a wide variety of speeds and loads, such that operation at rated power (full-speed and full-load) is rare. To take into account the effect of operating at idle and partial load conditions, a load factor indicates the degree to which average engine operation is scaled back from full power. For example, at a 0.3 (or 30 percent) load factor, an engine rated at 100 hp would be producing an average of 30 hp over the course of normal operation. For many nonroad applications, this can vary widely (and quickly) between 0 and 100 percent of full power. Table 2-2 shows the load factors that apply to each nonroad equipment application.

Table 2-2 also shows annual operating hours that apply to the various applications. These figures represent the operating levels that apply through the median lifetime of equipment.

2.2.3.1 Automotive-Derived Engines

The majority of Large SI engines are industrial versions of automotive engines. Tables 2.2-3 and 2.2-4 show that four-cylinder engines rated under 100 horsepower dominate the market. There are also substantial niche markets available for smaller and larger engines. In the absence of emission standards, there has been limited transfer of emission-control technology from automotive to industrial engines.

Producing an industrial version of an automotive engine typically involves fitting a common engine block with less expensive systems and components appropriate for nonroad use. Manufacturers remove most of the sophisticated systems in place for the high-performance, low-emission automotive engines to be able to produce the industrial engine at a lower cost. For example, while cars have used electronic fuel systems for many years, almost all industrial engines still rely on mechanical fuel systems. Chapter 3 describes the baseline and projected engine technologies in greater detail.

Table 2.2-3
Power Distribution

Power Rating	Average Annual Sales	Distribution
25 < HP < 49	34,400	34%
50 < HP < 99	47,300	46%
100 < HP < 174	19,000	19%
HP > 174	1,600	2%
Total	102,300	100%

Table 2.2-4
Engine Sizes

Number of Cylinders	Average Annual Sales	Distribution
1	100	0.1%
2	500	0.4%
3	7,000	7%
4	78,100	76%
6	10,700	11%
8	6,000	6%
Total	102,300	100%

2.2.3.2 Air-Cooled Engines

Some manufacturers produce engines exclusively for industrial use, most of which are air-cooled models. Air-cooled engines with less than one liter total displacement are typically very similar to the engines used in lawn and garden applications. Total sales of air-cooled engines over one liter are about 9,200 per year, 85 percent of which are rated under 50 hp. While these engines can use the same emission-control technologies as water-cooled engines, they have unique constraints on how well they control emissions. Air-cooling doesn’t cool the engine block as uniformly as water-cooling. This uneven heating can lead to cylinder-to-cylinder variations that make it difficult to optimize fuel and air intake variables consistently. Uneven heating can also distort cylinders to the point that piston rings don’t consistently seal the combustion chamber. Finally, the limited cooling capacity requires that air-cooled engines stay at fuel-rich conditions when operating near full power.

While air-cooled engines account for about 9 percent of Large SI engine sales, their use is concentrated in a few specialized applications. Almost all of these are portable (non-motive) applications with engine operation at constant speeds (the speed setting may be adjustable, but operation at any given time is at a single speed). Many applications, such as concrete saws and chippers, expose the engine to high concentrations of ambient particles that may reduce an engine’s lifetime. These particles would also form deposits on radiators, making water-cooling less effective. Because lower-emitting water-cooled engines may not be suitable alternatives in these severe-duty applications, the proposed emission standards take into account the technology constraints of air-cooled engines.

2.2.4 Customer Concerns

Most Large SI engines are used in industrial applications. These industrial customers have historically been most concerned about the cost of the engine and equipment, and about reliability. In many cases, the customer values consistent and familiar technology as a means of simplifying engine maintenance. As described in Chapter 5, equipment users have largely ignored the potential for improving fuel economy in making purchasing decisions. As a result most Large SI engines being sold today have relatively simple carburetor technology that is similar to automotive technology of the early 1980s.

There is a large subset of these engines that are operated indoors or in other areas with restricted airflow much of the time. For these indoor engines, customers have generally wanted engines with lower CO emissions. Thus most indoor engines are fueled with LPG or CNG. In some cases, where the customer wants even lower emissions, they will purchase engines equipped with exhaust catalysts.

2.3 Snowmobiles

Snowmobiles are normally one or two passenger vehicles that are used to traverse over snow-covered terrain. They have a track in the rear similar to that of a bulldozer, and runners (similar to skis) in the front for steering. Snowmobiles are used primarily for recreational purposes. However, a small number of them are produced and used for utility purposes, such as search and rescue operations. Annual snowmobile sales in the U.S. have varied dramatically over the years, but sales between 1996 and 2000 have averaged about 157,000 units per year.

2.3.1 Manufacturers

Manufacturers of snowmobiles are classified under the North American Industrial Classification Code System (NAICS) as code 336999, Other Transportation Equipment Manufacturing. These codes are used by the Small Business Administration (SBA) in classifying businesses as large or small, depending on the number of employees. Snowmobile manufacturers have the NAICS subclassification 3369993414, and must have fewer than 500 employees to be considered a small business.

There are four major manufacturers of snowmobiles which account for almost the entire U.S. snowmobile market. These manufacturers are Arctic Cat, Bombardier (Ski-Doo), Polaris and Yamaha. Polaris is the largest snowmobile manufacturer, by sales volume, followed by Arctic Cat, Bombardier and Yamaha. There are less than five small snowmobile manufacturers that combined make up significantly less than one percent of the U.S. snowmobile market. These small manufacturers specialize in high performance snowmobiles and other unique designs (such as stand-up snowmobiles).

2.3.2 Sales and Fleet Size

Snowmobile sales tend to vary both with the state of the U.S. economy (being a discretionary recreational purchase) and snowfall. Thus, annual sales have varied, sometimes dramatically, over the years. Table 2.3.-1 shows annual U.S. snowmobile sales from 1992 through 2000, as reported by the International Snowmobile Manufacturers Association. The current snowmobile fleet in the U.S. is roughly 1.5 million units.

Table 2.3.-1
U.S. Snowmobile Sales

Year	Unit Sales
2000	136,601
1999	147,867
1998	162,826
1997	170,325
1996	168,509
1995	148,207
1994	114,057
1993	87,809
1992	81,946

2.3.3 Usage

There are a variety of snowmobile types currently produced and tailored to a variety of riding styles. The majority of the snowmobile market is made up of high performance machines. These snowmobiles have fairly high powered engines and are very light, giving them good acceleration, speed and handling. The performance sleds come in several styles. Cross country sleds are designed for aggressive trail and cross country riding. Mountain sleds have longer tracks and a wider runner stance for optimum performance in mountainous terrain. Finally, muscle sleds are designed for high top speeds (in excess of 120 miles per hour) over flat terrain such as frozen lakes. Performance snowmobiles are generally designed for a single rider.

The second major style of snowmobile is designed for casual riding over groomed trails. These touring sleds are designed for one or two riders, and tend to have lower powered engines than performance snowmobiles. The emphasis in this market segment is more on comfort and convenience. As such, these sleds feature a more comfortable ride than the performance machines and tend to have features such as electric start, reverse, and electric warming hand grips.

The last, and smallest, segment of the snowmobile market is the utility sled segment. Utility snowmobiles are designed for pulling loads and for use in heavy snow. Thus, the engines are designed more for producing torque at low engine speeds, which typically corresponds to a reduced maximum speed of the snowmobile. Utility snowmobiles are common in search and rescue operations.

A typical snowmobile lasts seven to nine years and travels over 5,000 miles during its lifetime, with annual mileage dropping with age. The average snowmobile is used 57 hours per year.

2.3.4 Customer Concerns

2.3.4.1 Performance

Good snowmobile performance is very important to snowmobilers. This is especially true for the performance segment of the market, where high power and low weight are crucial for the enjoyment of the performance snowmobile enthusiast. The performance snowmobile segment is driven by a constant demand for more power and lower weight. In the touring segment of the market performance in terms of power and weight is somewhat less important, but still significant. In this segment comfort features and fuel economy play a bigger role in customer satisfaction than in the performance segment. In all snowmobile market segments durability and reliability are very important to the customer.

2.3.4.2 Cost

The price of snowmobiles produced by the four major manufacturers currently ranges from about $3,700 for some entry level models to around $12,000 for some high performance and luxury touring machines. The average cost of snowmobiles sold in the U.S. is in the $6,000 to $7,000 range. Some of the high performance snowmobiles produced by the small manufacturers can approach $20,000, but this is an extremely small niche market.

Snowmobiles are for the most part a recreational product and are thus a discretionary purchase. Cost is an important factor for snowmobilers, and significant cost increases could cause people to spend their discretionary income on other recreational opportunities. This is especially significant in the low cost, entry level snowmobile segment (the point of entry into the sport of snowmobiling) where significant cost increases could discourage people from taking up snowmobiling.

2.4 All-Terrain Vehicles

All Terrain Vehicles (ATVs) are normally one-passenger open vehicles that are used for recreational and other purposes requiring the ability to traverse over most types of terrain. Most modern ATVs have four-wheels, and have evolved from three-wheeled designs that were first introduced in the 1970s. According to data provided by an EPA contractor, production for ATVs sold in the U.S. has averaged about 390,000 units between 1996 and 2000. However, ATV sales have increased during that time to more than 550,000 units in 2000. Thus, ATVs constitute the largest single category of non-highway recreational vehicles, although it is difficult to calculate the total vehicle population at any given point in time because of the fact that many states do not require registration of ATVs.

2.4.1 Manufacturers

Manufacturers of ATVs are classified under the North American Industrial Classification System (NAICS) as code 336999, Other Transportation Equipment Manufacturing. These codes are used by the Small Business Administration (SBA) in classifying businesses as large or small, depending on the number of employees. ATV manufacturers have the NAICS sub-classification 3369993101, and must have fewer than 500 employees to be considered a small business. In addition to manufacturers, there are a number of importers of ATVs, which fall under NAICS code 42111, which also includes importers of automobiles, trucks, motorcycles and motor homes. To be classified as a small business by SBA, an importer must have fewer than 100 employees.

We contracted with ICF Consulting to help us characterize the off-highway recreational vehicle market.[6] Using data which included the Power Systems Research (PSR) Database, Dun & Bradstreet (D&B) Market Identifiers Online Database, and information from the Motorcycle Industry Council (MIC), our contractor identified 16 manufacturers of ATVs. These can be found in Table 2.4.1. Six large manufacturers, Honda, Polaris, Kawasaki, Yamaha, Suzuki, and Arctic Cat accounted for approximately 98 percent of all U.S. ATV production in calendar year 2000.

The 10 other manufacturers accounted for the remaining two percent of U.S. production in 2000. Only three of these are non-U.S.-owned. Available D&B data on numbers of employees for five of the companies show that they are small businesses according to the SBA definition.

There are also some 17 firms that import ATVs. Thirteen of these are U.S.-owned. Dun and Bradstreet data on numbers of employees are available for four of these companies, and indicate that these are small businesses according to the SBA definition. Since none of these had more than 40 employees and two had less than 20 employees, it seems safe to assume that the others are also small businesses according to the SBA definition.

Table 2.4.-1
ATV Manufacturers/Importers

Firm Name	Type
ATK	IMPORTER
COSMOPOLITAN MOTORS	IMPORTER
D.R.R. INC.	IMPORTER
E-TON DISTRIBUTION LP	IMPORTER
HOFFMAN GROUP INC.	IMPORTER
J & J SALES	IMPORTER
JEHM POWERSPORTS	IMPORTER
KASEA MOTORSPORTS	IMPORTER
MANCO PRODUCTS	IMPORTER

MOTORRAD OF NORTH AMERICA	IMPORTER
PANDA MOTORSPORTS	IMPORTER
POWERGROUP INTERNATIONAL ALPHASPORTS	IMPORTER
REINMECH MOTOR COMPANY, LTD	IMPORTER
TRANSNATIONAL OUTDOOR POWER LLC	IMPORTER
TWS-USA, INC	IMPORTER
ULTIMAX LCC	IMPORTER
UNITED MOTORS OF AMERICA, INC	IMPORTER
AMERICAN SUNDIRO	MANUFACTURER
ARCTIC CAT, INC.	MANUFACTURER
BOMBARDIER	MANUFACTURER
CANNONDALE CORP - BEDFORD	MANUFACTURER
HONDA AMERICAN MANUFACTURING	MANUFACTURER
HYOSUNG MOTORS AND MACHINERY	MANUFACTURER
INTERNATIONAL POWERCRAFT	MANUFACTURER
KAWASAKI MOTORS CORPORATION	MANUFACTURER
KEEN PERCEPTION INDUSTRIES	MANUFACTURER
MOSS	MANUFACTURER
PANDA MOTORSPORTS	MANUFACTURER
POLARIS INDUSTRIES	MANUFACTURER
ROADMASTER /FLEXIBLE FLYER	MANUFACTURER
SUZUKI	MANUFACTURER
TAI LING MOTOR COMPANY	MANUFACTURER
YAMAHA MOTOR MANUFACTURING CORP.	MANUFACTURER

2.4.1.1 Engine Manufacturers

Four of the major ATV producers, Honda, Kawasaki, Yamaha and Suzuki, are both engine and equipment manufacturers. In addition, Suzuki produces engines for Arctic Cat, and in fact owns a significant amount of Arctic Cat common stock. Hyosung Motors and Machinery and the Tai Ling Motor company also use Suzuki engines in ATVs that are sold in the U.S. Although Polaris produces some of its own engines, a substantial number are supplied by Fuji Heavy Industries, primarily an auto and truck manufacturer, and its U.S. subsidiary, Robin Industries. Polaris owns a substantial amount of Robin common stock.

Other engine manufacturers include Rotax, which is a subsidiary of Bombardier Inc., a large Canadian company. Bombardier is primarily a snowmobile manufacturer, but has recently entered the ATV market. Bombardier/Rotax also produces engines for a wide variety of other applications, including snowmobiles, motorcycles, ATVs, personal water craft (PWC), utility vehicles and aircraft. A few small ATV manufacturers use Briggs or Kohler utility engines, but these are covered by EPA's Small Spark Ignition (SI) Engine regulations and are not included in this analysis [7]

2.4.1.2 Equipment Manufacturers

Four of the six major ATV manufacturers, Honda, Kawasaki, Yamaha and Suzuki, are primarily automobile and/or on-highway motorcycle manufacturers who also produce ATVs, off-highway motorcycles, snowmobiles, PWC and other non-highway vehicles. Polaris and Arctic Cat are major snowmobile manufacturers, in addition to producing ATVs. Polaris also produces on-highway motorcycles and Arctic Cat produces PWC.

Of the remaining 10 producers, 5 are classified as large businesses, and 5 are classified as small businesses. As noted above, Bombardier is a large Canadian snowmobile manufacturer that has recently entered the ATV market. Cannondale is a large American bicycle manufacturer that has also recently entered the ATV market. Hyosung and Tai Ling are large Far Eastern manufacturers, who also manufacture motorcycles and motorscooters (in the case of Hyosung). Roadmaster/Flexible Flyer is primarily a large bicycle and toy manufacturer which also produces youth ATVs that are sold in large discount stores. The 17 importers and 5 small manufacturers either import completed ATV's or assemble them in this country from imported parts.

2.4.2 Applications

As noted above, ATVs are used for recreational and other purposes. Examples of non-recreational uses are for hauling and towing on farms, ranches or in commercial applications. Some ATVs are sold with attachments that allow them to take on some of the functions of a garden tractor or snow blower. ATVs are also used for competitive purposes, although not to the same extent as off-highway motorcycles.

2.4.3 Engine Design and Operation

The majority of ATVs sold in the U.S. are powered by single-cylinder, four-stroke cycle engines of less than 40 horsepower, operating under a wide variety of operating conditions and load factors. Engine displacements range from 50cc for an entry-level youth model to 660cc for a high-performance adult model, but more than three-fourths of them fall in the 200-500cc range.

2.4.3.1 Two-Stroke vs Four-Stroke Cycle Engine Usage

According to statistics compiled by our contractor, more than 92 percent of all ATVs produced for US consumption use four-stroke cycle engines. However, estimates provided by MIC reduce this percentage to 88 percent. Of the six major manufacturers, only Polaris, Suzuki and Yamaha used two-stroke cycle engines at all. The remainder of the two-stroke engines in

ATVs sold in U.S. are found in entry-level or youth models, which are imported from the Far East, or assembled in this country from imported parts. In general two-stroke engines are less expensive to produce than four-stroke engines, thus providing a marketing advantage in the youth and entry-level categories. We estimate that two-strokes make up roughly twenty percent of the market when the imported youth models are included.

2.4.3.2 Use of Engines in Other Applications

Although a few ATV engine lines have been used in other applications, such as some smaller on- and off-highway motorcycles, manufacturers have stated that ATV engines are normally designed only for use in ATVs. ATV engines may share certain components with motorcycles, snowmobiles and PWC, but many major components such as pistons, cylinders and crankcases differ within given engine displacement categories.

2.4.3.3 Customer Concerns

Except for the competitive segment of the market, performance seems to be somewhat less important to ATV purchasers than it is to purchasers of snowmobiles or off-highway motorcycles. Most youth models, which form a significant portion of the market, are normally equipped with governors or other speed-limiting devices. Performance can be important for some of the higher-end adult models, but handling is also an important consideration, particularly when riding in dense wooded areas. Durability and reliability are also important to the customer, but perhaps not as important as price.

The price of an ATV can ranges from about $1,200 for an entry-level youth model to around $7,000 or more for a large, high performance machine. ATVs, like other recreational vehicles, are basically discretionary purchases, although utility may enter into the equation more often than in the case of off-highway motorcycles or snowmobiles.. Cost is an important factor, particularly in the youth or entry-level segments of the market, and significant cost increases could cause people to spend their discretionary funds in other areas.

2.5 Off-Highway Motorcycles

Off-highway motorcycles, commonly referred to as “dirt bikes,” are designed specifically for use on unpaved surfaces. As such, they have certain characteristics in common, such as a large amount of clearance between the fenders and the wheels, tires with aggressive knobby tread designs, and they lack some of the equipment typically found on highway motorcycles, e.g., lights, horns, turn signals, and often mufflers. They are thus not normally able to be licensed for on-highway use. There are a limited number of motorcycles, known as dual-purpose motorcycles, that can be used for both on- and off-highway purposes. These can be licensed for highway use, and so fall under the current highway motorcycle regulations, assuming that they are powered by engines of 50cc or larger displacement. Off-highway motorcycles are used for recreational riding, but substantial numbers are also used for competition purposes. Some in fact can be used for little else, e.g., machines that are designed for observed trials competition, which have no seats in the conventional sense of the term, and engine characteristics that are totally unlike those of most other motorcycles. Only a few thousand observed trials bikes are produced each year.

Our contractor found that production of off-highway motorcycles produced for sale in the U.S. has averaged about 110,000 units between 1995 and 1999. As is the case with ATVs, off-highway motorcycle production has increased considerably in later years, to more than 150,000 units in 1999, and assumed to be the same or higher for 2000, although the exact numbers were not available at the time of preparation of this analysis. Since many states do not require registration of off-highway motorcycles, it is difficult to estimate a total population at any given time.

2.5.1 Manufacturers

Motorcycle manufacturers are classified under the NAICS system as code 336991, Motorcycle, Bicycle and Parts Manufacturers. Motorcycle manufacturers have the subcode 3369913, which includes manufacturers of scooters, mopeds and sidecars. To be classified as a small business, the manufacturer must have fewer than 500 employees. Motorcycle Importers are classified as subcode 4211101, which also includes automobile importers, and has an SBA cutoff of 100 employees to be considered a small business.

Our contractor has identified 24 manufacturers of off-highway motorcycles. These can be found in Table 2.5.1. Five large manufacturers, Honda, Kawasaki, Yamaha, Suzuki, and KTM. accounted for approximately 85 percent of all production for sale in the U.S. in calendar year 2000. These are all companies that manufacture automobiles and/or on-highway motorcycles, motorscooters, ATVs, and PWC as well as off-highway motorcycles. Honda is by far the largest producer of off-highway motorcycles, with over 45 percent of the total production for sale in the U.S. Figure 2.5.1 shows the market shares for the top five and the other producers

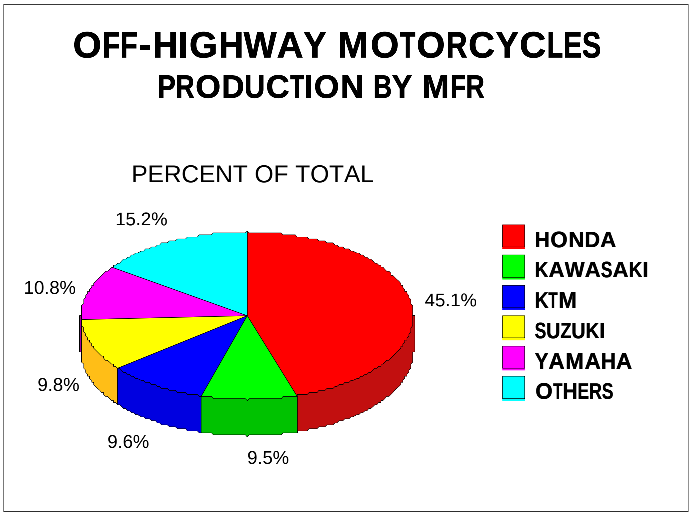

Figure 2.5.1

The 19 other manufacturers accounted for the remaining 15 percent of production for U.S. sale. Six of these firms, accounting for approximately 3 percent of total production for the U.S. market, are located in this country. Dun and Bradstreet employee data are available for four of the six U.S. manufacturers, indicating that these are small businesses according to the SBA definition.

Our contractor has also identified 16 off-highway motorcycle importers. Eight of these are U.S.-owned. Dun and Bradstreet data are available for five of the eight U.S. importers, indicating that they are small businesses. Again, it seems likely that all eight are small businesses.

Table 2.5.-1
U.S. Off-Highway Motorcycle Manufacturers/Importers

Firm Name	Type
ACTION POLINI	IMPORTER
BETA USA	IMPORTER
CODY RACING PRODUCTS	IMPORTER
COSMOPOLITAN MOTORS INC.	IMPORTER
CRE IMPORTS/E-LINE ACCESSORIES	IMPORTER
GAS GAS NORTH AMERICA	IMPORTER
HUSQVARNA USA	IMPORTER
KASEA MOTORSPORTS	IMPORTER
KTM SPORTMOTORCYCLE USA, INC.	IMPORTER
MIDWEST MOTOR VEHICLES, INC.	IMPORTER
TRANSNATIONAL OUTDOOR POWER, LLC	IMPORTER
TRYALS SHOP	IMPORTER
TWS-USA INC.	IMPORTER
U.S. MONTESA	IMPORTER
UNITED MOTORS OF AMERICA	IMPORTER
VOR MOTORCYCLES USA	IMPORTER
AMERICAN DIRT BIKE INC. (U.S.)	MANUFACTURER
ATK MOTORCYCLES (U.S.)	MANUFACTURER
BETAMOTOR SPA (ITALY)	MANUFACTURER
CAGIVA MOTORCYCLE SPA (ITALY)	MANUFACTURER
CANNONDALE CORP - BEDFORD (U.S.)	MANUFACTURER
CCM MOTORCYCLES LTD (U.K.)	MANUFACTURER
COBRA MOTORCYCLE MFG. (U.S.)	MANUFACTURER
GAS GAS MOTOS SPA (SPAIN)	MANUFACTURER
HM MOTORCYCLES (U.S.)	MANUFACTURER
HONDA MOTORCYCLES (JAPAN)	MANUFACTURER
HUSABERG MOTOR AB (SWEDEN)	MANUFACTURER
HYOSUNG MOTORS AND MACHINERY (KOREA)	MANUFACTURER
KAWASAKI HEAVY INDUSTRIES (JAPAN)	MANUFACTURER
KTM SPORT MOTORCYCLE AG (AUSTRIA)	MANUFACTURER
LEM MOTOR SAS (ITALY)	MANUFACTURER
MADFAST MOTORCYCLES (IRELAND)	MANUFACTURER
MINSK MOTOVELOZAVOD (BELARUS)	MANUFACTURER
MONTESA-HONDA ESPANA, SA (SPAIN)	MANUFACTURER
PIAGGIO GROUP (ITALY)	MANUFACTURER
POLINI (ITALY)	MANUFACTURER
REV! MOTORCYCLES (U.S.)	MANUFACTURER
SUZUKI (JAPAN)	MANUFACTURER
TAI LING MOTOR COMPANY LTD. (TAIWAN)	MANUFACTURER
VOR MOTORI (ITALY)	MANUFACTURER

YAMAHA MOTOR COMPANY LTD. (JAPAN)	MANUFACTURER

2.5.1.1 Engine Manufacturers

For the majority of off-highway motorcycles, the vehicle manufacturer is also the engine manufacturer. However, a few motorcycle manufacturers use engines produced by other firms. ATK Motorcycles and CCM Motorcycles Ltd. use Bombardier/Rotax engines, while the Tai Ling Motor Company uses Suzuki engines. A Spanish manufacturer, Gas Gas Motos, SA, noted primarily for its observed trials machines, produces some of its own engines and buys others from Cagiva, a large Italian manufacturer. One U.S. manufacturer, Rokon, markets a low-production trail motorcycle resembling a large motorscooter, which is intended for hunters and fishermen. Rokon uses industrial-type engines made by Honda and other manufacturers which again would fall under the EPA Small SI regulations. Rokon is therefore not included here.

2.5.1.2 Equipment Manufacturers

Our contractor has identified some 24 firms that manufacture off-highway motorcycles for the U.S. market. Six of these are U.S. manufacturers. With the exception of Connondale, which is primarily a bicycle manufacturer, all of them produce only motorcycles. Italy has five manufacturers. One of these, Cagiva, is mainly a producer of on-highway motorcycles. Piaggio is primarily a motorscooter manufacturer; Betamotor makes motorscooters and trials bikes. Lem and Polini manufacturer youth motorcycles. Spanish manufacturers of off-highway motorcycles that are imported to the U.S. include Gas Gas, primarily an observed trials bike manufacturer, and Montesa, which is owned by Honda. Other manufacturing companies whose products are imported into the U.S. market are also found in Austria, Belarus, Ireland, Korea, Sweden, Taiwan, and the United Kingdom. KTM, an Austrian company with a U.S. branch, is one of the five major producers for the U.S. market.

2.5.2 Applications

As noted above, off-highway motorcycles can be used for recreational purposes or for competition. EPA defines vehicles that are “used solely for competition” as those with features (not easily removable from the vehicle) that would make the vehicle’s use in other recreational activities unsafe, impractical, or highly unlikely. EPA’s noise regulations also exempt any off-highway motorcycle that is designed and marketed solely for use in closed-course competition.

Certain types of off-highway motorcycles are designed and marketed for closed-course competition. These are commonly known as “motocross bikes.” We have information from our contractor indicating that some 12-14 percent of off-highway motorcycles produced from 1996 to 2000 were motocross bikes. Other sources have estimated motocross to be closer to 30 percent of off-highway sales.[8] Other types of competition motorcycles are the observed trials machines mentioned above, which emphasize handling ability rather than speed, and the so-called “enduro bikes.” Enduro bikes are designed for cross-country type racing, rather than closed-course competition. As such, they do have need for some of the equipment normally found on non-racing machines, such as spark arrestors (required by U.S. Forest Service regulations) and at least minimal lighting packages, but are exempt from the muffler requirement contained in the EPA noise regulations.

Whether for competition or recreational use, off-highway motorcycles are operated under transient conditions that include a wide variety of speeds and load factors.

2.5.3 Engine Design and Operation

Off-highway motorcycle engines have traditionally been about two-thirds smaller and less powerful than those used in on-highway cycles. For 2000, about 68 percent of the models produced were less than 300cc displacement, and half of these were 100cc or less. Percentages for the top five producers were approximately the same as for the industry as a whole. The distribution of engine sizes tends to be somewhat bimodal, with another 14 percent of the total falling into the 500-700cc range. (See Figure 2.5.2) This is likely because of the increase in the number of four-stroke engines in recent years, most of which tend to fall in the larger (500-700cc) displacement ranges. Unlike on-highway motorcycles, our contractor found no off-highway engines larger than 700cc.

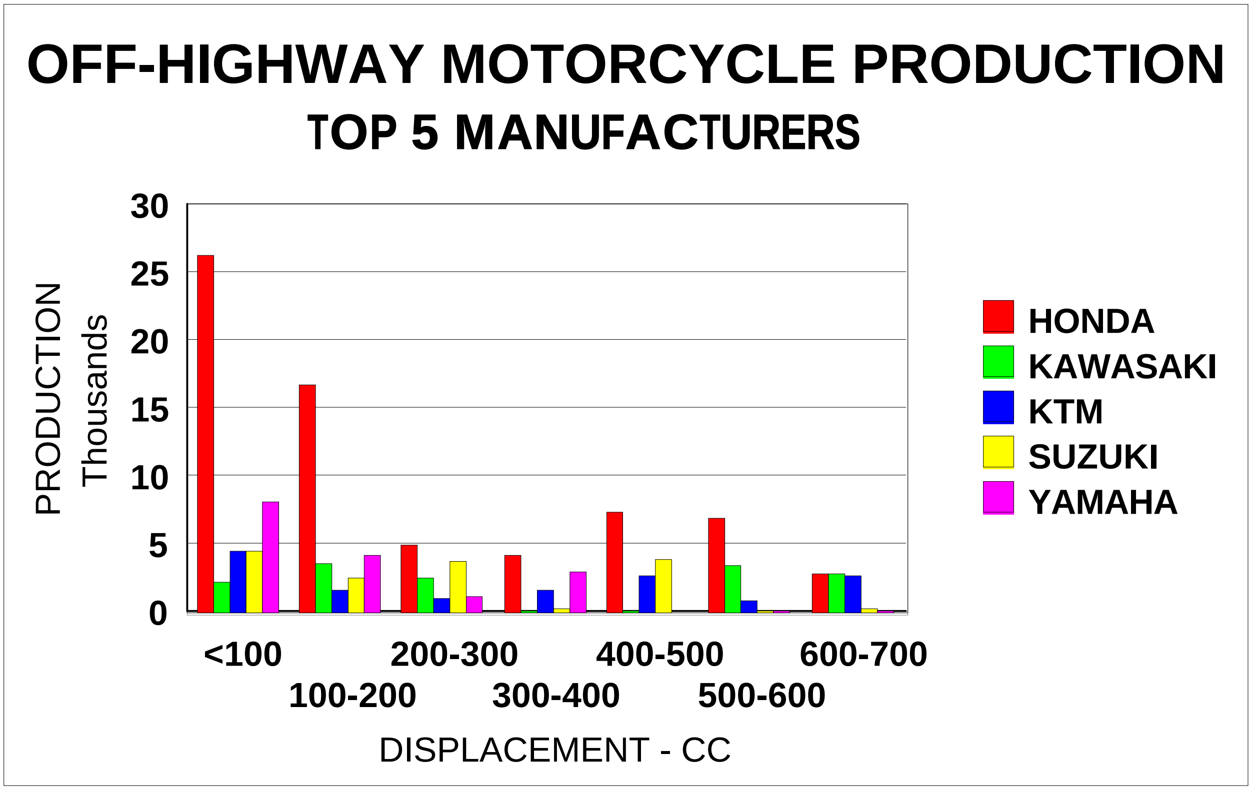

Figure 2.5.2

2.5.3.1 Two-Stroke vs Four-Stroke Cycle Engine Usage

Data from our contractor, using the PSR database, indicate that slightly more than half of the off-highway motorcycles produced for sale in the United States are powered by four-stroke cycle engines. However, estimates from MIC place the percentage of two-stroke sales at more than 60 percent. The percentage of two-strokes varies considerably by manufacturer. Honda, which accounts for more than 45 percent of this production, is predominantly a four-stroke manufacturer. Four-strokes comprise about two-thirds of its production. For Yamaha, the percentage is about 57 percent. The remainder of the foreign and domestic producers make more two-stroke engines than four-strokes. For the other top-five producers, KTM, Kawasaki and Suzuki, the percentage of two-stroke engines varies from 58 to 72 percent, and can be even higher (up to 100 percent) for some of the remaining manufacturers on the list.

Two-stroke engines are normally used in two primary applications: (1) racing machines, because they tend to have a higher power-to-weight ratio than four-stroke engines (this is important for competition, especially in the smaller displacement classes), and (2) youth model or entry-level motorcycles, because two-strokes are cheaper to produce than four-strokes. Since youth or entry-level motorcycles also tend to have smaller displacement engines, the higher power-to-weight ratio of the two-stroke tends to provide a little better performance. However, there has been a growing tendency in recent years for manufacturers to bring out more new four-stroke engines, particularly in the higher displacement ranges. This is also true in their competition lines.

2.5.3.2 Use of Engines in Other Applications

Only a few engine lines, primarily among the top five producers, are used in both off-highway and on-highway motorcycles. Part of the reason for this is because over half of the off-highway bikes use two-stroke engines, whereas there are almost no two-stroke engines to be found in on-highway motorcycles. Also, as noted above, off-highway motorcycles generally have much smaller displacement engines than their on-highway counterparts. Off-highway motorcycle engines are closer in terms of engine size to ATV engines. However, ATVs also use predominantly four-stroke engines and these are not as likely to be highly-tuned for performance as are many off-highway motorcycle engines.

2.5.3.3 Customer Concerns

Performance is highly important to motocross and other racers. The competitive segment is consistent in its demand for machines with higher power-to-weight ratios that will make them more competitive in racing circles. Light weight is an important aspect of this equation, since it allows easier handling in difficult situations, in addition to increasing performance. Performance is also important in other portions of the market as well. There seems to be a certain amount of status involved in owning a really high-performance machine, and this may outweigh some of the disadvantages of ownership. Durability and reliability may be of less importance to this type of consumer, although they are important to professional racers.

Except for a few dual-purpose machines, off-highway motorcycles are purely recreational in nature, and not suitable for day-to-day personal transportation. Unless the purchaser is an all-out competition model customer, price can therefore be an important consideration to an off-highway motorcycle purchaser. The price of a dirt bike can range from about $1,500 for a 50cc entry-level model to $8,000 for a larger high performance machine. Along with other recreational machines, off-highway motorcycles are discretionary purchases. Significant cost increases could therefore result in decreased sales of these motorcycles, as potential customers turned to other recreational opportunities for spending their discretionary income. Again, this is most likely in the youth/entry level segment of the market. At the other end of the spectrum, cost is relatively unimportant to the high-end motocross or other competitors.

Chapter 2 References

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4. National Marine Manufacturers Association -http:/www.nmma.org

5.“The Role of Propane in the Fork Lift/Industrial Truck Market: A Study of its Status, Threats, and Opportunities,” Robert E. Myers for the National Propane Gas Association, December 1996, Docket A-98-01, Document II-D-2.

6. “Industry Characterization of Non-Road Recreational Vehicles,” ICF Consulting, September, 2001.

7. See 40CFR Part 90, Subpart B.

8. “Year 2000 Facts & Figures,” *Dirt Bike* Magazine, September, 2000.

CHAPTER 3: Technology

This chapter describes the current state of spark-ignition technology for engines, evaporative emission technology, and compression-ignition technology for marine engines, as well as the emission control technologies expected to be available for manufacturers. Chapter 4 presents the technical analysis of the feasibility of the proposed standards.

3.1 Introduction to Spark-Ignition Engine Technology

The two most common types of engines are gasoline-fueled engines and diesel-fueled engines. These engines have very different combustion mechanisms. Gasoline-fueled engines initiate combustion using spark plugs, while diesel fueled engines initiate combustion by compressing the fuel and air to high pressures. Thus these two types of engines are often more generally referred to as "spark-ignition" and "compression-ignition" (or SI and CI) engines, and include similar engines that used other fuels. SI engines include engines fueled with LPG and CNG.

3.1.1 Four-Stroke Engines

Four-stroke engines are used in many different applications. Virtually all automobiles and many trucks are powered by four-stroke SI engines. Four-stroke engines are also very common in motorcycles, all-terrain vehicles (ATVs), boats, airplanes, and numerous nonroad applications such as lawn mowers, lawn and garden tractors, and generators, to name just a few.

A “four-stroke” engine gets it’s name from the fact that the piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, power, and exhaust. Two of the strokes are downward (intake & power) and two of the strokes are upward (compression & exhaust). Valves in the combustion chamber open and close to route gases into and out of the combustion chamber or create compression.

The first step of the cycle is for an intake valve in the combustion chamber to open during the “intake” stroke allowing a mixture of air and fuel to be drawn into the cylinder while an exhaust valve is closed and the piston moves down the cylinder. The piston moves from top dead center (TDC) or the highest piston position to bottom dead center (BDC) or lowest piston position. This creates a vacuum or suction in the cylinder, which draws air and fuel past the open intake valve into the combustion chamber.

The intake valve then closes and the momentum of the crankshaft causes the piston to move back up the cylinder from BDC to TDC, compressing the air and fuel mixture. This is the “compression” stroke. As the piston nears TDC, at the very end of the compression stroke, the air and fuel mixture is ignited by a spark from a spark plug and begins to burn. As the air and fuel mixture burns, increasing temperature and pressure cause the piston to move back down the cylinder, transmitting power to the crankshaft. This is referred to as the “power” stroke. The last stroke in the four-stroke cycle is the “exhaust” stroke. At the bottom of the power stroke, an exhaust valve opens in the combustion chamber and as the piston moves back up the cylinder, the burnt gases are pushed out through the exhaust valve to the exhaust manifold, and the cycle is complete.

3.1.2 Two-Stroke Engines

Two-stroke SI engines are widely used in nonroad applications, especially for recreational vehicles, such as snowmobiles, off-highway motorcycles and ATVs. The basic operating principle of the charge scavenged two-stroke engine (traditional two-stroke) is well understood; in two-strokes the engine performs the operations of intake, compression, expansion and exhaust, which the four-stroke engine requires four strokes to accomplish. Two-stroke engines have several advantages over traditional four-stroke engines for use in recreational vehicles: high power-to-weight ratios; simplicity; ease of starting; and lower manufacturing costs. However, they also have much higher emission rates.

Another difference between two- and four-stroke engines is how the engines are lubricated. Four-stroke engines use the crankcase as a sump for lubricating oil. Oil is distributed throughout the engine by a pump through a series of small channels. Because the crankcase in a two-stroke engine serves as the pump for the scavenging process, it is not possible to use it as an oil sump as is the case for four-stroke engines. Otherwise, gasoline would mix with the oil and dilute it. Instead, lubrication for two-stroke engines is provided by mixing specially-formulated two-stroke oil with the incoming charge of air and fuel mixture. The oil is either mixed with the gasoline in the fuel tank, or metered into the gasoline as it is consumed, using a small metering pump. As the gasoline/oil mixture passes through the carburetor, it is atomized into fine droplets and mixed with air. The gasoline quickly vaporizes, while the less volatile oil forms a fine mist of fine droplets. Some of these droplets contact the crankshaft, piston pin, and cylinder walls, providing lubrication. Most of the oil droplets, however, pass out of the crankcase and into the cylinder with the rest of the incoming charge.

In a two-stroke engine, combustion occurs in every revolution of the crankshaft. Two-stroke engines eliminate the intake and exhaust strokes, leaving only compression and power strokes. This is due to the fact that two-stroke engines do not use intake and exhaust valves. Instead, they have openings, referred to as “ports,” in the sides of the cylinder walls. There are typically three ports in the cylinder; an intake port that brings the air-fuel mixture into the crankcase; a transfer port that channels the air and fuel mixture from the crankcase to the combustion chamber; and an exhaust port that allows burned gases to leave the cylinder and flow into the exhaust manifold. Two-stroke engines route incoming air and fuel mixture first into the crankcase, then into the cylinder via the transfer port. This is fundamentally different from a four-stroke engine which delivers the air and fuel mixture directly to the combustion chamber.

With a two-stroke engine, as the piston approaches the bottom of the power stroke, it uncovers exhaust ports in the wall of the cylinder. The high pressure burned combustion gases blow into the exhaust manifold. At the same time, downward piston movement compresses the fresh air and fuel mixture charge in the crankcase. As the piston gets closer to the bottom of the power stroke, the transfer ports are uncovered, and fresh mixture of air and fuel are forced into the cylinder while the exhaust ports are still open. Exhaust gas is "scavenged" or forced into the exhaust by the pressure of the incoming charge of fresh air and fuel. In the process, however, some mixing between the exhaust gas and the fresh charge of air and fuel takes place, so that some of the fresh charge is also emitted in the exhaust. Losing part of the fuel out of the exhaust during scavenging causes the very high hydrocarbon emission characteristics of two-stroke engines.

At this point, the power, exhaust, and transfer events have been completed. When the piston begins to move up, its bottom edge uncovers the intake port. Vacuum draws fresh air and fuel into the crankcase. As the piston continues upward, the transfer port and exhaust ports are closed. Compression begins as soon as the exhaust port is blocked. When the piston nears TDC, the spark plug fires and the cycle begins again.

3.1.3 Engine Calibration

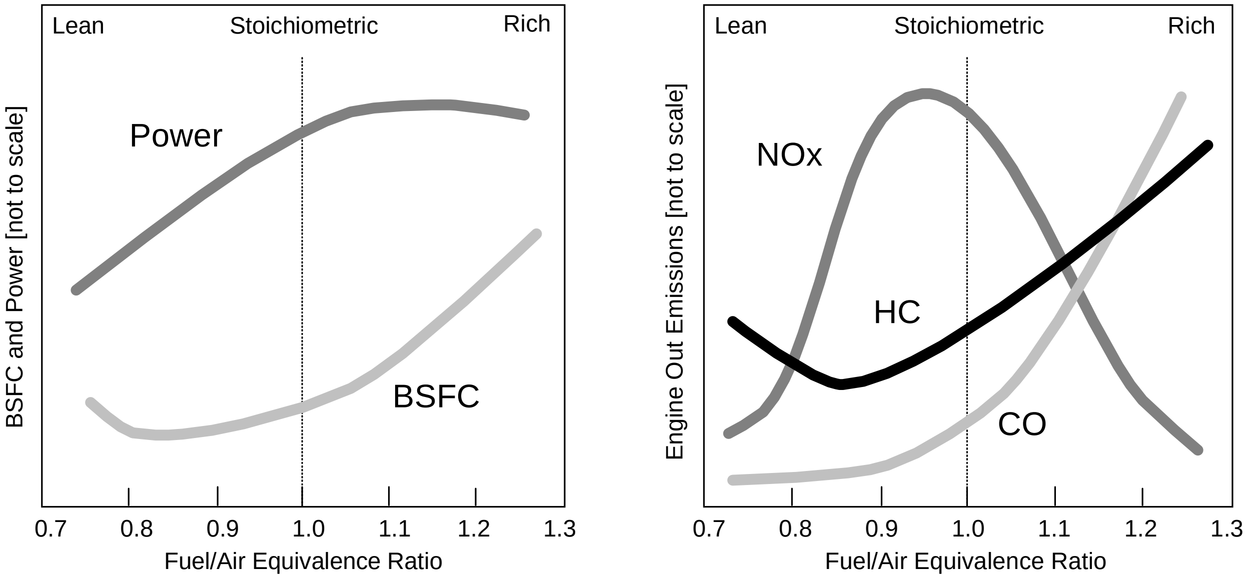
For most current SI engines, the two primary variables that manufacturers can control to reduce emissions are the air and fuel mixture (henceforth referred to as air-fuel ratio) and the spark timing. For highway motorcycles, these two variables are the most common methods for controlling exhaust emissions. However, for many nonroad engines and vehicles, the absence of emission standards have resulted in air-fuel ratio and spark timing calibrations optimized for engine performance and durability rather than for low emissions.

3.1.3.1 Air-fuel ratio

The calibration of the air-fuel mixture affects power, fuel consumption (referred to as Brake Specific Fuel Consumption (BSFC)), and emissions for SI engines. The effects of changing the air-fuel mixture are shown in Figure 3-1.[1] Traditionally, in most nonroad SI applications, manufacturers have calibrated their fuel systems for rich operation for two main advantages. First, by running the engine rich, manufacturers can reduce the risk of lean misfire due to imperfect mixing of the fuel and air and variations in the air-fuel mixture from cylinder to cylinder. Second, by making extra fuel available for combustion, it is possible to get more power from the engine. At the same time, since a rich mixture lacks sufficient oxygen for full combustion, it results in increased fuel consumption rates and higher HC and CO emissions. As can be seen from the figure, the best fuel consumption rates occur when the engine is running lean.

With the use of more advanced fuel systems, manufacturers would be able to improve control of the air-fuel mixture in the cylinder. This improved control allows for leaner operation without increasing the risk of lean misfire. This reduces HC and CO emissions and fuel consumption. Leaner air-fuel mixtures, however, increase NOx emissions due to the higher temperatures and increased supply of oxygen.

Figure 3-1: Effects of Air-fuel Ratio on Power, Fuel Consumption, and Emissions



3.1.3.2 Spark-timing:

For each engine speed and air-fuel mixture, there is an optimum spark-timing that results in peak torque. If the spark is advanced to an earlier point in the cycle, more combustion occurs during the compression stroke. If the spark is retarded to a later point in the cycle, peak cylinder pressure is decreased because too much combustion occurs later in the expansion stroke when it generates little torque on the crankshaft. Timing retard may be used as a strategy for reducing NOx emissions, because it suppresses peak cylinder temperatures that lead to high NOx levels. Timing retard also results in higher exhaust gas temperatures, because less mechanical work is extracted from the available energy. This may have the benefit of warming catalyst material to more quickly reach the temperatures needed to operate effectively during light-load operation.[2] Some automotive engine designs rely on timing retard at start-up to reduce cold-start emissions.

Advancing the spark-timing at higher speeds gives the fuel more time to burn. Retarding the spark timing at lower speeds and loads avoids misfire. With a mechanically controlled engine, a fly-weight or manifold vacuum system adjusts the timing. Mechanical controls, however, limit the manufacturer to a single timing curve when calibrating the engine. This means that the timing is not completely optimized for most modes of operation.

3.1.3.3 Fuel Metering

Fuel injection has proven to be an effective and durable strategy for controlling emissions and reducing fuel consumption from highway gasoline engines. Comparable upgrades are also available for gaseous fuels. This section describes a variety of technologies available to improve fuel metering.

Throttle-body gasoline injection: A throttle-body system uses the same intake manifold as a carbureted engine. However, the throttle body replaces the carburetor. By injecting the fuel into the intake air stream, the fuel is better atomized than if it were drawn through with a venturi. This results in better mixing and more efficient combustion. In addition, the fuel can be more precisely metered to achieve benefits for fuel economy, performance, and emission control.

Throttle-body designs have the drawback of potentially large cylinder-to-cylinder variations. Like a carburetor, TBI injects the fuel into the intake air at a single location upstream of all the cylinders. Because the air-fuel mixture travels different routes to each cylinder, the amount of fuel that reaches each cylinder will vary. Manufacturers account for this variation in their design and may make compromises such as injecting extra fuel to ensure that the cylinder with the leanest mixture will not misfire. These compromises affect emissions and fuel consumption.

Multi-port gasoline injection: As the name suggests, multi-port fuel injection means that a fuel injector is placed at each of the intake ports. A quantity of fuel is injected each time the intake valve opens for each cylinder. This allows manufacturers to more precisely control the amount of fuel injected for each combustion event. This control increases the manufacturer’s ability to optimize the air-fuel ratio for emissions, performance, and fuel consumption. Because of these benefits, multi-port injection is has been widely used in automotive applications for over 15 years.

Sequential injection has further improved these systems by more carefully timing the injection event with the intake valve opening. This improves fuel atomization and air-fuel mixing, which further improves performance and control of emissions.

A newer development to improve injector performance is air-assisted fuel injection. By injecting high pressure air along with the fuel spray, greater atomization of the fuel droplets can occur. Air-assisted fuel injection is especially helpful in improving engine performance and reducing emissions at low engine speeds. In addition, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold. On a highway 3.8-liter engine with sequential fuel injection, the air assist was shown to reduce HC emissions by 27 percent during cold-start operating conditions. At wide-open-throttle with an air-fuel ratio of 17, the HC reduction was 43 percent when compared with a standard injector.[3]

3.1.4 Alternate Fuels

2. Gaseous-fuel engines

Engines operating on LPG or natural gas carry compressed fuel that is gaseous at atmospheric pressure. The technical challenges for gasoline related to an extended time to vaporize the fuel don’t apply to gaseous-fuel engines. Typically, a mixer introduces the fuel into the intake system. Manufacturers are pursuing new designs to inject the fuel directly into the intake manifold. This improves control of the air-fuel ratio and the combustion event, similar to the improvements in gasoline injection technology.

3.2 Exhaust Emissions and Control Technologies

3.2.1 Current Two-Stroke Engines

As discussed above, two-stroke engines are typically found in applications where light weight, low cost, simplistic design, easy starting, and high power-to-weight ratio are desirable attributes. Of the engines and vehicles and covered by this proposal, the engines found in recreational vehicles tend to have a high percentage of two-stroke engines. For example, all snowmobiles use two-stroke engines, while 40 percent of off-highway motorcycles are equipped with two-strokes. Approximately 15 percent of all ATVs use two-stroke engines.

California ARB has had exhaust emission standards for off-highway motorcycles and ATVs since 1996. However, the regulations allow the sales and use of non-certified vehicles within the state. Thus, recreational vehicles equipped with two-stroke engines have essentially been unregulated. As a result, two-stroke engines used in recreational vehicles are typically designed for optimized performance and durability rather than low emissions. Current two-stroke engines emit extremely high levels of HC and CO emissions. The scavenging of unburned fuel into the exhaust contributes to the bulk of the HC emissions. Up to 30 percent[b] of the air and fuel mixture (along with lubricating oil) can pass unburned from the combustion chamber to the exhaust, resulting not only in high levels of HC, but also in high levels of particulate matter (PM). As discussed above, two-stroke engines lubricate the engine by mixing specially-formulated two-stroke oil with gasoline. As the gasoline/oil mixture passes through the carburetor, it is atomized into fine droplets and mixed with air. The gasoline quickly vaporizes, while the less volatile oil forms a fine mist of fine droplets. Some of these droplets contact the crankshaft, piston pin, and cylinder walls, providing lubrication. Most of the oil droplets, however, pass out of the crankcase and into the cylinder with the rest of the incoming charge. Much of this oil mist will be trapped in the cylinder and burned along with the gasoline vapor. Since lubricating oil is less combustible than gasoline, some of the oil will survive the combustion process in the cylinder and be passed into the exhaust. In the hot exhaust, the oil may vaporize, however, as the exhaust cools and through mixing with air after it is emitted, the oil vapor recondenses into very fine droplets or particles and enter the atmosphere as PM.

Another major source of unburned HC emissions from two-stroke engines is due to misfire or partial combustion at light loads. Under light load conditions such as idle, the flow of fresh air and fuel into the cylinder is reduced, and substantial amounts of exhaust gas are retained in the cylinder. This high fraction of residual gas leads to incomplete combustion or misfire,

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[b] Hare et al, 1974; Batoni, 1978; Nuti and Martorano, 1985

which is the source of the "popping" sound produced by two-stroke engines at idle and light loads. These unstable combustion events are major sources of unburned HC at idle and light load conditions.[c]

High CO levels from two-stroke engines are a result of operating the engine at rich air and fuel mixture levels to promote engine cooling and enhance performance. Two-stroke engines typically have very low levels of NOx emissions due to relatively cool combustion temperatures. Two-stroke engines have cooler combustion temperatures as a result of two phenomenon: rich air and fuel mixture operation and internal exhaust gas recirculation. Two-stroke engines tend to operate with a rich air and fuel mixture to increase power and to help cool the engine. Because many two-stroke engines are air-cooled, the extra cooling provided by operating rich is a desirable engine control strategy. Combustion with a rich air and fuel mixture results in some incomplete combustion which means less efficient combustion and a lower combustion temperature. High combustion temperature is the main variable in producing NOx emissions. Two-stroke engines also tend to have a high levels of naturally occurring exhaust gas recirculation due to the scavenging process where some of the burned gases are drawn back into the cylinder rather than being emitted out into the exhaust. The addition of burned exhaust gas into the fresh charge of air and fuel mixture in the combustion chamber also results in less complete or efficient combustion, which lowers combustion temperatures and reduces NOx emissions.

HC emissions for recreational vehicle two-stroke engines are approximately 25 times higher than for recreational vehicle four-stroke emissions. CO levels are roughly the same for both types of engines, while NOx levels are 1.5 times lower than four-stroke engine levels. Table 3.2-1 shows two-stroke emission results for several off-highway motorcycles and ATVs tested by and for EPA in grams per kilometer (g/km). Table 3.2-2 shows two-stroke emission results from snowmobiles in grams per horsepower-hour (g/hp-hr).

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[c] Tsuchiya et al, 1983; Abraham and Prakash, 1992; Aoyama et al, 1977

Table 3.2-1
Baseline Two-Stroke Emissions From Off-Highway Motorcycles & ATVs (g/km)

MC or ATV	Manufacturer	Model	Model Year	Eng. Displ.	HC	CO	NOx
ATV	Suzuki	LT80	1998	80 cc	7.66	24.23	0.047
ATV	Polaris	Scrambler 80	2001	90 cc	38.12	25.08	0.057
MC	KTM	125SX	2001	125 cc	33.71	31.01	0.008
MC	KTM	125SX	2001	125 cc	61.41	32.43	0.011
MC	KTM	200EXC	2001	200 cc	53.09	39.89	0.025
MC	Honda	n/a	1993	200 cc	8.00	16.00	0.010
MC	Honda	n/a	1993	200 cc	26.00	28.00	1.010
MC	Honda	n/a	1995	249 cc	12.00	21.00	0.010
MC	Honda	CR250R	1997	249 cc	17.47	36.62	0.004
MC	Honda	n/a	1998	249 cc	23.00	36.00	0.010
MC	KTM	250SX	2001	249 cc	62.89	49.29	0.011
MC	KTM	250EXC	2001	249 cc	59.13	40.54	0.016
MC	KTM	300EXC	2001	298 cc	47.39	45.29	0.0124
Average					34.61	32.72	0.095

Table 3.2-2
Baseline Two-Stroke Emissions From Snowmobiles (g/hp-hr)

Source	Eng. Displ.	HC	CO	NOx	PM
Carroll 1999 (SwRI) YNP	480 cc	115	375	0.69	0.7
White et al. 1997	488 cc	150	420	0.42	1.1
White et al. 1997	440 cc	160	370	0.50	3.4
Hare & Springer 1974	436 cc	89	142	1.40	6.1
Hare & Springer 1974	335 cc	120	235	1.80	2.5
Hare & Springer 1974	247 cc	200	63	3.40	2.6
Wright & White 1998	440 cc	130	380	0.42	n/a
Wright & White 1998	503 cc	105	400	0.73	n/a
ISMA #1	600 cc	110	218	0.86	n/a
ISMA #2	440 cc	95	312	1.62	n/a
ISMA #3	600 cc	106	196	1.30	n/a
ISMA #4	900 cc	95	215	0.84	n/a
ISMA #5	698 cc	92	298	0.34	n/a
ISMA #6	597 cc	100	328	0.30	n/a
ISMA #7	695 cc	88	345	0.24	n/a
ISMA #8	485 cc	148	385	0.56	n/a
ISMA #9	340 cc	104	297	0.84	n/a
ISMA #10	440 cc	95	294	0.56	n/a
ISMA #11	600 cc	94	262	0.81	n/a
ISMA #12	700 cc	102	355	0.69	n/a
ISMA #13	593 cc	67	288	0.57	n/a
ISMA #14	494 cc	105	400	0.43	n/a

ISMA #15	699 cc	92	276	0.50	n/a
Average		111	298	0.86	2.7

3.2.2 Clean Two-Stroke Technologies

Technologies available for reducing two-stroke emissions can be grouped into several categories: calibration improvements; combustion chamber modifications; improved scavenging characteristics; advanced fuel metering systems; and exhaust aftertreatment technologies.

3.2.2.1 Calibration Improvements

The vast majority of two-stroke engines used in recreational vehicles use a carburetor as the means of metering the air and fuel that is supplied to the engine. The carburetion system supplies a controlled mixture of air and fuel to the engine, taking into consideration engine temperature and load and speed, while trying to optimize engine performance and fuel economy. A carburetor is a mechanical fuel atomizing device. It uses the venturi or Bernoulli's principle, which is based on pressure differences, to draw fuel into the air stream from a small reservoir (known as the "bowl"). A venturi is a restriction formed in the carburetor throat. As air passes through the venturi, it causes an increase in air velocity and creates a vacuum or low pressure. The fuel in the bowl is under atmospheric pressure. The higher pressure fuel will flow to the lower pressure (vacuum) created in the airstream by the venturi. The fuel is atomized (broken into small droplets) as it enters the airstream.

As discussed above in section 3.1.3.1, the calibration of the air-fuel mixture affects power, fuel consumption, and emissions. Traditionally, in most recreational vehicles using two-stroke engines, manufacturers have calibrated their fuel systems for rich operation for two main advantages. First, by running the engine rich, manufacturers can reduce the risk of lean misfire due to imperfect mixing of the fuel and air and variations in the air-fuel mixture from cylinder to cylinder. Second, by making extra fuel available for combustion, it is possible to get more power from the engine. At the same time, since a rich mixture lacks sufficient oxygen for full combustion, it results in increased fuel consumption rates and higher HC and CO emissions.

One means of reducing HC and CO emissions from two-stroke engines is to calibrate the air-fuel ratio for lower emissions. This means leaning the air-fuel mixture, so that there is more oxygen available to oxidize HC and CO. This strategy appears simplistic, but the manufacturer has to not only optimize the air-fuel ratio for emissions, but also allow acceptable performance and engine cooling. This means that the air-fuel ratio must not be leaned to the point of causing lean misfire or substantially reduced power. However, since it is common for manufacturers to set-up their carburetors to operate overly rich, there is opportunity for better optimization of carburetor air-fuel settings to account for performance, engine cooling and lower emissions.

3.2.2.2 Combustion Chamber Modifications

For two-stroke engines, if modifications are made to air-fuel calibrations that result in leaner operation, one of the main concerns is that the combustion temperature will increase and result in engine damage. It is fairly common for two-stroke engines to seize the piston in the cylinder if they operate at too high of combustion temperatures. Piston seizure results when combustion chamber temperatures become excessive and the piston heats-up and expands until it becomes lodged or seizes in the cylinder. Depending on the level of enleanment used to control HC and CO emissions, it may be necessary to also incorporate modifications to the combustion chamber. Combustion chamber and piston configuration can be improved to induce more swirl and squish or turbulent motions during the compression stroke, as well as control the flow direction of the air and fuel mixture as it enters the combustion chamber to minimize short-circuiting (unburned fuel leaving thru the exhaust port). Increasing turbulence in the combustion chamber improves thermal efficiency by increasing the rate of burning in the chamber, which results in lower combustion temperatures. Improved combustion chamber and piston configurations can also minimize the formation of pocket or dead zones in the cylinder volume where unburned gases can become trapped. Many engine designs induce turbulence into the combustion chamber by increasing the velocity of the incoming air-fuel mixture and having it enter the chamber in a swirling motion (known as “swirl”).

3.2.2.3 Improved Scavenging Characteristics

As discussed above, the exhaust and intake events for two-stroke engines overlap extensively, resulting in considerable amounts of unburned gasoline and lubricating oil passing through the engine and out the exhaust into the atmosphere. As the piston moves downward uncovering the exhaust port, a fresh charge of air and fuel enters the combustion chamber under pressure from the transfer port and pushes the burned gases from the previous combustion event out into the exhaust. Since the burned gases are pushed out of the chamber by the intake mixture, some of the fresh air and fuel mixture being introduced into the chamber are also lost through the exhaust port. The ideal situation would be to retain all of the fresh charge in the cylinder while exhausting all of the burned gases from the last cycle. This is difficult in most current two-stroke engine designs, since the cylinder ports and piston timing are generally designed for high scavenging efficiency, in order to achieve maximum power and a smoother idle, which results in higher scavenging losses and emissions. It is possible to reconfigure the cylinder ports to fine tune the scavenging characteristics for lower emissions, but this involves significant trade-offs with engine performance. There are, however, several techniques that can be employed to improve scavenging losses.

Exhaust charge control technology modifies the exhaust flow by introducing one-way control valves in the exhaust, or by making use of the exhaust pressure pulse wave. In order to get increased power out of a two-stroke engine, it is imperative that the engine combust as much air and fuel as possible. Scavenging losses from two-stroke engines (called “short-circuiting”) allow a large percentage of the air and fuel to leave the combustion chamber before they can be combusted. Two-stroke engines used in recreational vehicles all tend to use an exhaust system equipped with an "expansion chamber." An expansion chamber is typically made of two cones, one diverging and the other converging, with a short straight section of pipe between the two cones. As the exhaust pulse leaves the exhaust port and enters the exhaust pipe, it travels through the diverging cone and expands. The expanded pulse travels through the straight section of pipe and then meets the converging cone. Upon hitting the converging cone, the exhaust pulse wave becomes a sonic wave and travels back into the combustion chamber, pushing some of the burnt exhaust gases and fresh charge of air and fuel that escaped originally.

As part of the Society of Automotive Engineers (SAE) Clean Snowmobile Challenge 2001, a college competition which encourages the development clean snowmobile technologies, Colorado State University (CSU) developed a two-stroke snowmobile engine using a supercharged "reverse uniflow" design. The reverse uniflow design incorporates an exhaust port and a crankcase pressure activated intake valve. After the ignition of the charge occurs at TDC, the high combustion pressures and expanding gases force the piston downward. As the bottom of the piston covers the exhaust port, the pressure in the crankcase increases due to a decreasing volume. The increasing pressure is transmitted to the check-valve diaphragm. As the piston fully uncovers the exhaust port, the exhaust gases are expelled out of the port, and the cylinder pressure goes to approximately atmospheric pressure. Due to the larger pressure in the crankcase (and thus on the diaphragm) as compared to the cylinder, the check-valve opens and the supercharged intake begins to runs into the cylinder. As the intake air is entering the cylinder, expelling the exhaust gases out of the bottom ports, a fuel injector or carburetor provides fuel into the intake air stream. After the piston reaches BDC, and begins to move back upwards, the crankcase pressure decreases. Once the piston moves past the exhaust port, the crankcase pressure returns to approximately atmospheric pressure, and the check-valve completely closes. The piston continues up, compressing the air-fuel mixture until the point that ignition can once again occur, completing the cycle.

3.2.2.4 Advanced Fuel Metering Systems

The most promising technology for reducing emissions from two-stroke engines are advanced fuel metering systems, otherwise known as fuel injection systems. For two-stroke engines, there are two types of fuel injection systems available. The first system is electronic fuel injection (EFI), similar to what exists on automobiles. This system consists of an electronic fuel injector, an electronic fuel pump, pressurized fuel lines and an electronic control unit (ECU) or computer. EFI also requires the use of various sensors to provide information to the ECU so that precise fuel control can be delivered. These sensors typically monitor temperature, throttle position and atmospheric pressure. The use of EFI can provide better atomization of the fuel and more precise fuel delivery than found with carburetors, which can reduce emissions. EFI systems also have the advantage of providing improved power and fuel economy, when compared to a carburetor. However, EFI does not address the high emission resulting from short-circuiting or scavenging losses.

The second type of fuel injection system, known as Direct Injection (DI), does address scavenging losses. DI systems are very similar to EFI systems, since both are electronically controlled systems. The main difference is that DI systems more fully atomize (i.e., break-down into very small droplets) the fuel, which can greatly improve combustion efficiency resulting in improved power and reduced emissions. DI engines pump only air into the cylinder, rather than air and fuel. Finely atomized fuel is then injected into the combustion chamber once all of the ports are closed. This eliminates the short-circuiting of fresh air and fuel into the exhaust port. The biggest problem with DI is that there is very little time for air to be pumped into the cylinder and fuel then injected after all of the ports have closed. This is overcome by the use of numerous engines sensors, a high-speed electronic control module, and software which uses sophisticated control algorithms.

DI systems have been in use for the past several years in some small motorcycle, scooter and marine applications, primarily for personal watercraft (PWC) and outboard engines. There are numerous variations of DI systems, but two primary approaches that are commercially available today: high pressure injection and air-assisted injection. There are a number of companies who have developed high pressure DI systems, but the most successful systems currently belong to FICHT and Yamaha. The FICHT system uses a special fuel injector that is able to inject fuel at very high pressure (e.g., over 250 psi). The fuel injector itself is essentially a piston that is operated by an electromagnet. Fuel enters the injector at low pressure from an electric fuel pump and is forced out of the injector nozzle at high pressure when the piston hammers down on the fuel. The Yamaha system uses a high pressure fuel pump to generate the high fuel pressure. The other DI approach that is most common in various engine applications is the air-assisted injection system which has been developed by Orbital. The Orbital system uses pressurized air to help inject the fuel into the combustion chamber. The system uses a small single cylinder reciprocating air compressor to assist in the injection of the fuel. All three systems are currently used in some marine applications by companies such as Kawasaki, Polaris, Sea-Doo, and Yamaha. The Orbital system is also currently used on some small motorcycle and scooter applications by Aprilla. Certification data from various engines certified with DI have shown HC and CO emission reductions of 60 to 75 percent from baseline emission levels.

There is at least one other injection technology that has had success in small two-stroke SI engines used in lawn and garden applications, such as trimmers and chainsaws. Compression Wave technology, referred to as Low Emission (LE) technology, developed by John Deere, uses a compressed air assisted fuel injection system, similar to the Orbital system, to reduce the unburned fuel charge during the scavenging process of the exhaust portion of the two-stroke cycle. The system has shown the ability to reduce HC and CO emissions by up to 75 percent from baseline levels. Although this technology has not yet been applied to any recreational vehicle engines, it appears to have significant potential, especially because of its simplistic design and low cost. For a detailed description of the LE technology, refer to the Nonroad Small SI regulatory support document.

3.2.2.5 Exhaust Aftertreatment Technologies

There are two exhaust aftertreatment technologies that can provide additional emission reductions from two-stroke engines: thermal oxidation (e.g., secondary air) and oxidation catalyst. Thermal oxidation reduces HC and CO by promoting further oxidation of these species in the exhaust. The oxidation usually takes place in the exhaust port or pipe, and may require the injection of additional air to supply the needed oxygen. If the exhaust temperature can be maintained at a high enough temperature (e.g., 600 to 700°C) for a long enough period, substantial reductions in HC and CO can occur. Air injection at low rates into the exhaust system has been shown to reduce emissions by as much as 77 percent for HC and 64 percent for CO.[d] However, this was effective only under high-power operating conditions, and the high exhaust temperatures required to achieve this oxidation substantially increased the skin temperature of the exhaust pipe, which can be a concern for off-highway motorcycle applications where the operators legs could come in contact with the pipe.

Like thermal oxidation, the oxidation catalyst is used to promote further oxidation of HC and CO emissions in the exhaust stream, and it also requires sufficient oxygen for the reaction to take place. Some of the requirements for a catalytic converter to be used in two-stroke engines include high HC conversion efficiency, resistance to thermal damage, resistance to poisoning from sulfur and phosphorus compounds in lubricating oil, and low light-off temperature. Additional requirements for catalysts to be used in recreational vehicle two-stroke engines include extreme vibration resistance, compactness, and light weight.

Application of catalytic converters to two-stroke engines presents a problem, because of the high concentrations of HC and CO in their exhaust. If combined with sufficient air, these high pollutant concentrations result in catalyst temperatures that can easily exceed the temperature limits of the catalyst. Therefore, the application of oxidation catalysts to two-stroke engines may first require engine modifications to reduce HC and CO and may also require secondary air be supplied to the exhaust in front of the catalyst.

Researchers of Graz University of Technology and the Industrial Technology Research Institute (ITRI) in Taiwan have published data on the application of catalytic converters in small two-stroke moped and motorcycle engines using catalytic converters. The Graz researchers focused on reducing emissions using catalysts, as well as by improving the thermodynamic characteristics of the engines, such as gas exchange and fuel handling systems, cylinder and piston geometry and configurations, and exhaust cooling systems. For HC and CO emissions, they found that an oxidation catalyst could reduce emissions by 88 to 96 percent. Researchers at ITRI successfully retrofitted a catalytic converter to a 125 cc two-stroke motorcycle engine, and demonstrated both effective emissions control and durability.[e] The Manufacturers of Emission Controls Association (MECA)in their publication titled “Emission Control of Two-and Three-

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[d] White, J.J., Carroll,J.N., Hare, C.T., and Lourenco, J.G. (1991), “Emission Control Strategies for Small Utility Engines,” SAE Paper No. 911807, Society of Automotive Engineers, Warrendale, PA, 1991.

[e] Hsien, P.H., Hwang, L.K., and Wang, H.W> (1992), “Emission Reduction by Retrofitting a 125 cc Two-Stroke Motorcycle with Catalytic Converter,” SAE Paper No. 922175, Society of Automotive Engineers, Warrendale, PA, 1992.

wheel Vehicles," published May 7, 1999, state that catalyst technology has clearly demonstrated the ability to achieve significant emissions reductions from two-stroke engines. MECA points to the success of two-stroke moped and motorcycle engines equipped with catalysts that have been operating for several years in Taiwan, Thailand, Austria, and Switzerland.

3.2.3 Current Four-Stroke Engines

Four-stroke engines are the most common engine today. Large nonroad SI engines are exclusively four-stroke. Recreational vehicles are also predominantly four-stroke. Four-stroke engines have considerably lower HC emissions than two-stroke engines, due to the fact that four-stroke engines do not experience short circuiting of raw fuel. CO emissions from four-stroke engines is very similar to two-stroke engines, since CO emissions are the result of inefficient combustion of the air-fuel mixture within the cylinder, typically resulting from rich operation. Since the combustion of fuel within the cylinder of a four-stroke engine is more efficient than that of a two-stroke engine, combustion temperatures are higher, which results in higher NOx emission levels.

The four-stroke engines covered under this proposal are typically either automotive engines (large nonroad SI) or motorcycle-like engines (including ATVs). Large nonroad SI engines, off-highway motorcycles, ATVs, and snowmobiles are unregulated federally. Therefore, while they have relatively low HC emissions compared to two-stroke engines, they can still have high levels of CO (due to rich air-fuel calibration) and NOx. Table 3.2-3 shows baseline emission levels for four-stroke equipped off-highway motorcycles and ATVs.

Table 3.2-3
Baseline Four-Stroke Emissions From Off-Highway Motorcycles & ATVs (g/km)

MC or ATV	Manufacturer	Model	Model Year	Eng. Displ.	HC	CO	NOx
MC	Yamaha	WR250F	20001	249 cc	1.46	26.74	0.110
MC	Yamaha	WR400	1999	399 cc	1.07	20.95	0.112
MC	KTM	400EXC	2001	398 cc	1.17	28.61	0.050
MC	Husaberg	FE501	2001	499 cc	1.30	25.81	0.163
ATV	Kawasaki	Bayou	1989	280 cc	1.17	14.09	0.640
ATV	Honda	300EX	1997	298 cc	1.14	34.60	0.155
ATV	Polaris	Trail Boss	1998	325 cc	1.56	43.41	0.195
ATV	Yamaha	Banshee	1998	349 cc	0.98	19.44	0.190
ATV	Polaris	Sportsman	2001	499 cc	2.68	56.50	0.295
Average					1.39	30.01	0.212

3.2.4 Clean Four-Stroke Technologies

The emission control technologies for four-stroke engines are very similar to those used for two-stroke engines. HC and CO emissions from four-stroke engines are primarily the result of poor in-cylinder combustion. Higher levels of NOx emissions are the result of leaner air-fuel ratios and the resulting higher combustion temperatures. Combustion chamber modifications can help reduce HC emission levels, while using improved air-fuel ratio and spark timing calibrations, as discussed in sections 3.1.3.1 and 3.1.3.2, can further reduce HC emissions and lower CO emissions. The conversion from carburetor to EFI will also help reduce HC and CO emissions. The use of exhaust gas recirculation on large SI engines can reduce NOx emissions, but is not necessarily needed for recreational vehicles, due to their relatively low NOx emission levels. The addition of secondary air into the exhaust can significantly reduce HC and CO emissions. Finally, the use catalytic converters can further reduce all three emissions.

3.2.4.1 Combustion chamber design

Unburned fuel can be trapped momentarily in crevice volumes (especially the space between the piston and cylinder wall) before being released into the exhaust. Reducing crevice volumes decreases this amount of unburned fuel, which reduces HC emissions. One way to reduce crevice volumes is to design pistons with piston rings closer to the top of the piston. HC may be reduced by 3 to 10 percent by reducing crevice volumes, with negligible effects on NOx emissions.[4]

HC emissions also come from lubricating oil that leaks into the combustion chamber. The heavier hydrocarbons in the oil generally don't burn completely. Oil in the combustion chamber can also trap gaseous HC from the fuel and prevent it from burning. For engines using catalytic control, some components in lubricating oil can poison the catalyst and reduce its effectiveness, which would further increase emissions over time. To reduce oil consumption, manufacturers can tighten tolerances and improve surface finishes for cylinders and pistons, improve piston ring design and material, and improve exhaust valve stem seals to prevent excessive leakage of lubricating oil into the combustion chamber.

3.2.4.2 Exhaust gas recirculation

Exhaust gas recirculation (EGR) has been in use in cars and trucks for many years. The recirculated gas acts as a diluent in the air-fuel mixture, slowing reaction rates and absorbing heat to reduce combustion temperatures. These lower temperatures can reduce the engine-out NOx formation rate by as much as 50 percent.[5] HC is increased slightly due to lower temperatures for HC burn-up during the late expansion and exhaust strokes.

Depending on the burn rate of the engine and the amount of recirculated gases, EGR can improve fuel consumption. Although EGR slows the burn rate, it can offset this effect with some benefits for engine efficiency. EGR reduces pumping work since the addition of recirculated gas increases intake pressure. Because the burned gas temperature is decreased, there is less heat loss to the exhaust and cylinder walls. In effect, EGR allows more of the chemical energy in the fuel to be converted to useable work.[6]

For catalyst systems with high conversion efficiencies, the benefit of using EGR becomes proportionally smaller. Also, including EGR as a design variable for optimizing the engine adds significantly to the development time needed to fully calibrate engine models.

3.2.4.3 Secondary air

Secondary injection of air into exhaust ports or pipes after cold start (e.g., the first 40-60 seconds) when the engine is operating rich, coupled with spark retard, can promote combustion of unburned HC and CO in the exhaust manifold and increase the warm-up rate of the catalyst. By means of an electrical or mechanical pump, secondary air is injected into the exhaust system, preferably in close proximity of the exhaust valve. Together with the oxygen of the secondary air and the hot exhaust components of HC and CO, oxidation ahead of the catalyst can bring about an efficient increase in the exhaust temperature which helps the catalyst to heat up quicker. The exothermic reaction that occurs is dependent on several parameters (secondary air mass, location of secondary air injection, engine A/F ratio, engine air mass, ignition timing, manifold and headpipe construction, etc.), and ensuring reproducibility demands detailed individual application for each vehicle or engine design.

Secondary air injection was first used as an emission control technique in itself without a catalyst, and still is used for this purpose in many highway motorcycles and some off-highway motorcycles to meet federal and California emission standards. For motorcycles, air is usually provided or injected by a system of check valves which uses the normal pressure pulsations in the exhaust manifold to draw in air from outside, rather than by a pump.

3.2.4.4 Catalytic Aftertreatment

Over the last several years, there have been tremendous advances in exhaust aftertreatment systems. Catalyst manufacturers are progressively moving to palladium (Pd) as the main precious metal in automotive catalyst applications. Improvements to catalyst thermal stability and washcoat technologies, the design of higher cell densities, and the use of two-layer washcoat applications are just some of the advances made in catalyst technology. There are two types of catalytic converters commonly used: oxidation and three-way. Oxidation catalysts use platinum and/or palladium to increase the rate of reaction between oxygen in the exhaust and unburned HC and CO. Ordinarily, this reaction would proceed very slowly at temperatures typical of engine exhaust. The effectiveness of the catalyst depends on its temperature, on the air-fuel ratio of the mixture, and on the mix of HC present. Highly reactive species such as formaldehyde and olefins are oxidized more effectively than less-reactive species. Short-chain paraffins such as methane, ethane, and propane are among the least reactive HC species, and are difficult to oxidize.

Three-way catalysts use a combination of platinum and/or pallabium and rhodium. In addition to promoting oxidation of HC and CO, these metals also promote the reduction of NO to nitrogen and oxygen. In order for the NO reduction to occur efficiently, an overall rich or stoichiometric air-fuel ratio is requires. The NOx efficiency drops rapidly as the ai-fuel ratio becomes leaner than stoichiometric. If the air-fuel ratio can be maintained precisely at or just rich of stoichiometic, a three-way catalyst can simultaneously oxidize HC and CO and reduce NOx. The window of air-fuel ratios within which this is possible is very narrow and there is a trade-off between NOx and HC/CO control even within this window.

There are several issues involved in designing catalytic control systems for the four-stroke engines covered by this proposal. The primary issues are the cost of the system, packaging constraints, and the durability of the catalyst. This section addresses these issues.

3.2.4.4.1. System cost

Sales volumes of industrial and recreational equipment are small compared to automotive sales. Manufacturers therefore have a limited ability to recoup large R&D expenditures for Large SI and recreational engines. For this reason, we believe it is not appropriate to consider highly refined catalyst systems that are tailored specifically to nonroad applications. For large SI engines, we have based the feasibility of the emission standards on the kind of catalysts that manufacturers have already begun to offer for these engines. These systems are currently produced in very low volumes, but the technology has been successfully adapted to Large SI engines. The cost of these systems will decrease substantially when catalysts become commonplace. This approach is also true for phase 2 ATV standards that may require catalysts for some models. Chapter 4 describes the estimated costs for a nonroad catalyst system.

3.2.4.4.2 Packaging constraints

Large SI engines power a wide range of nonroad equipment. Some of these have no significant space constraints for adding a catalyst. In contrast, equipment designs such as forklifts have been fine-tuned over many years with a very compact fit. The same is even more true for recreational vehicles, such as ATVs and motorcycles.

Automotive catalyst designs typically have one or two catalyst units upstream of the muffler. This is a viable option for most nonroad equipment. However, if there is no available space to add a separate catalyst, it is possible to build a full catalyst/muffler combination that fits in the same space as the conventional muffler. With this packaging option, even compact applications should have little or no trouble integrating a catalyst into the equipment design. The hundreds of catalysts currently operating on forklifts and highway motorcycles clearly demonstrate this.

3.2.5 Advanced Emission Controls

On February 10, 2000, EPA published new "Tier 2" emissions standards for all passenger vehicles, including sport utility vehicles (SUVs), minivans, vans and pick-up trucks. The new standards will ensure that exhaust VOC emissions be reduced to less than 0.1 g/mi on average over the fleet, and that evaporative emissions be reduced by at least 50 percent. Onboard refueling vapor recovery requirements were also extended to medium-duty passenger vehicles. By 2020, these standards will reduce VOC emissions from light-duty vehicles by more than 25 percent of the projected baseline inventory. (See Chapter 4 for a more detailed discussion of the impact of the Tier 2 FRM on VOC inventories.) To achieve these reductions, manufacturers will need to incorporate advanced emission controls, including: larger and improved close-coupled catalysts, optimized spark timing and fuel control, improved exhaust systems.

To reduce emissions gasoline-fueled vehicle manufacturers have designed their engines to achieve virtually complete combustion and have installed catalytic converters in the exhaust system. In order for these controls to work well for gasoline-fueled vehicles, it is necessary to maintain the mixture of air and fuel at a nearly stoichiometric ratio (that is, just enough air to completely burn the fuel). Poor air-fuel mixture can result in significantly higher emissions of incompletely combusted fuel. Current generation highway vehicles are able to maintain stoichiometry by using closed-loop electronic feedback control of the fuel systems. As part of these systems, technologies have been developed to closely meter the amount of fuel entering the combustion chamber to promote complete combustion. Sequential multi-point fuel injection delivers a more precise amount of fuel to each cylinder independently and at the appropriate time increasing engine efficiency and fuel economy. Electronic throttle control offers a faster response to engine operational changes than mechanical throttle control can achieve, but it is currently considered expensive and only used on some higher-price vehicles. The greatest gains in fuel control can be made through engine calibrations -- the algorithms contained in the powertrain control module (PCM) software that control the operation of various engine and emission control components/systems. As microprocessor speed becomes faster, it is possible to perform quicker calculations and to increase response times for controlling engine parameters such as fuel rate and spark timing. Other advances in engine design have also been used to reduce engine-out emissions, including: the reduction of crevice volumes in the combustion chamber to prevent trapping of unburned fuel; "fast burn" combustion chamber designs that promote swirl and flame propagation; and multiple valves with variable-valve timing to reduce pumping losses and improve efficiency. These technologies are discussed in more detail in the RIA for the Tier 2 FRM.[f]

As noted above, manufacturers are also using aftertreatment control devices to control emissions. New three-way catalysts for highway vehicles are so effective that once a TWC reaches its operating temperature, emissions are virtually undetectable.[g] Manufacturers are now working to improve the durability of the TWC and to reduce light-off time (that is, the amount of time necessary after starting the engine before the catalyst reaches its operating temperature and is effectively controlling VOCs and other pollutants). EPA expects that manufacturers will be able to design their catalyst systems so that they light off within less than thirty seconds of engine starting. Other potential exhaust aftertreatment systems that could further reduce cold-start emissions are thermally insulated catalysts, electrically heated catalysts, and HC adsorbers (or traps). Each of these technologies, which are discussed below, offer the potential for VOC reductions in the future. There are technological, implementation, and cost issues that still need to be addressed, and at this time, it appears that these technologies would not be a cost-effective means of reducing nonroad emissions on a nationwide basis.

Thermally insulated catalysts maintain sufficiently high catalyst temperatures by surrounding the catalyst with an insulating vacuum. Prototypes of this technology have demonstrated the ability to store heat for more than 12 hours.[h] Since ordinary catalysts typically cool down below their light-off temperature in less than one hour, this technology could reduce in-use emissions for vehicles that have multiple cold-starts in a single day. However, this technology would have less impact on emissions from vehicles that have only one or two cold-starts per day.

Electrically-heated catalysts reduce cold-start emissions by applying an electric current to the catalyst before the engine is started to get the catalyst up to its operating temperature more

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[f] http://www.epa.gov/otaq/tr2home.htm#Documents. EPA 420-R-99-023

[g] McDonald, J., L. Jones, Demonstration of Tier 2 Emission Levels for Heavy Light-Duty Trucks, SAE 2000-01-1957.

[h] Burch, S.D., and J.P. Biel, SULEV and "Off-Cycle" Emissions Benefits of a Vacuum-Insulated Catalytic Convert, SAE 1999-01-0461.

quickly.[i] These systems require a modified catalyst, as well as an upgraded battery and charging system. These can greatly reduce cold-start emissions, but could require the driver to wait until the catalyst is heated before the engine would start to achieve optimum performance.

Hydrocarbon adsorbers are designed to trap VOCs while the catalyst is cold and unable to sufficiently convert them. They accomplish this by utilizing an adsorbing material which holds onto the VOC molecules. Once the catalyst is warmed up, the trapped VOCs are automatically released from the adsorption material and are converted by the fully functioning downstream three-way catalyst. There are three principal methods for incorporating an adsorber into the exhaust system. The first is to coat the adsorber directly on the catalyst substrate. The advantage is that there are no changes to the exhaust system required, but the desorption process cannot be easily controlled and usually occurs before the catalyst has reached light-off temperature. The second method locates the adsorber in another exhaust pipe parallel with the main exhaust pipe, but in front of the catalyst and includes a series of valves that route the exhaust through the adsorber in the first few seconds after cold start, switching exhaust flow through the catalyst thereafter. Under this system, mechanisms to purge the adsorber are also required. The third method places the trap at the end of the exhaust system, in another exhaust pipe parallel to the muffler, because of the low thermal tolerance of adsorber material. Again a purging mechanism is required to purge the adsorbed VOCs back into the catalyst, but adsorber overheating is avoided. One manufacturer who incorporates a zeolite hydrocarbon adsorber in its California SULEV vehicle found that an electrically heated catalyst was necessary after the adsorber because the zeolite acts as a heat sink and nearly negates the cold start advantage of the adsorber. This approach has been demonstrated to effectively reduce cold start emissions.

3.2.5.1 Multiple valves and variable valve timing

Four-stroke engines generally have two valves for each cylinder, one for intake of the air-fuel mixture and the other for exhaust of the combusted mixture. The duration and lift (distance the valve head is pushed away from its seat) of valve openings is constant regardless of engine speed. As engine speed increases, the aerodynamic resistance to pumping air in and out of the cylinder for intake and exhaust also increases. Automotive engines have started to use two intake and two exhaust valves to reduce pumping losses and improve their volumetric efficiency and useful power output. Some highway motorcycles have used multiple valves for years, especially the high-performance sport motorcycles.

In addition to gains in breathing, 4-valve designs allow the spark plug to be positioned closer to the center of the combustion chamber, which decreases the distance the flame must travel inside the chamber. This decreases the likelihood of flame-out conditions in the areas of the combustion chamber farthest from the spark plug. In addition, the two streams of incoming gas can be used to achieve greater mixing of air and fuel, further increasing combustion efficiency and lowering engine-out emissions.

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[i] Laing, P.M., Development of an Alternator-Powered Electrically-Heated Catalyst System, SAE 941042.

Control of valve timing and lift take full advantage of the 4-valve configuration for even greater improvement in combustion efficiency. Engines normally use fixed-valve timing and lift across all engine speeds. If the valve timing is optimized for low-speed torque, it may offer compromised performance under higher-speed operation. At light engine loads, for example, it is desirable to close the intake valve early to reduce pumping losses. Variable-valve timing can enhance both low-speed and high-speed performance with compromise. Variable-valve timing can allow for increased swirl and intake charge velocity, especially during low-load operating conditions where this is most problematic. By providing a strong swirl formation in the combustion chamber, the air-fuel mixture can mix sufficiently, resulting in a faster, more complete combustion, even under lean air-fuel conditions, thereby reducing emissions.

Variable-valve technology by itself may have somewhat limited effect on reducing emissions, but combining it with optimized spark plug location and exhaust gas recirculation can lead to substantial emission reductions.

3.3 Evaporative Emissions

3.3.1 Sources of Evaporative Emissions

Evaporative emissions from nonroad SI equipment represents a small but significant part of their NMHC emissions. The significance of the emissions varies widely depending on the engine design and application. LPG-fueled equipment generally has very low evaporative emissions because of the tightly sealed fuel system. At the other extreme, carbureted gasoline-fueled equipment with open vented tanks can have very high evaporative emissions. Evaporative emissions can be grouped into five categories:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day, heating the fuel tank and venting gasoline vapors.

RUNNING LOSSES: The hot engine and exhaust system can vaporize gasoline when the engine is running.

HOT SOAK: The engine remains hot for a period of time after the engine is turned off and gasoline evaporation continues.

REFUELING: Gasoline vapors are always present in typical fuel tanks. These vapors are forced out when the tank is filled with liquid fuel.

PERMEATION: Gasoline molecules can saturate plastic fuel tanks and rubber hoses, resulting in a relatively constant rate of emissions as the fuel continues to permeate through these components.

Among the factors that affect emission rates are: (1) fuel metering (fuel injection or carburetor); (2) the degree to which fuel permeates fuel lines and fuel tanks; (3) the proximity of the fuel tank to the exhaust system or other heat sources; (4) whether the fuel system is sealed and the pressure at which fuel vapors are vented; and (5) fuel tank volume.

3.3.1.1 Diurnal and Running Loss Emissions

In an open fuel tank, the vapor space is at atmospheric pressure (typically about 14.7 psi), and contains a mixture of fuel vapor and air. At all temperatures below the fuel's boiling point, the vapor pressure of the fuel is less than atmospheric pressure. This is also called the partial pressure of the fuel vapor. The partial pressure of the air is equal to the difference between atmospheric pressure and the fuel vapor pressure. For example, in an open-vented fuel tank at 60°F, the vapor pressure of typical gasoline would be about 4.5 psi. In this example, the partial pressure of the air would be about 10.2 psi. Assuming that the vapor mixture behaves as an ideal gas, then the mole fractions (or volumetric fractions) of fuel vapor and air would be equal to their respective partial pressures divided by the total pressure; thus, the fuel would be 31 percent of the mixture (4.5/14.7) and the air would be 69 percent of the mixture (10.2/14.7).

Diurnal emissions occur when the fuel temperature increases, which increases the equilibrium vapor pressure of the fuel. For example, assume that the fuel in the previous example was heated to 90°F, where the vapor pressure that same typical fuel would be about 8.0 psi. To maintain the vapor space at atmospheric pressure, the partial pressure of the air would need to decrease to 6.7 psi, which means that the vapor mixture must expand in volume. This forces some of the fuel-air mixture to be vented out of the tank. When the fuel later cools, the vapor pressure of the fuel decreases, contracting the mixture, and drawing fresh air in through the vent. When the fuel is heated again, another cycle of diurnal emissions occurs. It is important to note that this is generally not a rate-limited process. Although the evaporation of the fuel can be slow, it is generally fast enough to maintain the fuel tank in an essentially equilibrium state.

Consider a typical fuel use cycle beginning with a full tank. As fuel is used by the engine, and the liquid fuel volume decreases, air is drawn into the tank to replace the volume of the fuel. (Note: the decrease in liquid fuel could be offset to some degree by increasing fuel vapor pressure caused by increasing fuel temperature.) This would continue while the engine was running. If the engine was shut off and the tank was left overnight, the vapor pressure of the fuel would drop as the temperature of the fuel dropped. This would cause a small negative pressure within the tank that would cause it to fill with more air until the pressure equilibrated. The next day, the vapor pressure of the fuel would increase as the temperature of the fuel increased. This would cause a small positive pressure within the tank that would force a mixture of fuel vapor and air out. In poorly designed gasoline systems, where the exhaust is very close to the fuel tank, the fuel can actually begin to boil. When this happens, large amounts of gasoline vapor can be vented directly to the atmosphere. Southwest Research Institute measured emissions from several large nonroad gasoline engines and found them to vary from about 12 g/day up to almost 100 g/day. They also estimated that a typical large nonroad gasoline engine in the South Coast Air Basin (the area involved in their study) would have an evaporative emission rate of about 0.4 g/kW-hr.

3.3.1.2 Hot Soak Emissions

Hot soak emissions occur after the engine is turned off, especially during the resulting temperature rise. For nonroad engines, the primary source of hot soak emissions is the evaporation of the fuel left in the carburetor bowl. Other sources can include increased permeation and evaporation of fuel from plastic or rubber fuel lines in the engine compartment.

3.3.1.3 Refueling Emissions

Refueling emissions occur when the fuel vapors are forced out when the tank is filled with liquid fuel. At a given temperature, refueling emissions are proportional to the volume of the fuel dispensed into the tank. Every gallon of fuel put into the tank forces out one-gallon of the mixture of air and fuel vapors. Thus, refueling emissions are highest when the tank is near empty. Refueling emissions are also affected by the temperature of the fuel vapors. At low temperatures, the fuel vapor content of the vapor space that is replaced is lower than it is at higher temperatures.

3.3.1.4 Permeation

The polymeric material (plastic or rubber) of which many gasoline fuel tanks and fuel hoses generally have a chemical composition much like that of gasoline. As a result, constant exposure of gasoline to these surfaces allows the material to continually absorb fuel. The outer surfaces of these materials are exposed to ambient air, so the gasoline molecules permeate through these fuel-system components and are emitted directly into the air. Permeation rates are relatively low, but emissions continue at a nearly constant rate, regardless of how much the vehicle or equipment is used. Permeation-related emissions can therefore

3.3.2 Evaporative Emission Controls

Several emission-control technologies can be used to reduce evaporative emissions. The advantages and disadvantages of the various possible emission-control strategies are discussed below. Chapter 4 presents more detail on how we expect manufacturers to use these technologies to meet proposed emission standards for the individual applications.

3.3.2.1 Sealed System with Pressure Relief

Evaporative emissions are formed when the fuel heats up, evaporates, and passes through a vent into the atmosphere. By closing that vent, evaporative emissions are prevented from escaping. However, as vapor is generated, pressure builds up in fuel tank. Once the fuel cools back down, the pressure subsides.

For forklifts, the primary application of Large SI engines, Underwriters Laboratories specifies that units operating in certain areas where fire risk is most significant must use pressurized fuel tanks. Underwriters Laboratories requires that trucks use self-closing fuel caps with tanks that stay sealed to prevent evaporative losses; venting is allowed for positive pressures above 3.5 psi or for vacuum pressures of at least 1.5 psi.[j] These existing requirements are designed to prevent evaporative losses for safety reasons. This same approach for other types of engines would similarly reduce emissions for air-quality reasons.

An alternative to using a pressure relief valve to hold vapors in the fuel tank would be to use a limited flow orifice. However, the orifice size may be so small that there would be a risk of fouling. In addition, an orifice designed for a maximum of 2 psi under worst case conditions may not be very effective at lower temperatures. One application where a limited flow orifice may be useful is if it is combined with an insulated fuel tank as discussed below.

3.3.2.2 Insulated Fuel Tank

Another option for reducing diurnal emissions is insulating the fuel tank. Rather than capturing the vapors in the fuel tank, this strategy would minimize the fuel heating which therefore minimizes the vapor generation. However, significant evaporative emissions would still occur through the vent line due to diffusion even without temperature gradients. A limited-flow orifice could be used to minimize the to loss of vapor through the vent line due to diffusion. In this case, the orifice could be sized to prevent diffusion losses without causing pressure build-up in the tank. Additional control could be achieved with the use of a pressure relief valve or a smaller limited flow orifice. Note that an insulated tank could maintain the same emission control with a lower pressure valve than a tank that was not insulated.

3.3.2.3 Volume Compensating Air Bag

Another concept for minimizing pressure in a sealed fuel tank is through the use of a volume compensating air bag. The purpose of the bag is to fill up the vapor space in the fuel tank above the fuel itself. By minimizing the vapor space, less air is available to mix with the heated fuel and less fuel evaporates. As vapor is generated in the small vapor space, air is forced out of the air bag, which is vented to atmosphere. Because the bag collapses as vapor is generated, the volume of the vapor space grows and no pressure is generated. Once the fuel tank cools as ambient temperature goes down, the resulting vacuum in the fuel tank will open the bag back up. Depending on the size of the bag, pressure in the tank could be minimized; therefore, the use of a volume compensating air bag could allow a manufacturer to reduce the pressure limit on its relief valve.

We are still investigating materials that would be the most appropriate for the construction of these bags. The bags would have to hold up in a fuel tank for years and resist permeation while at the same time be light and flexible. One such material that we are considering is fluoro-silicon fiber. Also, the bag would have to be positioned so that it did not interfere with other fuel system components such as the fuel pick-up or catch on any sharp edges

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[j] UL558, paragraphs 26.1 through 26.4

in the fuel tank.

3.3.2.4 Collapsible Bladder Fuel Tank

Probably the most effective technology for reducing evaporative emissions from fuel tanks is through the use of a collapsible fuel bladder. In this concept, a non-permeable bladder would be installed in the fuel tank to hold the fuel. As fuel is drawn from the bladder, the vacuum created collapses the bladder. Therefore, there is no vapor space and no pressure build up. Because the bladder would be sealed, there would be no vapors vented to the atmosphere. We have received comments that this would be cost prohibitive because it could double costs for smaller fuel tanks. However, bladder fuel tanks are sold today by at least one manufacturer in limited volumes.

3.3.2.5 Charcoal Canister

The primary evaporative emission control device used in automotive applications is a charcoal canister. With this technology, vapor generated in the tank is vented through a charcoal canister. The activated charcoal collects and stores the hydrocarbons. Once the engine is running, purge air is drawn through the canister and the hydrocarbons are burned in the engine. These charcoal canisters generally are about a liter in size and have the capacity to store three days of vapor over the test procedure conditions.

For industrial applications, engines are typically used frequently which would limit the size of canister needed; however, introducing an evaporative canister is a complex undertaking, requiring extensive efforts to integrate evaporative and exhaust emission-control strategies. Large SI engine manufacturers also often sell loose engines to equipment manufacturers, who would also need to integrate the new technology into equipment designs.

3.3.2.6 Floating Fuel and Vapor Separator

Another concept used in some stationary engine applications is a floating fuel and vapor separator. Generally small, impermeable plastic balls are floated in the fuel tank. The purpose of these balls is to provide a barrier between the surface of the fuel and the vapor space. However, this strategy does not appear to be viable for industrial fuel tanks. Because of the motion of the equipment, the fuel sloshes and the barrier would be continuously broken. Even small movements in the fuel could cause the balls to rotate and transfer fuel to the vapor space.

3.3.2.7 Non-permeable Materials

Another source of evaporative emissions is permeation through the walls of plastic fuel tanks and rubber hoses. In highway applications, non-permeable plastic fuel tanks are typically produced by blow molding a layer of ethylene vinyl alcohol between two layers of polyethylene. However, blow molding is expensive and requires high production volumes to be cost effective. Manufacturers of rotationally molded plastic fuel tanks generally have low production volumes and have commented that there is no low permeability material available for their production processes.

Another type of barrier technology for fuel tanks would be to treat the inside of a plastic fuel tanks with sulfur trioxide. This sulfonation process causes a reaction between the sulfur and polyethylene which creates a barrier that reduces gasoline permeation. One study shows reductions in gasoline permeation of 90% through the sulfonation process.[7]

By replacing rubber hoses with non-permeable lines, the evaporative emissions through the fuel and vent hoses can be prevented. An added benefit is that these non-permeable lines are non-conductive and can prevent the buildup of static charges. These non-permeable lines are used in automotive applications.

3.4 CI Recreational Marine Engines

In this section, we discuss how emissions can be reduced from compression-ignition (CI) recreational marine engines. We believe recreational marine diesel engines can use the same technology for reducing emissions that will be used to meet the standards for commercial marine diesel engines.[8] Because of the similarities between recreational and commercial diesel engines, this chapter builds off the technological analysis in the Regulatory Impact Analysis (RIA) for the commercial diesel marine engine rule.[9] This section discusses emissions formation, baseline technology, control strategies for CI recreational marine engines.

3.4.1 Background on Emissions Formation from Diesel Engines

Most, if not all, of compression-ignition recreational marine engines use diesel fuel. For this reason, we focus on recreational marine diesel engines in this section. In a diesel engine, the liquid fuel is injected into the combustion chamber after the air has been heated by compression (direct injection), or the fuel is injected into a prechamber, where combustion initiates before spreading to the rest of the combustion chamber (indirect injection). The fuel is injected in the form of a mist of fine droplets or vapor 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 auto-ignites 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 or vapor 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. Although the fuel-air ratio in a diesel cylinder is very lean, the air and fuel are not a homogeneous charge as in a gasoline engine. As the fuel is injected, the combustion takes place at the flame-front where the fuel-air ratio is near stoichiometry (chemically correct for combustion). At localized areas, or in cases where light-ends have vaporized and burned, molecules of carbon remain when temperatures and pressures in the cylinder become too low to sustain combustion as the piston reaches bottom dead center. Therefore, these heavy products of incomplete combustion are exhausted as PM.

NOx formation requires high temperatures and excess oxygen which are found in a diesel engine. Therefore, the diesel combustion process can cause the nitrogen in the air to combine with available oxygen to form NOx. High peak temperatures can be seen in typical unregulated diesel engine designs. This is because the fuel is injected early to help lead to more complete combustion, therefore, higher fuel efficiency. If fuel is injected too early, significantly more fuel will mix with air prior to combustion. Once combustion begins, the premixed fuel will burn at once leading to a very high temperature spike. This high temperature spike, in turn, leads to a high rate of NOx formation. Once combustion begins, diffusion burning occurs while the fuel is being injected which leads to a more constant, lower temperature, combustion process.

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 since NOx forms at high temperatures. In contrast, the key to controlling PM is higher temperatures in the combustion chamber or faster burning. This reduces PM by decreasing the formation of particulates and by oxidizing those particulates that have formed. To control both NOx and PM, manufacturers need to combine approaches using many different design variables to achieve optimum performance. These design variables are discussed in more detail below.

3.4.2 Marinization Process

Like commercial marine engines, recreational marine engines are not generally built from the ground up as marine engines. Instead, they are often marinized land-based engines. The main difference between recreational and commercial marine engines is the application for which they are designed. Commercial engines are designed for high hours of use. Recreational engines are generally designed for higher power, but less hours of use. The following is a brief discussion of the marinization process, as it is performed by either engine manufacturers or post-manufacture marinizers (PMM).

3.4.2.1 Process common to all marine diesel engines

The most obvious changes made to a land-based engine as part of the marinization process concern the engine’s cooling system. Marine engines generally operate in closed compartments without much air flow for cooling. This restriction can lead to engine performance and safety problems. To address engine performance problems, these engines make use of the ambient water to draw the heat out of the engine coolant. To address safety problems, marine engines are designed to minimize hot surfaces. One method of ensuring this, used mostly on smaller marine engines, is to run cooling water through a jacket around the exhaust system and the turbocharger. Larger engines generally use a thick insulation around the exhaust pipes.

Hardware changes associated with these cooling system changes often include water jacketed turbochargers, water cooled exhaust manifolds, heat exchangers, sea water pumps with connections and filters, and marine gear oil coolers. In addition, because of the greater cooling involved, it is often necessary to change to a single-chamber turbocharger, to avoid the cracking that can result from a cool outer wall and a hot chamber divider.

Marinization may also involve replacing engine components with similar components that are made of materials that are more carefully adapted to the marine environment. Material changes include more use of chrome and brass including changes to electronic fittings to resist water induced corrosion. Zinc anodes are often used to prevent engine components, such as raw-water heat exchangers, from being damaged by electrolysis.

3.4.2.2 Process unique to recreational marine diesel engines

Other important design changes are related to engine performance. Especially for planing hull vessels used in recreational and light duty commercial marine applications, manufacturers strive to maximize the power-to-weight ratio of their marine engines, typically by increasing the power from a given cylinder displacement. The most significant tool to accomplish this is the fuel injection system: the most direct way to increase power is to inject more fuel. This can require changes to the camshaft, cylinder head, and the injection timing and pressure.

Design limits for increased fuel to the cylinder are smoke and durability. Modifications made to the cooling system also help enhance performance. By cooling the charge, more air can be forced into the cylinder. As a result, more fuel can be injected and burned efficiently due to the increase in available oxygen. In addition, changes are often made to the pistons, cylinder head components, and the lubrication system. For instance, aluminum piston skirts may be used to reduce the weight of the pistons. Cylinder head changes include changing valve timing to optimize engine breathing characteristics. Increased oil quantity and flow may be used to enhance the durability of the engine.

Depending on the stage of production and the types of changes made, the marinization process can have an impact on the base engine’s emission characteristics. In other words, a land-based engine that meets a particular set of emission limits may no longer meet these limits after it is marinized. This can be the case, for example, if the fuel system is changed to enhance engine power or if the cooling system no longer achieves the same degree of engine cooling as that of the base engine. Because marine diesel engines are currently unregulated, engine manufacturers have been able to design their marine engines to maximize performance. Especially for recreational marine engines, manufacturers often obtain power/weight ratios much higher than for land-based applications.

Recreational engine manufacturers strive for higher power/weight ratios than are necessary for commercial marine engines. Because of this, recreational marine engines use technology we projected to be used by commercial marine engines to meet the Tier 2 emissions standards such as raw-water aftercooling and electronic control. However, this technology is used to gain more power rather than to reduce emissions. The challenge presented by the proposed emission control program will be to achieve the emission limits while maintaining favorable performance characteristics.

3.4.3 General Description of Technology for Recreational Marine Diesel Engines

We believe that the proposed standards can be met using technology that has been developed for and used on land-based nonroad and highway engines. The Regulatory Impact Analysis for the commercial marine rule includes a lengthy description of emission control technology for diesel marine engines. Table 3.4-1 outlines this description. By combining the strategies shown below, manufacturers can optimize the emissions and performance of their engines. A more detailed analysis of the application of several of these technologies to recreational marine engines is discussed in Chapter 4. The costs associated with applying these systems are considered in Chapter 5.

Table 3.4-1: Emission Control Strategies for Marine Diesel Engines

Technology	Description	HC	CO	NOx	PM
Combustion optimization:	timing retard–reduce peak cylinder temperatures by shortening the premixed burning phase	↑	↑	↓↓	↑↑
	reduced crevice volume–such as raising the top piston ring	↓	↓	↔	↓
	geometry–match piston crown geometry to injector spray	↓	↓	↓	↓
	increased compression ratio–raises cylinder pressures	↓	↓	↑	↓
	increased swirl–control of air motion for better mixing	↓	↓	↑,↔	↓
Advanced fuel injection controls	increased injection pressure–better atomization of fuel	↓	↓	↑,↔	↓
	nozzle geometry–optimize spray pattern	↓	↓	↓	↓
	valve-closed orifice–minimize leakage after injection	↓	↔	↔	↓
	rate shaping–inject small amount of fuel early to begin combustion to reduce premixed burning	↔	↔	↓	↔
	common rail–high pressure rail to injectors, excellent control of fuel rate, pressure, and timing	↓	↓	↓	↓
Improving charge air characteristics	turbocharging–increases available oxygen in the cylinder but heats intake air	↓	↓	↑	↓
	jacket-water aftercooling–uses engine coolant to cool charged air which increases available oxygen in cylinder	↔	↔	↓	↔
	raw-water aftercooling–uses ambient water to cool charge air; more effective than jacket-water aftercooling; may result in additional maintenance such as changing anodes	↔	↔	↓↓	↔
Electronic control	better control of fuel system including rate, pressure, and timing especially under transients; can use feedback loop	↓	↓	↓	↓
Exhaust gas recirculation	hot EGR–recirculated exhaust gas reduces combustion temperatures by absorbing heat and slowing reaction rates	↑	↑	↓	↑
	cooled EGR–reduces volume of recirculated gases so to allow more oxygen in the cylinder	↔	↔	↓↓	↑,↔
	soot removal–soot in recirculated gases may cause durability problems at high EGR rates; gas filter or trap; oil filter	↔	↔	↔	↓
Exhaust aftertreatment devices	oxidation catalyst–oxidizes hydrocarbons and soluble organic fraction of PM; will be poisoned by high levels of sulfur	↓	↓	↔	↓
	particulate trap–collect PM; regenerate at high temperature	↓	↓	↔	↓
(would require “dry” exhaust)	selective catalytic reduction–uses a catalyst and a reducing agent such as ammonia	↔	↔	↓	↔
Water emulsification	water is mixed with fuel or injected into the cylinder; water has a high heat capacity and will lower in-cylinder temperatures	↔	↔	↓	↔

Chapter 3 References

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4. Energy and Environmental Analysis, "Benefits and Cost of Potential Tier 2 Emission Reduction Technologies", Final Report, November 1997, Docket A-2000-01, Document II-A-01.

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CHAPTER 4: Feasibility of Proposed Standards

Section 213(a)(3) of the Clean Air Act presents statutory criteria that EPA must evaluate in determining standards for nonroad engines and vehicles. The standards must "achieve the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the engines or vehicles to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology." This chapter presents the technical analyses and information that form the basis of EPA's belief that the proposed emission standards are technically achievable accounting for all the above factors.

4.1 CI Recreational Marine

The proposed emission standards CI recreational marine engines are summarized in the Executive Summary. We believe that manufacturers will be able to meet these standards using technology similar to that required for the commercial marine engine standards. This section discusses technology currently used on CI recreational marine engines and anticipated technology to meet the proposed standards. In addition, this section discusses the emission test procedures and not-to-exceed requirements.

4.1.1 Baseline Technology for CI Recreational Marine Engines

We developed estimates of the current mix of technology for CI recreational marine engines based on data from the 1999 Power Systems Research (PSR) database and from conversations with marine manufacturers. Based on this information, we estimate that 97 percent of new marine engines are turbocharged, and 80% of these turbocharged engines use aftercooling. The majority of these engines are four-strokes, but about 14% of new engines are two-strokes. Electronic controls have only recently been introduced into the marketplace; however, we anticipate that their use will increase as customers realize the performance benefits associated with electronic controls and as the natural migration of technology from on-highway to nonroad to marine occurs.

Table 4.1-1 presents data[1,2,3,4,5,6] from 25 recreational marine diesel engines based on the ISO E5 duty cycle. This data shows to what extent emissions need to be reduced from today's CI recreational marine engines to meet the proposed standards.[k] On average, we are requiring significant reductions in HC+NOx and PM. However, this data seems to show that the diesel engine designs will either have to be focused on NOx or PM due to the trade-off between calibrating to minimize these pollutants. The proposed CO standards will just act as a cap.

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[k] For most of the engines in Table 4.1-1, the proposed standards are of 7.2 g/kW-hr HC+NOx, 5 g/kW-hr CO, and 0.2 g/kW-hr PM

Table 4.1-1: Emissions Data from CI Recreational Marine Engines

Rated Power (kW)	*Control Management*	*Aftercooling*	*Emissions Data g/kW-hr*			
			HC	*NOx*	*CO*	*PM*
120	electronic	raw-water	0.09	5.8	0.9	–
132	mechanical	raw-water	0.07	4.2	0.2	–
142	mechanical	separate circuit	0.79	8.6	1.1	–
162	mechanical	raw-water	0.11	4.0	0.2	–
164	electronic	raw-water	0.28	5.1	1.6	–
170	mechanical	raw-water	0.36	8.1	0.6	0.20
186	mechanical	raw-water	0.30	10.2	1.2	0.12
209	mechanical	raw-water	0.42	10.8	2.3	0.22
230	electronic	raw-water	0.28	5.5	1.8	0.39
235	mechanical	raw-water	0.45	9.8	1.8	0.20
265	mechanical	jacket-water	0.58	10.8	1.4	–
276	mechanical	raw-water	0.60	10.7	1.9	0.24
287	electronic	raw-water	0.28	7.9	–	0.12
321	mechanical	raw-water	0.37	7.7	0.9	0.23
324	mechanical	jacket-water	0.30	7.9	2.9	0.95
336	electronic	jacket-water	0.18	11.0	0.5	0.10
336	electronic	jacket-water	0.09	11.9	–	0.16
447	electronic	raw-water	0.12	9.3	–	0.17
447	mechanical	jacket-water	0.60	12.0	1.5	0.18
474	electronic	raw-water	0.34	7.7	0.5	0.07
537	electronic	jacket-water	0.08	10.7	–	0.19
820	electronic	separate circuit	0.33	9.5	0.8	0.13
1040	electronic	jacket-water	0.09	9.3	–	0.21
1080	electronic	separate circuit	0.18	7.6	1.2	0.15
1340	electronic	separate circuit	0.27	7.2	0.9	0.15

4.1.2 Anticipated Technology for CI Recreational Marine Engines

Marine engines are generally derived from land-based nonroad, locomotive, and to some extent highway engines. In addition, recreational marine engines will be able to use technology developed for commercial marine engines. This allows recreational marine engines, which generally have lower sales volumes than other nonroad engines, to be produced more cost-effectively. Because the marine designs are derived from land-based engines, we believe that many of the emission-control technologies which are likely to be applied to nonroad engines to meet their Tier 2 and 3 emission standards will be applicable to marine engines. We also believe that the technologies listed below will be sufficient for meeting both the new emission standards and the Not to Exceed requirements discussed later in this chapter.

We anticipate that timing retard will likely be used in most CI recreational marine applications, especially at cruising speeds, to gain NOx reductions. The negative impacts of timing retard on HC, PM and fuel consumption can be offset with advanced fuel injection systems with higher fuel injection pressures, optimized nozzle geometry, and potentially through rate shaping. We do not expect marine engine manufacturers to convert from direct injection to indirect injection due to these standards.

Regardless of environmental regulations, we believe that recreational marine engine manufacturers would make more use of electronic engine management controls in the future to satisfy customer demands of increased power and fuel economy. Through the use of electronic controls, additional reductions in HC, CO, NOx, and PM can be achieved. Electronics may be used to optimize engine calibrations under a wider range of operation. Most of the significant research and development for the improved fuel injection and engine management systems should be accomplished for land-based nonroad diesel engines which are being designed to meet Tier 2 and Tier 3 standards. Common rail should prove to be a useful technology for meeting even lower emission levels in the future, especially for smaller engines. Thus, the challenge for this control program will be transferring land-based techniques to marine engines.

We project that all CI recreational marine engines will be turbocharged and most will be aftercooled to meet proposed emission standards. Aftercooling strategies will likely be mostly jacket-water charge air cooling, and in some cases, we believe that separate cooling circuits for the aftercooling will be used. We do not expect a significant increase in the use of raw-water charge air cooling for marine engines as a result of this proposed rule. We recognize that raw-water aftercooling systems are currently in use in many applications. Chapter 4 presents one possible scenario of how these technologies could be used on Category 1 marine diesel engines to meet the proposed standards.

By proposing standards that will not go into effect until 2006, we are 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 commercial marine engines allows for a comprehensive program to integrate the most effective emission control approaches into the manufacturers' overall design goals related to performance, durability, reliability, and fuel consumption.

4.1.3 Emission Measurement Procedures for CI Recreational Marine Engines

In any program we design to achieve emissions reductions from internal combustion engines, the test procedures we use to measure emissions are as important as the standards we put into place. These test procedure issues include duty cycle for certification, in-use verification testing, emission sampling methods, and test fuels.

4.1.3.1 Certification Duty Cycles

In choosing duty cycles for certification, we turned to the International Standards Organization (ISO).[7] For CI recreational marine engines, we based our standards on the ISO E5 duty cycle. This duty cycle is intended for "diesel engines for craft less than 24m length (propeller law)."

We are proposing to use the E5 duty cycle to measure emissions from diesel recreational marine engines. This cycle is similar to the E3 duty cycle which is used for commercial marine in that both cycles have four steady-state test points on an assumed cubic propeller curve. However, the E5 includes an extra mode at idle and has an average weighted power of 34% compared to the 69% for the E3. This duty cycle is presented in Table 4.1-2.

Table 4.1-2: ISO E5 Marine Duty Cycle

Mode	*% of Rated Speed*	*% of Power at Rated Speed*	*Weighting Factor*
1	100	100	0.08
2	91	75	0.13
3	80	50	0.17
4	63	25	0.32
5	idle	0	0.30

4.1.3.2 Emission Control of Typical In-Use Operation

We are concerned that if a marine engine is designed for low emissions on average over a low number of discrete test points, it may not necessarily operate with low emissions in-use. This is due to a range of speed and load combinations that can occur on a boat which do not necessarily lie on the test duty cycles. For instance, the test modes for the E5 duty cycle lie on average propeller curves. However, a propulsion marine engine may never be fitted with an "average propeller." In addition, a given engine on a boat may operate at higher torques than average if the boat is heavily loaded. We are also aware that, before a boat comes to plane, the engine operates closer to its full torque map than to the propeller curve.

We propose to apply the “not-to-exceed” (NTE) limit concept to recreational marine engines similar to commercial marine engines. This concept basically picks a zone of operation under which a marine engine must not exceed the standard by a fixed percentage and is discussed in more detail in the commercial marine FRM. Of course, the shape of the zone must be adjusted to reflect recreational engine use.

Under this proposal, we would have the authority to use test data from new or in-use engines to confirm emissions compliance. The engines tested would have to be within their regulatory useful lives.

4.1.3.2.1 Engine operation included for NTE

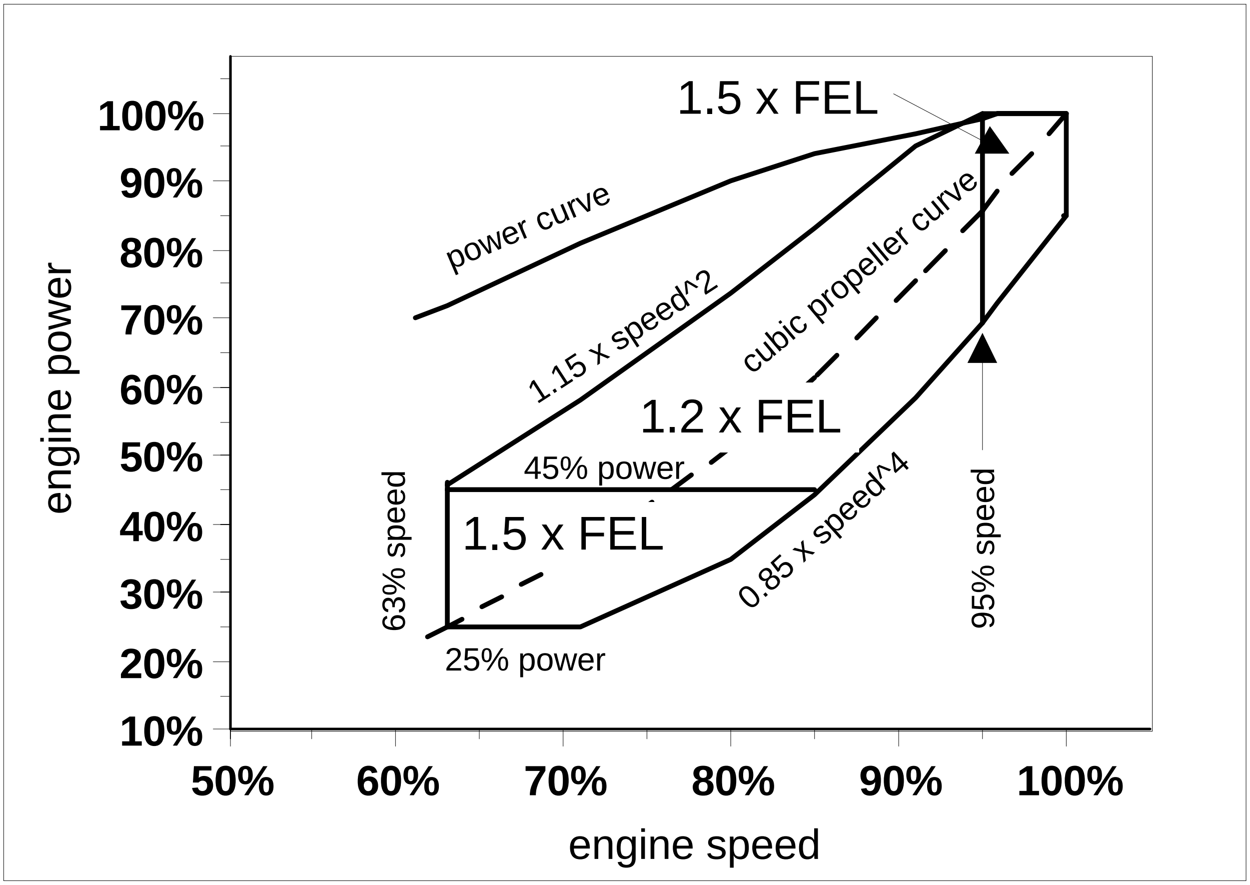
The shape of the NTE zones are based on our understanding of how recreational marine engines are used. Operation at low power is omitted from the NTE zone even though marine engines operate here in use. This omission is because, by definition, brake-specific emissions become very large at low power due to dividing by power values approaching zero.

We believe that the majority of marine engine operation is steady-state. This is why we are proposing that only steady-state operation be considered in the NTE requirements. Also, this is a technology forcing proposal and we would expect to see reductions even under transient operation. If we were to find that the effectiveness of this program is hurt due to high emissions under transient operation, we would revisit this issue in the future.

It should be noted that the emissions caps for operation in the NTE zone would be based on the weighted emissions over the E5 duty cycle. Because idle emissions are part of these weighted values but not included in the NTE zone, it is likely that emissions in the NTE zone will be less than the weighted average. This alone reduces the stringency of a “not-to-exceed” approach for recreational when compared to commercial marine engines.

For compression-ignition engines, the NTE zone is defined by the maximum power curve, actual propeller curves, and speed and load limits. The E5 duty cycle itself is based on a cubic power curve through the peak power point. For the NTE zone, we propose to define the upper boundary using a speed squared propeller curve passing through the 115% load point at rated speed and the lower boundary using on a speed to the fourth power curve passing through the 85% load point at rated speed. We believe these propeller curves represent the range of propeller curves seen in use.[8] To prevent imposing an unrealistic cap on a brake-specific basis, we are proposing to limit this region to power at or above 25% of rated power and speeds at or above 63% of rated speed. These limits are consistent with mode 4 of the E5 duty cycle. Figure 4.1-1 presents the proposed NTE zone for CI recreational marine engines.

Figure 4.1-1: Proposed NTE Zone for Recreational CI Marine Engines



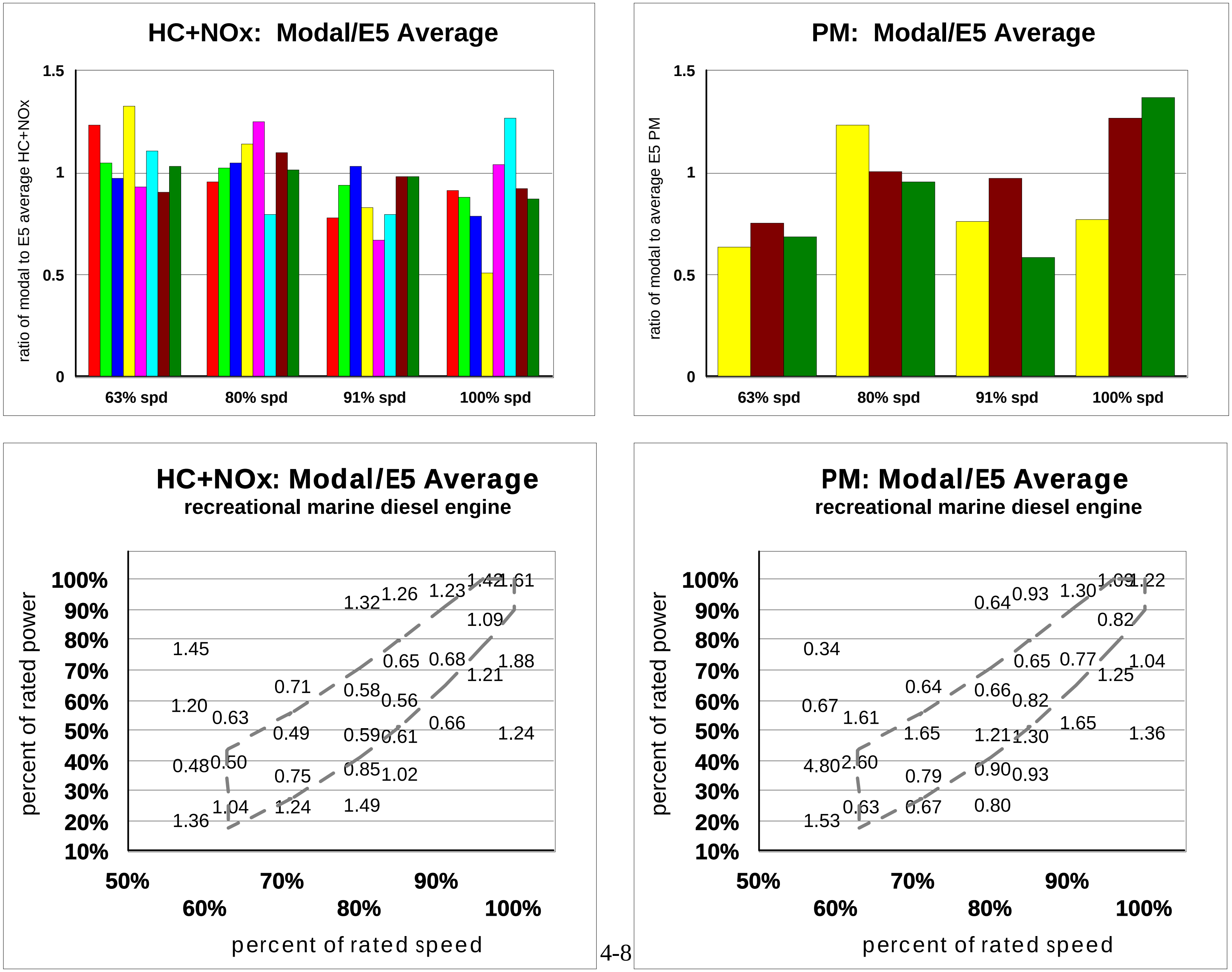
We understand that an engine tested onboard a boat in use may not be operating as the manufacturer intended. Specifically, the owner may not be using a propeller that is properly matched to the engine and boat. Or, the owner may have a boat that is overloaded and too heavy for the engine. The boundaries in Figure 4.1-1 are intended to contain typical operation of recreational diesel engines and exclude engines which are not used properly. Although the E5 uses a cubic power curve engines generally see some variation in use. These boundaries are consistent with operational data we collected.[9]

We are proposing emissions caps for the NTE zone which represent a multiplier times the weighted test result used for certification. Although ideally the engine should meet the certification level throughout the NTE zone, we understand that a cap of 1.0 times the standard is not reasonable, because there is inevitably some variation in emissions over the range of engine operation. This is consistent with the concept of a weighted modal emission test such as the steady-state tests included in this rule.

Consistent with the commercial requirements, we propose that recreational CI marine engines must meet a cap of 1.5 times the certified level for HC+NOx, PM, and CO for the speed and power subzone below 45% of rated power and a cap of 1.2 times the certified levels at or above 45% of rated power. However, we are proposing an additional subzone, when compared to the commercial NTE zone, at speeds greater than 95% of rated. We are proposing a cap of 1.5 times the certified levels for this subzone. Our purpose for this additional subzone is to address the typical recreational design for higher rated power. This power is needed to ensure that the engine can bring the boat to plane.

We based the proposed caps both on emissions data collected on the assumed propeller curve and on data collected from a recreational marine diesel engine over a wide range of steady-state operation. All of this data is cited earlier in this chapter. The data in Figure 4.1-2 shows that, within the range of in-use testing points, HC+NOx and PM are generally well below the E5 weighted averages. This is likely due to the effects of emissions at idle. For all of these engines, modal CO results were well below the proposed standard. None of these engines are calibrated for emissions control.

Figure 4.1-2: Ratio of Modal Emissions to E5 Cycle Weighted Emissions for Marine Diesel Engines



4.1.3.2.2 Ambient conditions during testing

Variations in ambient conditions can affect emissions from a marine engine. Such conditions include air temperature, humidity, and (especially for diesels) water temperature. We are proposing to apply the commercial marine engine ranges for these variables. Within the ranges, no corrections can be made for emissions. Outside of the ranges, emissions can be corrected back to the nearest edge of the range. The proposed ambient variable ranges are:

intake air temperature	13-35°C (55-95°F)
intake air humidity	7.1-10.7 g water/kg dry air (50-75 grains/lb. dry air)
ambient water temperature	5-27°C (41-80°F)

The proposed air temperature and humidity ranges are consistent with those developed for NTE testing of highway heavy-duty diesel engines. The air temperature ranges were based on temperatures seen during ozone exceedences.[10] For NTE testing in which the air temperature or humidity is outside of the range, we propose that the emissions be corrected back to the air temperature or humidity range. These corrections would have to be consistent with the equations in Title 40 of the Code of Federal Regulations except that these equations correct to 25°C and 10.7 grams per kilogram of dry air while corrections associated with the NTE testing shall be to the nearest outside edge of the specified ranges. For instance, if the temperature were higher than 35°C, a temperature correction factor may be applied to the emissions results to determine what the emissions would be at 35°C.

For marine engines using aftercooling, we believe the charge air temperature is insensitive to ambient air temperature compared to the cooling effect of the aftercooler. SwRI tested this theory and found that when the ambient air temperature was increased from 21.9 to 32.2°C, the cooling water to the aftercooler of a diesel marine engine only had to be reduced by 0.5°C to maintain a constant charge air temperature.[11] According to the CFR correction factor, there is only a ±3% variation in NOx in the proposed NTE humidity range.

Some CI recreational marine engines, are naturally aspirated. Naturally aspirated engines should be more sensitive to intake air temperature because the temperature affects the density of the air into the engine. Therefore, high temperatures can limit the amount of air drawn into the cylinder. However, our understanding is that many engines operate in and draw air from small engine compartments. This suggests that most recreational engines are already designed to operate with high intake air temperatures.

Ambient water temperature also may affect emissions due to its impact on engine and charge air cooling. We believe that this effect is small for naturally aspirated engines. We based the proposed water temperature range on temperatures that marine engines experience in the U.S. in use. Although marine engines experience water temperatures near freezing, we don't believe that additional emission control will be gained by lowering the minimum water temperature below 5°C. At this time, we aren't aware of an established correction factor for ambient water temperature. For this reason, we propose that NTE zone testing must be within the specified ambient water temperature range.

We don't think that the range of ambient water temperatures discussed above will have a significant effect on the stringency of the NTE requirements, even for aftercooled engines. Following the normal engine test practice recommended by SAE[12] for aftercooled engines, the cooling water temperature would be set to 25±5°C. This upper portion of the NTE temperature range is within the range suggested by SAE for engine testing. For lower temperatures, manufacturers would be able to use a thermostat or other temperature regulating device to ensure that the charge air is not overcooled. In addition, the SAE practice presents data from four aftercooled diesel engines on the effects of cooling medium temperature on emissions. For every 5°C increase in temperature, HC decreases 1.8%, NOx increases 0.6%, and PM increases 0.1%.

We are aware that many marine engines are designed for operation in a given climate. For instance, recreational vessels operated in Seattle don't need to be designed for 27°C water temperatures. For situations such as this, we propose that manufacturers be allowed to petition for the appropriate temperature ranges associated with the NTE zone for a specific engine design. In addition, we understand there are times when emission control needs to be compromised for startability or safety. Manufacturers would not be responsible for the NTE requirements under start up conditions. In addition, we propose that manufacturers would be able to petition to be exempt from emission control under specified extreme conditions such as engine overheating where emissions may increase under the engine protection strategy.

4.1.3.3 Emissions Sampling

Aside from the duty cycle, the test procedures for marine engines are similar to those for land-based nonroad engines. However, there are a few other aspects of marine engine testing that need to be considered. Most recreational marine engines mix cooling water into the exhaust. This exhaust cooling is generally done to keep surface temperatures low for safety reasons and to tune the exhaust for performance and noise. Because the exhaust must be dry for dilute emission sampling, the cooling water must be routed away from the exhaust in a test engine.

Even though many marine engines exhaust their emissions directly into the water, we base our proposed test procedures and associated standards on the emissions levels in the "dry" exhaust. Relatively little is known about water scrubbing of emissions. We must therefore consider all pollutants out of the engine to be a risk to public health. Additionally, we are not aware of a repeatable laboratory test procedure for measuring "wet" emissions. This sort of testing is nearly impossible from a vessel in-use. Finally, a large share of the emissions from this category come from large engines which emit their exhaust directly to the atmosphere.

The established method for sampling emissions is through the use of full dilution sampling. However, for larger engines the exhaust flows become so large that conventional dilute testing requires a very large and costly dilution tunnel. One option for these engines is to use a partial dilute sampling method in which only a portion of the exhaust is sampled. It is important that the partial sample be representative of the total exhaust flow. The total flow of exhaust can be determined by measuring fuel flow and balancing the carbon atoms in and out of the engine. For guidance on shipboard testing, the MARPOL NOx Technical Code specifies analytical instruments, test procedures, and data reduction techniques for performing test-bed and in-use emission measurements.[13] Partial dilution sampling methods can provide accurate steady-state measurements and show great promise for measuring transient emissions in the near future. We intend to pursue development of this method and put it in place prior to the date that the standards in this final rule become enforceable.

Pulling a marine engine from a boat and bringing it to a laboratory for testing could be burdensome. For this reason, we propose to be able to perform in-use confirmatory testing onboard a boat. Our goal would be to perform the same sort of testing as proposed for the laboratory. However, engines tested in a boat are not likely to operate exactly on the assumed propeller curve. For this reason, we propose that emissions measured within the NTE zone must meet the subzone caps based on the certified level during onboard testing. To facilitate onboard testing, our proposal requires that manufacturers provide a location with a threaded tap where a sampling probe may be inserted. This location would have to be upstream of where the water and exhaust mix at a location where the exhaust gases could be expected to be the most homogeneous.

There are several portable sampling systems on the market that, if used carefully, can give fairly accurate results for onboard testing. Engine speed can be monitored directly, but load may have to be determined indirectly. For engines operating at a constant speed, it should be relatively easy to set the engine to the points specified in the duty cycles.

4.1.3.4 Test Fuel Specifications

We propose to apply the recently finalized test fuel specifications for commercial marine engines to recreational marine diesel engines. These fuel specifications are similar to land-based nonroad fuel with a change in the sulfur content upper limit from 0.4 to 0.8 weight-percent (wt%). We believe that this will simplify development and certification burdens for marine engines that are developed from land-based counterparts. This test fuel has a sulfur specification range of 0.03 to 0.80 wt%, which covers the range of sulfur levels observed for most in-use fuels. Manufacturers will be able to test using any fuel within this range for the purposes of certification. Thus, they will be able to harmonize their marine test fuel with U.S. highway (<0.05 wt%) and nonroad (0.03 to 0.40 wt%), and European testing (0.1 to 0.2 wt%).

The intent of these proposed test fuel specifications is to ensure that engine manufacturers design their engines for the full range of typical fuels used by Category 1 marine engines in use. Because the technological feasibility of the new emission standards is based on fuel with up to 0.4 wt% sulfur, any testing done using fuel with a sulfur content above 0.4 wt% would be done with an allowance to adjust the measured PM emissions to the level they would be if the fuel used were 0.4 wt% sulfur. The full range of test fuel specifications are presented in Table 4.1-3. Because testing conducted by us is limited to the test fuel specifications, it is important that the test fuel be representative of in-use fuels.

Table 4.1-3: Recreational Marine Diesel Test Fuel Specifications

Item	*Procedure (ASTM)*	*Value (Type 2-D)*
Cetane	D613-86	40-48
Initial Boiling Point, °C	D86-90	171-204
10% point, °C	D86-90	204-238
50% point, °C	D86-90	243-282
90% point, °C	D86-90	293-332
End Point, °C	D86-90	321-366
Gravity, API	D287-92	32-37
Total Sulfur, % mass	D129-21 or D2622-92	0.03-0.80
Aromatics, % volume	D1319-89 or D5186-91	10 minimum
Parafins, Napthenes, Olefins	D1319-89	remainder
Flashpoint, °C	D93-90	54 minimum
Viscosity @ 38 °C, centistokes	D445-88	2.0-3.2

4.1.4 Impacts 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 CI recreational marine 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.

The impact of the new emission standards on energy is measured by the effect on fuel consumption from complying engines. Many of the marine engine manufacturers are expected to retard engine timing which increases fuel consumption somewhat. Most of the technology changes anticipated in response to the new standards, however, have the potential to reduce fuel consumption as well as emissions. Redesigning combustion chambers, incorporating improved fuel injection systems, and introducing electronic controls provide the engine designer with powerful tools for improving fuel efficiency while simultaneously controlling emission formation. To the extent that manufacturers add aftercooling to non aftercooled engines and shift from jacket-water aftercooling to raw-water aftercooling, there will be a marked improvement in fuel-efficiency. Manufacturers of highway diesel engines have been able to steadily improve fuel efficiency even as new emission standards required significantly reduced emissions.

There are no apparent safety issues associated with the new emission standards. Marine engine manufacturers will likely use only proven technology that is currently used in other engines such as nonroad land-based diesel applications, locomotives, and diesel trucks.

4.2 Large Industrial SI Engines

This category of engines generally includes all nonrecreational land-based spark-ignition engines rated above 19 kW that are not installed in motor vehicles or stationary applications. In an earlier memorandum, we described the rationale for developing emission measurement procedures for transient and off-cycle engine operation.[14] Information from that memorandum is not repeated here, except to the extent that it supports decisions about the selecting the proposed numerical emission standards.

The proposed emission standards for Large SI engines are listed in the Executive Summary. The following paragraphs summarize the data and rationale supporting the proposed standards.

4.2.1 Proposed 2004 Standards

Engine manufacturers are currently developing technologies and calibrations to meet the 2004 standards that apply in California. We expect manufacturers to rely on electronically controlled, closed-loop fuel systems and three-way catalysts to meet those emission standards. As described below, emission data show that water-cooled engines can readily meet the California ARB standards (3 g/hp-hr NMHC+NOx; 37 g/hp-hr CO).

Our projected date for a final rule—September 2002—allows manufacturers just over one year to prepare engines for nationwide sales starting in 2004. Implementing new standards with such a short lead time is only possible because manufacturers have been aware of their need to comply with the California ARB standards. With no need to further modify engine designs, manufacturers should have time before 2004 to plan for increasing production volume for nationwide sale of engines that can meet the 2004 California ARB standards.

Adopting standards starting in 2004 allows us to align near-term requirements with those adopted by California ARB. This also provides early emission reductions and gives manufacturers the opportunity to amortize their costs over a broader sales volume before investing in the changes needed to address the long-term standards described below.

4.2.2 Proposed 2007 Standards

The proposed 2004 standards described above would be effective in reducing emissions from Large SI engines, but we believe these levels don’t fulfill our obligation to adopt standards achieving the “greatest degree of reduction achievable” from these engines in the long term. With additional time to optimize designs to better control emissions, manufacturers can optimize their designs to reduce emissions below the levels required by the proposed 2004 standards. We are also proposing new procedures for measuring emissions starting in 2007, which would require further efforts to more carefully design and calibrate emission-control systems to achieve in-use emission reductions. The following discussion explains why we believe the proposed 2007 emission standards are feasible.

The biggest uncertainty in adopting emission standards for Large SI engines has been the degree to which emission-control systems deteriorate with age. While three-way catalysts and closed-loop fueling systems have been in place in highway applications for almost 20 years, there is very little information showing how these systems hold up under nonroad use. To address this, we participated in an investigative effort with Southwest Research Institute (SwRI), California ARB, and South Coast Air Quality Management District, as described in the memorandum referenced above. The engines selected for testing had been retrofitted with emission-control systems in Spring 1997 after having already run for 5,000 and 12,000 hours. Both engines are in-line four-cylinder models operating on liquefied petroleum gas (LPG)—a 2-liter Mazda engine rated at 32 hp and a 3-liter GM engine rated at 45 hp. The retrofit consisted of a new, conventional three-way catalyst, electronic controls to work with the existing fuel system, and the associated sensors, wiring, and other hardware. The electronic controller allowed only a single adjustment for controlling air-fuel ratios across the range of speed-load combinations.

Laboratory testing consisted of measuring steady-state and transient emission levels, both before and after taking steps to optimize the system for low emissions. While the engines' emission-control systems originally focused on controlling CO emissions, the testing effort focused on simultaneously reducing HC, NOx, and CO emissions. This testing provides a good indication of the capability of these systems to control emissions over an engine's full useful life. The testing also shows the degree to which transient emissions are higher than steady-state emission levels for Large SI engine operation. Finally, the testing shows how emission levels vary for different engine operating modes. Emission testing included engine operation at a wide range of steady-state operating points and further engine operation over several different transient duty cycles. Much of the emissions variability at different speeds and loads can be attributed to the basic design of the controller, which has a single, global calibration setting. This data showing the variability of emissions is necessary to support the proposed field-testing emission standards, as described further below.

4.2.2.1. Steady-state testing results

Testing results from the aged engines at SwRI showed very good emission control capability over the full useful life. Test results with new hardware on the aged engines lead to the conclusion that the systems operated with relatively stable emission levels over the several thousand hours. As shown in Table 4.2-1, the emission levels measured by SwRI are consistent with results from a wide variety of measurements on other engines. The data listed in the table includes only LPG-fueled engines. See Section 4.2.2.6 a discussion of gasoline-fueled engines.

Table 4.2-1
Steady-State Emission Results from LPG-fueled Engines

Test engine	HC+NOx* g/hp-hr	CO g/hp-hr	Notes**
Mazda 2L[15]	0.51	3.25	4,000 hours, add-on retrofit
GM 3L	0.87	1.84	5,600 hours, add-on retrofit
Engine B	0.22	2.79	250 hours
GFI[16]	0.52 NMHC+NOx	2.23	5,000 hours
Toyota/ECS 2L[17]	1.14	0.78	zero-hour; ISO C1 duty cycle for nonroad diesel engines
GM/Impco 3L[18]	0.26	0.21	zero-hour

*Measurements are THC+NOx, unless otherwise noted.
**Emissions were measured on the ISO C2 duty cycle, unless otherwise noted.

This data set supports emission standards significantly more stringent than the proposed 2004 standards. However, considering the need to focus on transient emission measurements, we believe it is not appropriate to adopt more stringent emission standards based on the steady-state duty cycles. Stringent emission standards based on certain discrete modes of operation may unnecessarily constrain manufacturers from controlling emissions across the whole range of engine speeds and loads. We therefore intend to rely more heavily on the transient testing to determine the stringency of the emission-control program.

4.2.2.2 Transient testing results

The SwRI testing is currently the only source of information available for evaluating the transient emission levels from Large SI engines equipped with emission-control systems. Table 4.2-2 shows the results of this testing. The transient emission levels, though considerably lower than the 2004 standards, are higher than those measured on the steady-state duty cycles. A combination of factors contribute to this. First, engines are unlikely to maintain precise control of air-fuel ratios during rapid changes in speed or load, resulting in decreased catalyst-conversion efficiency. Also, the transient duty cycle includes operation at engine speeds and loads that have higher steady-state emission levels than the seven modes constituting the C2 duty cycle. Both of these factors would also cause uncontrolled emission levels to be higher, so the measured emission levels with the catalyst system still show a substantial reduction in emissions.

Table 4.2-2
Transient Test Results from SwRI Testing

Engine*	Duty Cycle	THC+NOx g/hp-hr	CO g/hp-hr
Mazda	Variable-speed, variable-load	1.1	9.9
	Constant-speed, variable-load	1.5	8.4
GM	Variable-speed, variable-load	1.2	7.0

*Based on the best calibration on the engine operating with an aged catalyst.

4.2.2.3 Off-cycle testing results

Engines operate in the field under both steady-state and transient operation. Although these emission levels are related to some degree, they are measured separately. This section therefore first considers steady-state operation.

Figures 4.2-1 through 4.2-6 show plots of emission levels from the test engines at several different steady-state operating modes. This includes the seven speed-load points in the ISO C2 duty cycle, with many additional test points spread across the engine map to show how emissions vary with engine operation. The plotted emission level shows the emissions at each normalized speed and normalized load point. The 100-percent load points at varying engine speeds form the engine's lug curve, which appears as a straight line because of the normalizing step.

Figure 4.2-1 shows the THC+NOx emissions from the Mazda engine when tested with the aged catalyst. While several points are higher than the 0.51 g/hp-hr level measured on the C2 duty cycle, the highest levels observed from the Mazda engine are around 2.3 g/hp-hr. The highest emissions are generally found at low engine speeds. Emission testing on the Mazda engine with a new catalyst showed very similar results, so they are not shown here.

CO emissions from the same engine had a similar mix of very low emission points and several higher measurements. The CO levels along the engine's lug curve (100 percent load) range 12 to 22 g/hp-hr, well above the other points, most of which are under 4 g/hp-hr. The corner of the map with high-speed and low-load operation also has a high level of 9 g/hp-hr. These high-emission modes point to the need to address control of air-fuel ratios at these extremes of engine operation.

If CO emissions at these points would be an inherent problem associated with these engines, we could take that into account in setting the standard. Figure 4.2-4 shows, however, that the GM engine with the same kind of aged emission-control system had emission levels at most of these points ranging from 0.7 to 4.7 g/hp-hr. The one remaining high point on the GM engine was 11.6 g/hp-hr at full load and low speed. A new high-emission point was 28 g/hp-hr at the lowest measured speed and load. Both of these points are much lower on the same engine with the new catalyst installed (see Figure 4.2-6). These data reinforce the conclusion that adequate development effort will enable manufacturers to achieve broad control of emissions across the engine map.

Figure 4.2-3 shows the THC+NOx emissions from the GM engine when tested with the aged catalyst. Emission trends across the engine map are similar to those from the Mazda engine, with somewhat higher low-speed emission levels between 2.3 and 4.4 g/hp-hr at various points. Operation on the new catalyst shows a significant shifting of high and low emission levels at low-speed operation, but the general observation is that the highest emission levels disappear, with 2.3 g/hp-hr being again the highest observed emission level over the engine map (see Figure 4.2-5).

Figure 4.2-1

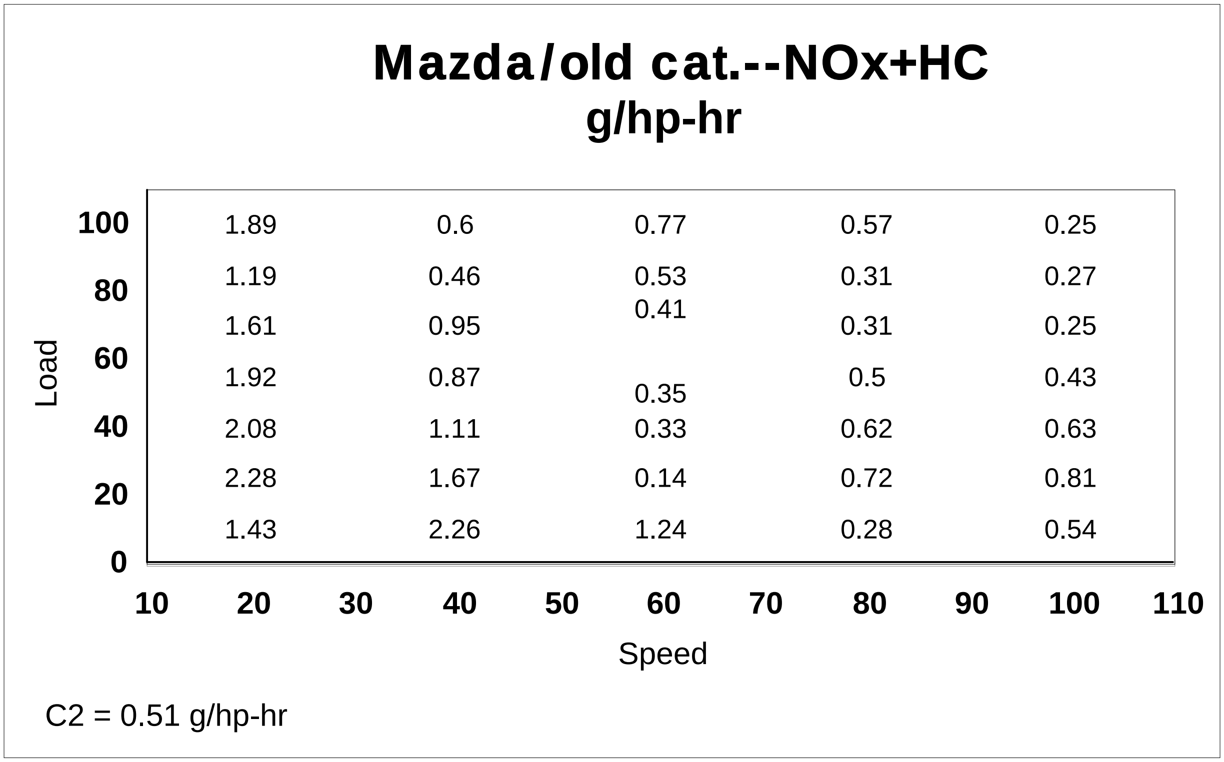


Figure 4.2-2

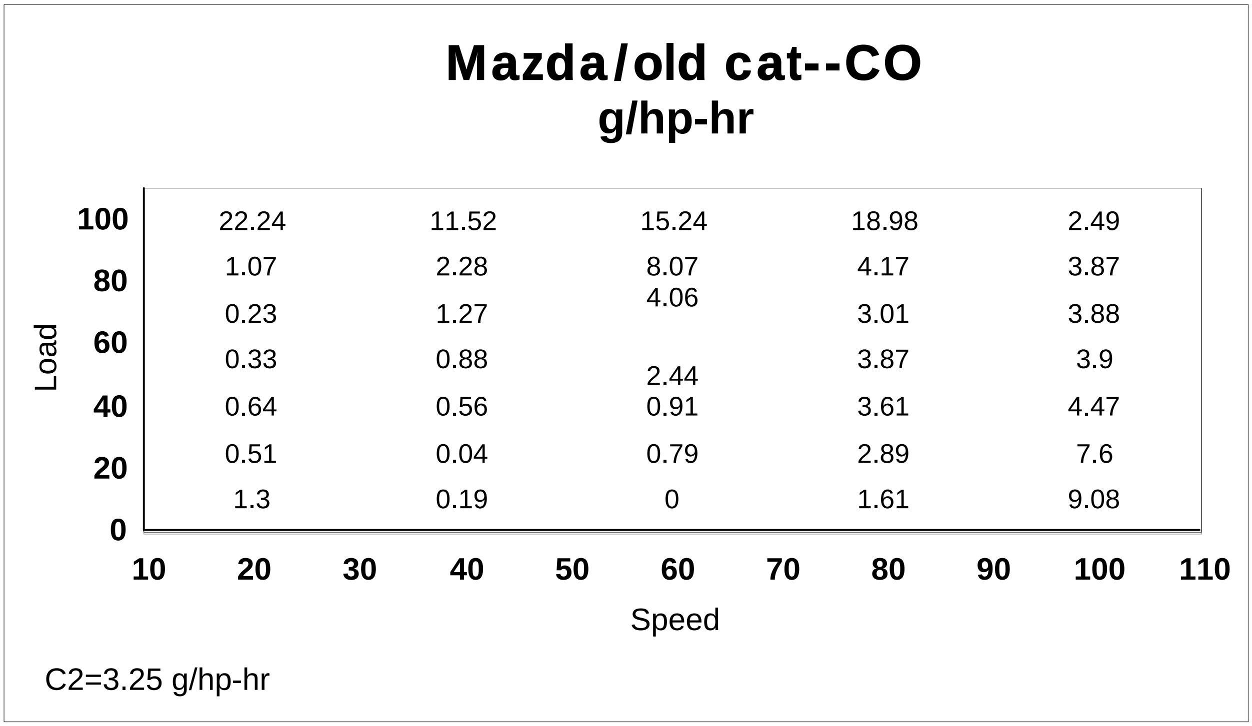


Figure 4.2-3

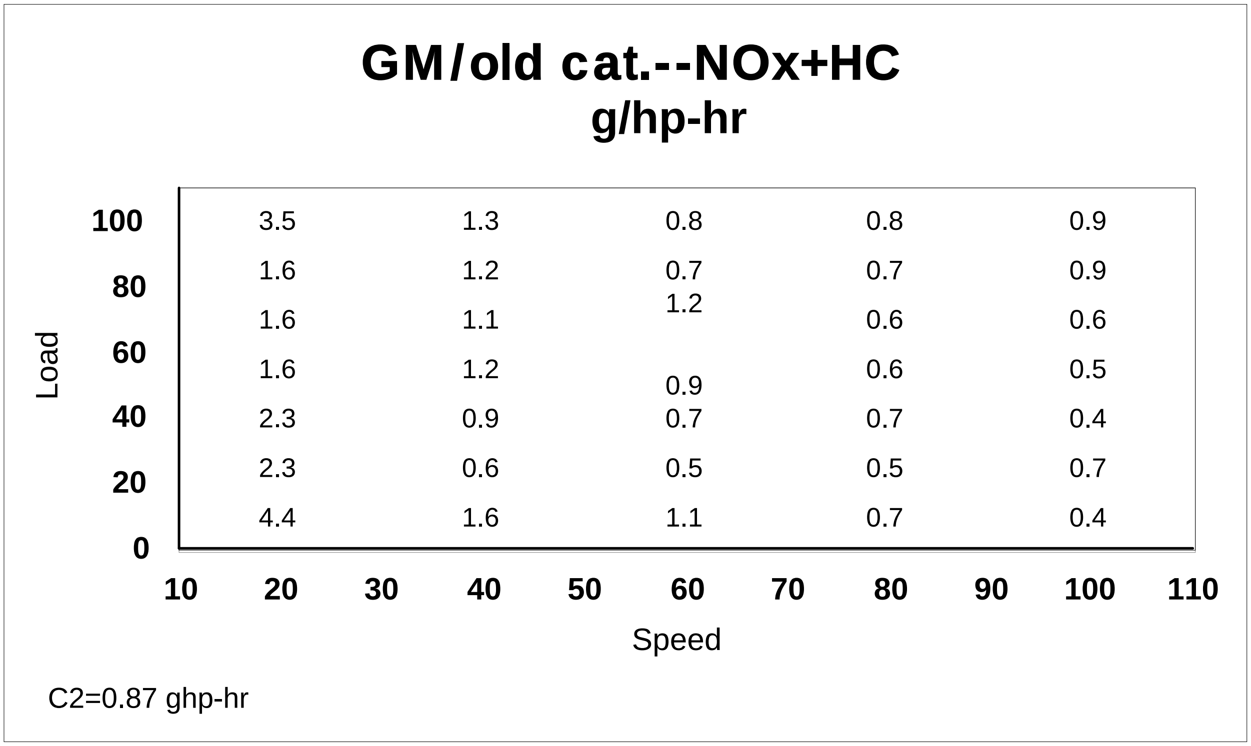


Figure 4.2-4

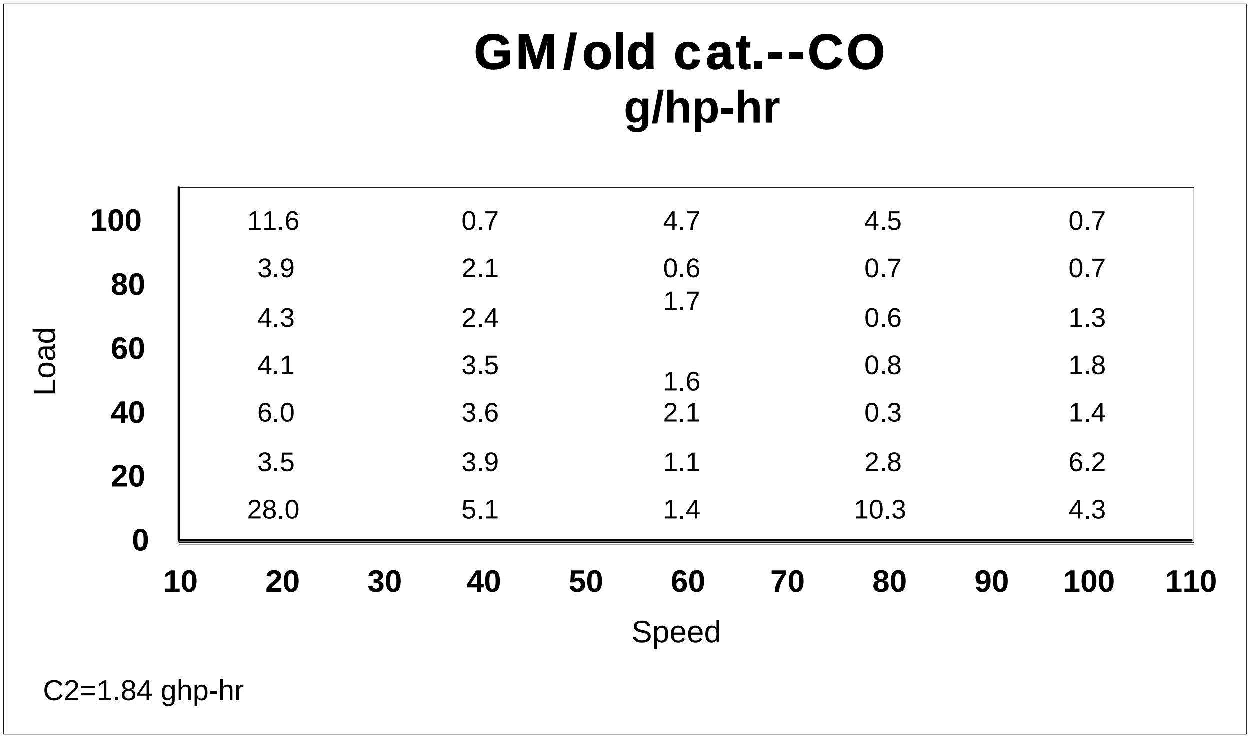
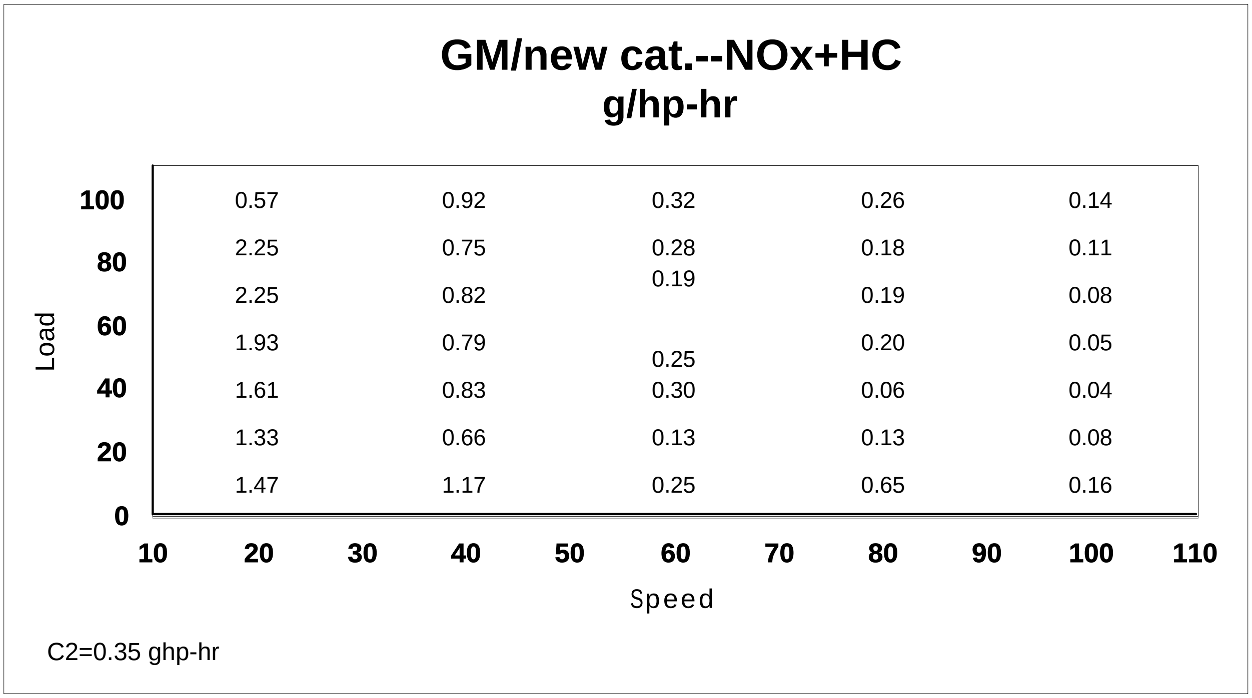
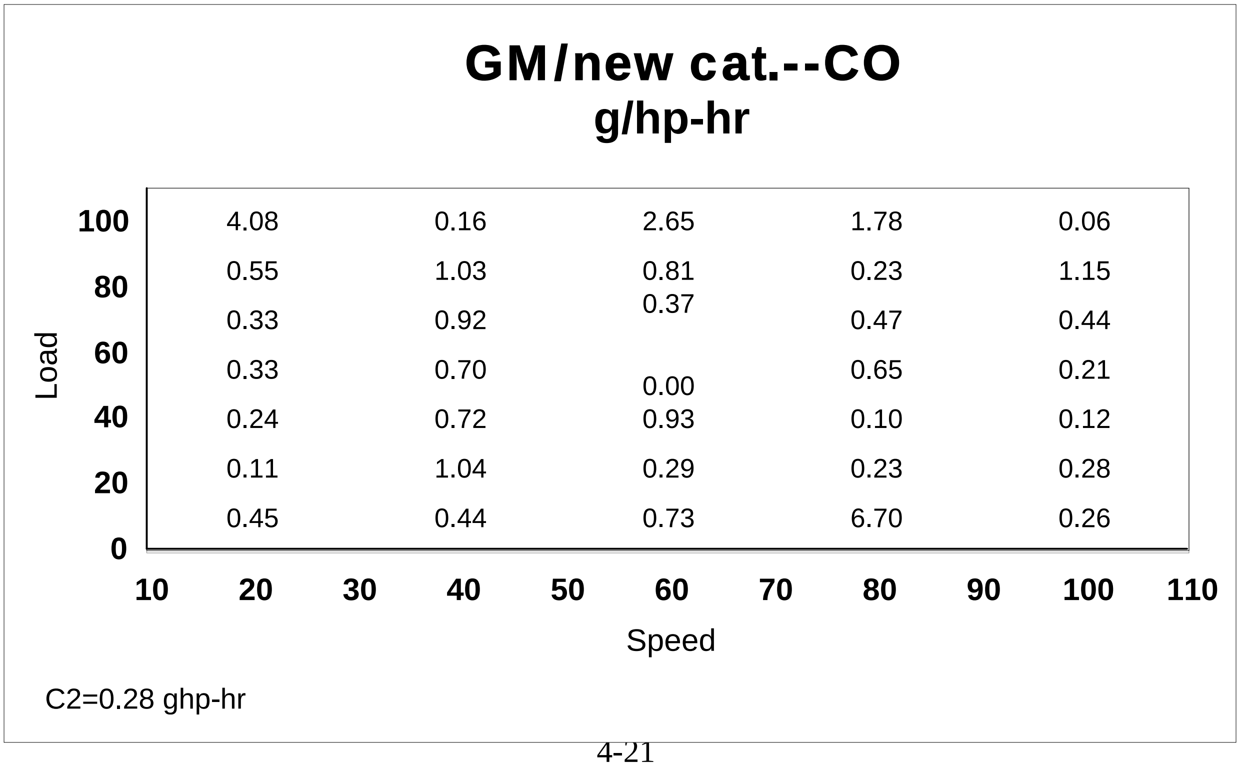


Figure 4.2-5



C2=0.35 ghp-hr

Figure 4.2-6



C2=0.28 ghp-hr

Field testing will typically also include transient emission measurement. We are proposing that a field-testing measurement may include any segment of normal operation with a two-minute minimum sampling period. This would not include engine starting, extended idling, or other cold-engine operation. Table 4.2-3 shows a wide variety of transient emission levels from the two test engines. While the engines were tested in the laboratory, the results show emissions would vary under normal operation when installed in nonroad equipment. These segments could be considered as valid field-testing measurements to show that an engine meets emission standards in the field when tested in nonroad equipment in which the engines are installed. Several segments included in the table were run with a hot start, which could significantly increase emission levels, depending on how long the engine runs in open loop after starting. This is especially important for CO emissions. Even with varied strategies for soaking and warming up engines, emission levels are generally between 1 and 2 g/hp-hr THC+NOx and between 4 and 13 g/hp-hr CO. Emission levels don't seem to vary dramatically between cycle segments, even where engine operation is significantly different.

Table 4.2-3
Transient Emission Measurements from SwRI Testing

Engine	Test Segment	THC+NOx g/hp-hr	CO, g/hp-hr	Notes
Mazda	"typical" forklift (5 min.)	2.0	5.7	hot start
	"high-transient" forklift (5 min.)	1.3	4.3	hot start
	highway certification test	1.2	4.6	hot start
	backhoe/loader cycle	1.3	9.1	20-minute soak before test
GM	"typical" forklift (5 min.)	1.3	9.5	hot start
	"high-transient" forklift (5 min.)	2.0	12.6	hot start
	highway certification test	1.0	4.4	3-minute warm-up; 2-minute soak
	backhoe/loader cycle	1.0	3.8	3-minute warm-up; 2-minute soak

4.2.2.4 Ambient conditions

While certification testing involves engine operation in a controlled environment, engines operate in conditions of widely varying temperature, pressure, and humidity. To take this into account, we are proposing to broaden the range of acceptable ambient conditions for field-testing measurements. We are proposing to limit field-testing emission measurements to ambient temperatures from 13° to 35° C (55° to 95° F), and to ambient pressures from 600 to 775 millimeters of mercury (which should cover almost all normal pressures from sea level to 7,000 feet above sea level). Tests would be considered valid regardless of humidity levels. This allows testing under a wider range of conditions in addition to helping ensure that engines are able to control emissions under the whole range of conditions under which they operate.

The SwRI test data published here are based on testing under laboratory conditions typical for the test location. Ambient temperatures ranged from 70 to 86° F. Barometric pressures were in a narrow range around 730 mm Hg. Humidity levels ranged from about 4 to 14 g of water per kg dry air, but all emission levels were corrected to a reference condition of 10.7 g/kg. Most testing occurred at humidity levels above 10.7, in which case actual NOx emission levels were up to 7 percent lower than reported by SwRI. In the driest conditions, measured NOx emission levels were up to 10 percent higher than reported. The proposed field-testing standards take into account the possibility of a humidity effect of increasing NOx emissions. We are not aware of any reasons that varying ambient temperatures or pressures would have an inherent effect on emission levels from spark-ignition engines.

4.2.2.5 Durability of Emission-Control Systems

SwRI tested engines that had already operated for the full proposed useful life period with functioning emission-control systems. Before being retrofitted with catalysts and electronic fuel systems, these engines had already operated for 5,000 and 12,000 hours, respectively. The tested systems therefore provide very helpful information to show the capability of the anticipated emission-control technologies to function over a lifetime of normal in-use operation.

The testing effort required selection, testing, and re-calibration of installed emission-control systems that were not designed specifically to meet emission standards. These systems were therefore not necessarily designed for simultaneously controlling NOx, HC, and CO emissions, for lasting 5,000 hours or longer, or for performing effectively under all conditions and all types of operation that may occur. The testing effort therefore included a variety of judgments, and adjustments to evaluate the emission-control capability of the installed hardware. This effort highlighted several lessons that should help manufacturers design and produce durable systems.

Selecting engines from the field provided the first insights into the functionality of these systems. Tailpipe ppm measurements showed that several engines had catalysts that were inactive (or nearly inactive). These units were found to have loose catalyst material inside the housing, which led to a significant loss of the working volume of the catalyst and exhaust flow bypassing the catalyst material. Dimensional measurements showed that this resulted from a straightforward production error of improperly assembling the catalyst inside the shell.[19] This is not an inherent problem with catalyst production and is easily addressed with automated or more careful manual production processes. The catalyst from the GM engine selected for testing had also lost some of its structural integrity. Almost 20 percent of the working volume of the catalyst had disappeared. This catalyst was properly re-assembled with its reduced volume for further testing. This experience underscores the need for effective quality-control procedures in assembling catalysts.

Substituting a new catalyst on the aged system allowed emission measurements that help us estimate how much the catalysts degraded over time. This assessment is rather approximate, since we have no information about the zero-hour emissions performance of that exact catalyst.

The new catalysts, which were produced about three years later under the same part numbers and nominal characteristics, generally performed in a way that was consistent with the aged catalysts. Not surprisingly, the catalyst with the reduced working volume showed a higher rate of deterioration than the intact catalyst. Both units, however, showed very stable control of NOx and HC emissions. CO deterioration rates were generally higher, but the degree of observed deterioration was very dependent on the particular duty cycle and calibration for a given set of emission measurements.

Measured emission levels from the aged catalysts shows what degree of conversion efficiency is possible for each pollutant after several thousand hours of operation. The emission data from the new catalysts suggest that manufacturers would probably need to target low enough zero-hour CO emission levels to account for significant deterioration. The data also show that catalyst size is an important factor in addressing full-life emission control. The nominal sizes of the catalysts on the test engines were between 50 and 55 percent of total engine displacement. The cost analysis in Chapter 5 is based on initial compliance with a catalyst sized at 60 percent of total engine displacement. We would expect manufacturers to reduce catalyst size as much as possible to reduce costs without risking the possibility of high in-use emissions.

Another important issue relates to degradation associated with fuel impurities, potential lack of maintenance, and wear of oxygen sensors. Fuel system components in LPG systems are prone to fuel deposits, primarily from condensation of heavy hydrocarbon constituents in the fuel. The vaporizer and mixer on the test engines showed a typical degree of fuel deposits from LPG operation. The vaporizer remained in the as-received condition for all emission measurements throughout the test program. Emission tests before and after cleaning the mixer give an indication of how much the deposits affect the ability of the closed-loop fueling system to keep the engine at stoichiometry. For the GM engine operating with the aged catalyst, the combined steps of cleaning the mixer and replacing the oxygen sensor improved overall catalyst efficiency on the C2 duty cycle from 55 to 61 percent for NOx. CO conversion efficiency improved only slightly. For the Mazda engine, the single step of cleaning the mixer slightly *decreased* average catalyst efficiency on the C2 duty cycle for NOx emissions; HC and CO conversion efficiency improved a small amount (see Table 4.2-4). Engines operating with new catalysts showed the same general patterns. These data show that closed-loop fueling systems can be relatively tolerant of problems related to fuel impurities.

Table 4.2-4
Average C2 Catalyst Conversion Efficiencies Before and After Maintenance

Engine	Pollutant	OLD CATALYST		NEW CATALYST	
		before maintenance	after maintenance	before maintenance	after maintenance
GM	NOx	54.7%	61.1%	45.6%	56.1%
	CO	96.3%	98.1%	99.3%	99.5%
	HC	93.8%	93.6%	93.6%	93.7%
Mazda	NOx	62.3%	61.5%	60.3%	60.1%
	CO	96.9%	98.9%	99.6%	99.6%
	HC	86.9%	93.2%	86.2%	94.3%

Manufacturers may nevertheless be concerned that some in-use operation can cause fuel deposits that exceed the fuel system’s compensating ability to maintain correct air-fuel ratios. Two technologies are available to address this concern. First, the diagnostic system we are proposing would inform the operator if fuel-quality problems are severe enough to prevent the engine from operating at stoichiometry. A straightforward cleaning step would restore the fuel system to normal operation. Manufacturers may also be able to monitor mixer performance directly to detect problems with fuel deposits, rather than depending on air-fuel ratios as a secondary indicator. In any case, by informing the operator of the need for maintenance, the diagnostic system reduces the chance that the manufacturer will find high in-use emissions that result from fuel deposits.

The second technology to consider is designed to prevent fuel deposits from forming. A commercially available thermostat regulates fuel temperatures to avoid high-temperature and low-temperature effects.

Maintaining the integrity of the exhaust pipe is another basic but essential element of keeping control of air-fuel ratios. Any leaks in the exhaust pipe between the exhaust valves and the oxygen sensor would allow dilution air into the exhaust stream. The extra oxygen from the dilution air would cause the oxygen sensor to signal a need to run at a air-fuel ratio that is richer than optimal. If an exhaust leak occurs between the oxygen sensor and the catalyst, the engine will run at the right air-fuel ratio, but the extra oxygen would affect catalyst conversion efficiencies. As evidenced by the test engines, manufacturers can select materials with sufficient quality to prevent exhaust leaks over the useful life of the engine.

4.2.2.6 Gasoline-fueled engines

Most of the available emission data for Large SI engines is from LPG-fueled engines. Gasoline-fueled engines, while less common, represent an important element of the market. Emission-control technologies for automotive engines and heavy-duty highway engines have advanced to the point of reducing emissions well below the standards we are proposing for Large SI engines. The experience with these highway applications makes clear that gasoline-fueled engines can achieve very low emissions.

Part of the concern expressed by manufacturers has been that gasoline-fueled engines sometimes need to operate at rich air-fuel ratios for short periods to protect engines from overheating. This generally causes higher CO emissions, while NOx emissions either decrease or stay the same. Concern related to the feasibility of meeting emission standard with gasoline-fueled engines are therefore mostly focused on achievable CO emission levels. Most people understand that gasoline-fueled industrial engines have high CO emissions, so they generally don't operate in indoor applications or in other enclosed areas. Controlling NOx emissions from these engines therefore becomes relatively more important than controlling CO emissions.

To address this concern, we are proposing alternate emission standards that provide flexibility in balancing the tradeoff between controlling NOx and CO emissions. We believe this flexibility will allow manufacturers to achieve the greatest degree of emission reduction at the lowest cost for their particular engines. See Section 4.2.2.7.3 for a discussion of the alternate emission standards.

4.2.2.7 Proposed emission standards

4.2.2.7.1 Technology Basis

Three-way catalyst systems with electronic, closed-loop fuel systems have a great potential to reduce emissions from Large SI engines. We believe these technologies are capable of the greatest degree of emission reduction achievable from these engines in the projected time frame, considering the various statutory factors. This reflects a concern for the cost sensitivity of Large SI engines. In particular, we are not basing the proposed emission standards on the emission-control capability from any of the following technologies.

- Spark timing
- Combustion-chamber redesign
- Gaseous fuel injection
- Exhaust gas recirculation

Incorporating these technologies with new engines could further reduce emissions; however, Large SI engine manufacturers typically produce 10,000 to 15,000 units annually, which limits the resources available for an extensive development program. Considering the limited development budgets for improving these engines, we believe it is more important to make a robust design with basic emission-control hardware than to achieve very low emission levels with complex hardware at a small number of steady-state test modes. Even without these additional technologies, we anticipate that manufacturers will be able to reduce emissions by 90 percent or more from uncontrolled levels. Further optimizing an engine with a full set of emission-control hardware while meeting transient and field-testing emission standards is more of a cost burden than Large SI manufacturers can bear in the projected time frame.

Manufacturers producing new engines may find it best to use some of these supplemental technologies to achieve the desired level of emission control and performance at an acceptable cost.

4.2.2.7.2 Duty-cycle emission standards

The SwRI testing program was based on aged engines and involved no effort to fine-tune air-fuel ratios or emission levels across the engine map. We expect that manufacturers will be able to take steps to control emission levels more broadly across the range of engine speeds and loads, which will correspondingly reduce transient emission levels. The data presented above show that Large SI engines can meet the proposed 2007 emission standards for both steady-state and transient duty cycles.

We project that the proposed emission standards will reduce NOx, HC, and CO emissions by about 90 percent from uncontrolled levels. Further reductions may be possible with a very extensive development effort to adapt advanced highway engine technologies to nonroad applications. We have, for example, adopted emission standards for gasoline-fueled engines for highway trucks that will require manufacturers to reduce emissions by 80 or 90 percent beyond the levels we are proposing for Large SI engines. Due to the relatively low sales volumes of Large SI engines, we believe it is not appropriate to propose standards at these more stringent levels. With smaller R&D budgets, Large SI engine manufacturers will need to apply a focused effort to meet the standards we are proposing.

On the other hand, the proposed emission standards for Large SI engines are significantly more stringent than those we are proposing for recreational vehicles and those we have adopted for lawn & garden engines. We believe this is appropriate, for several reasons. First, the similarity to automotive engines makes it possible to use basic automotive technology that has already been adapted to industrial use. Second the cost of Large SI equipment is typically much higher than the recreational or other light-duty products, so there is more capability for manufacturers to pass along cost increases in the marketplace. Third, the proposed Large SI emission standards correspond with a substantial fuel savings, which offset the cost of regulation and provide a great value to the many commercial customers.

The SwRI testing program involved about eight weeks of development effort to characterize and modify two engines to for optimized emissions on the steady-state and transient duty cycles, and for all kinds of off-cycle operation. Both of the test engines had logged several thousand hours of operation using off-the-shelf technologies that have been available for nonroad engines for many years. Several hardware and software adjustments were made to maintain optimal air-fuel ratios for effective control of all pollutants under all operating modes. Some further development effort will be necessary to address the few isolated modes with high emission levels, as described below. Manufacturers may save development time by upgrading to the modestly more expensive controller with independent air-fuel control capability in different speed-load zones. We believe that the several years until 2007 allow enough lead time for manufacturers to carry out this development effort for all their engines.

We expect the SwRI testing program to provide extensive, basic information on optimizing the subject engines for low emissions, so manufacturers will need significantly less time and testing resources to modify additional engine models. For example, the SwRI testing shows how emissions change over varying speeds and loads; as a result, future testing can focus on far fewer test points to characterize a calibration. The test results also show how manufacturers will need to balance calibrations for controlling emissions of different pollutants across the range of engine speeds and loads.

Given the control technology, as described above, there is a need to select emission standards that balance the tradeoff between NOx and CO emissions. Both NOx and CO vary with changing air-fuel ratios, but in an inverse relationship. This is especially important considering the degree to which these engines are used on enclosed areas. Table 4.2-5 shows the range of measured emission values from the engines with optimized emission controls. These values are plotted in Figure 4.2-7, showing the NOx-CO tradeoff. The measured emission levels include a variety of duty cycles, but this doesn’t seem to affect the observed trends. Also, Table 4.2-5 notes the length of time the engine was turned off before starting the transient duty cycle. All the data points shown are from measurements with the aged catalysts. Several measurements with the new catalyst showed that engines were able to achieve very low levels of both NOx and CO emissions.

Figures 4.2-8 and 4.2-9 show two attempts to apply a curve-fit to the data points. Using a log-log relationship as shown yielded an R-square value of 0.93, indicating a relatively good fit to the data. Similarly, the best curve-fit with the 1/CO relationship has an R-square value of 0.83. Table 4.2-6 shows a range of values relating CO and HC+NOx emission levels. This involves starting with a set of CO emission levels, then selecting the HC+NOx emission level corresponding with the higher of the two values predicted by the two curve-fitting equations. Finally, both CO and HC+NOx emission levels are increased by 10 percent to account for a compliance margin around the measured data points. This collection of points, shown in Figure 4.2-10, serve as a range of possible combinations of CO and HC+NOx emission standards.

Table 4.2-5
Range of Measured Emission Levels (g/hp-hr)

Engine*	HC	NOx	HC+NOx	CO	Cycle	soak, min.
GM	0.30	3.82	4.12	0.66	Backhoe-loader	4
GM	0.27	4.14	4.41	0.68	Backhoe-loader	2
GM	0.41	5.91	6.32	0.83	Backhoe-loader	20
GM	0.29	5.89	6.18	0.86	Large SI Composite	6
GM	0.27	4.42	4.69	0.87	Highway FTP	3
GM	0.28	5.33	5.61	0.89	Highway FTP	3
Mazda	0.34	0.88	1.22	4.61	Highway FTP	5
Mazda	0.58	0.15	0.73	6.66	Large SI Composite	5
Mazda	0.61	0.19	0.8	6.97	Large SI Composite	5
Mazda	0.66	0.14	0.8	7.5	Large SI Composite	5
Mazda	0.6	0.35	0.95	7.61	Large SI Composite	7
Mazda	0.51	0.7	1.21	7.76	Welder	4

*Both engines operated on LPG for all tests.

Figure 4.2-7

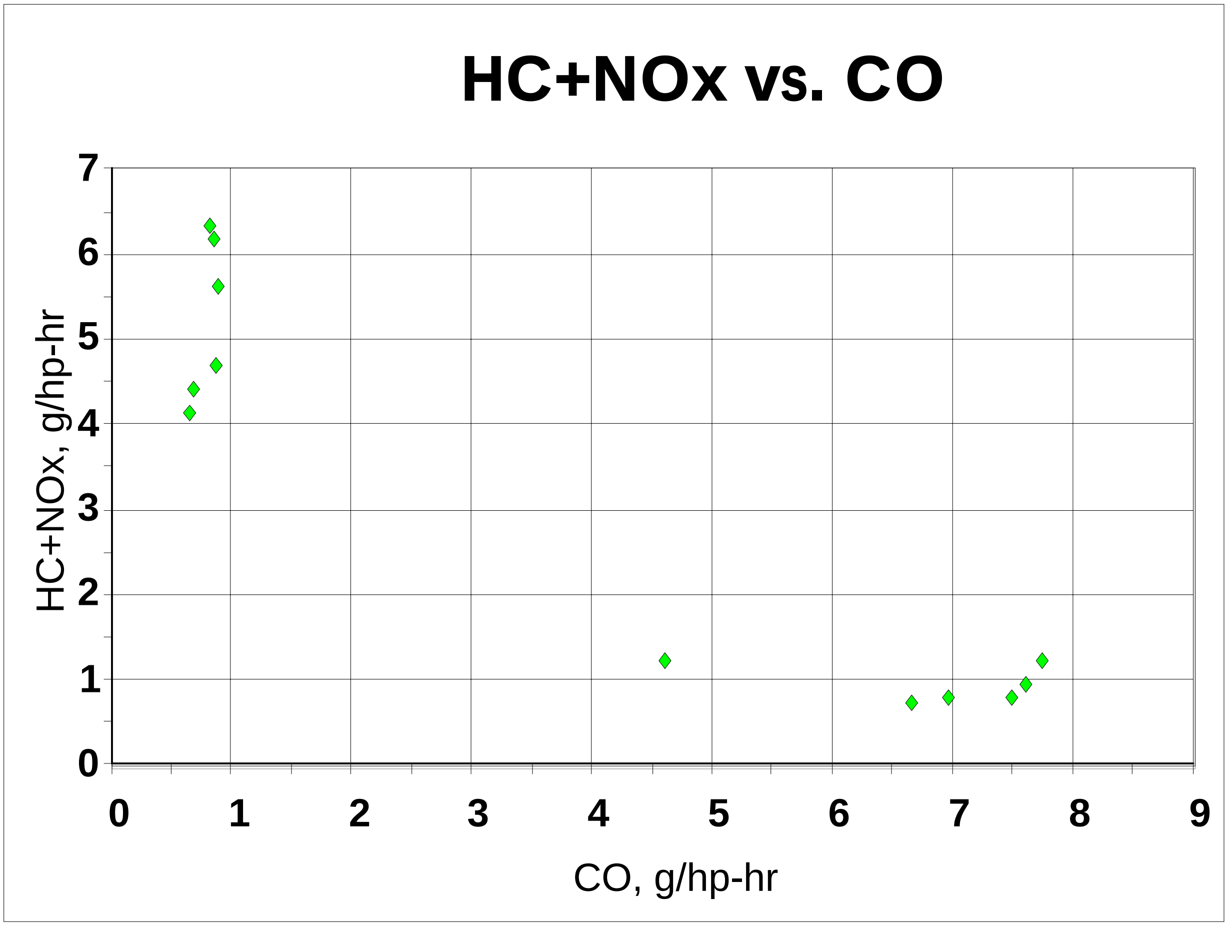


Figure 4.2-8

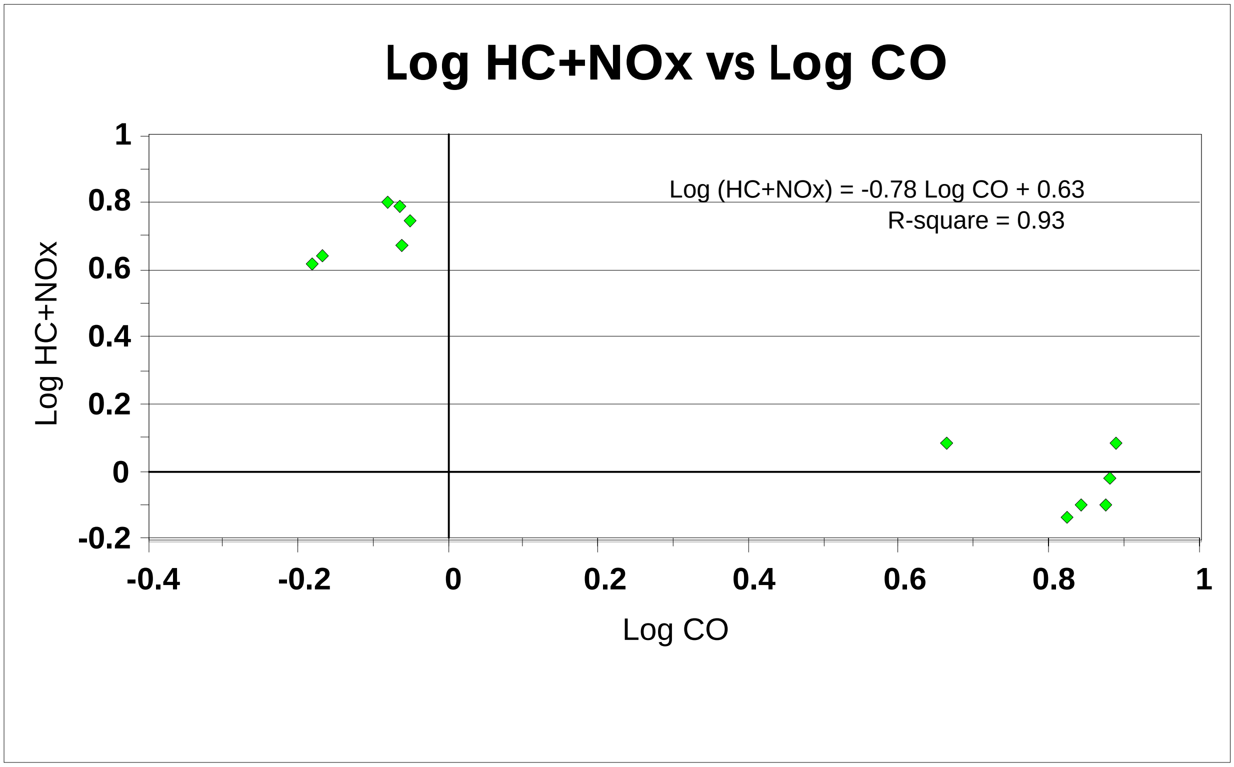


Figure 4.2-9

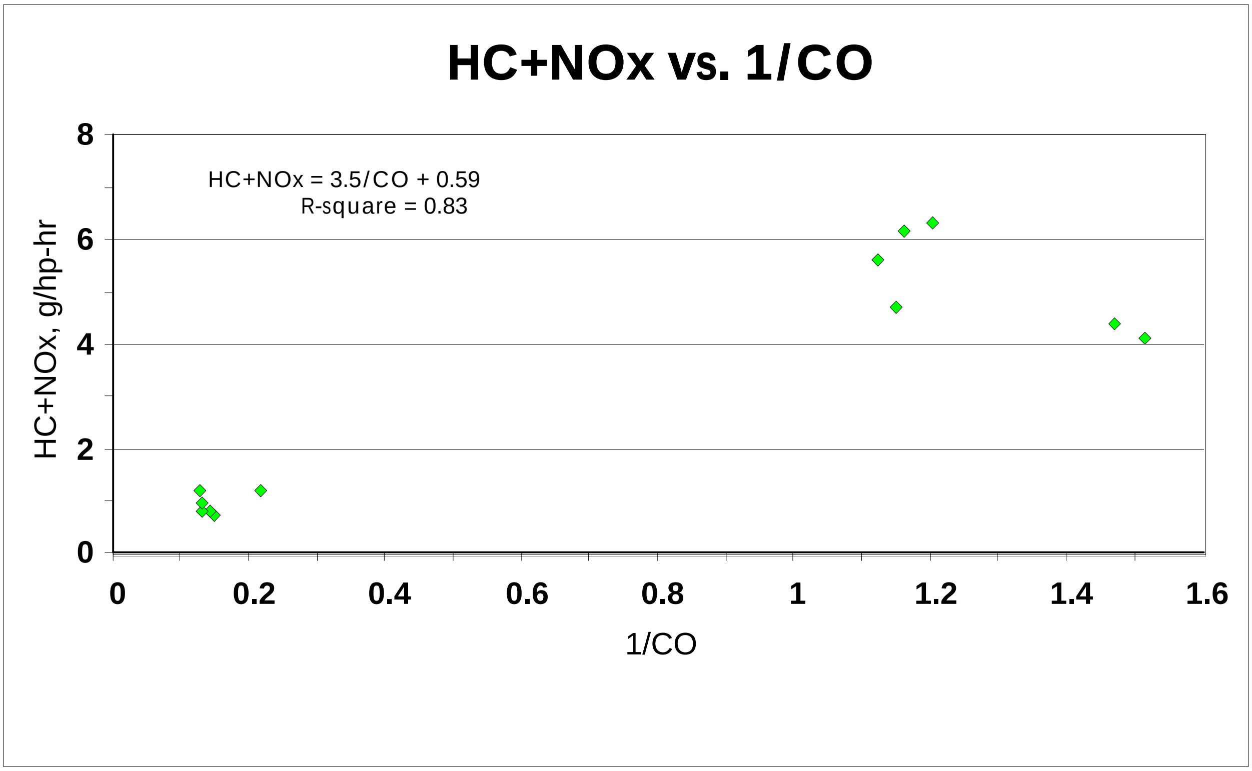


Table 4.2-6
Range of Feasible Emission Standards

CO Emission Level	Predicted HC+NOx Emission Level (Log basis)	Predicted HC+NOx Emission Level (1/CO basis)	Higher Predicted HC+NOx Emission Level	HC+NOx standard*	CO standard*
1.0	4.27	4.09	4.27	4.7	1.1
1.5	3.11	2.92	3.11	3.4	1.7
1.75	**2.76**	**2.59**	**2.76**	**3.0**	**1.9**
2.0	2.48	2.34	2.48	2.7	2.2
2.3	**2.27**	**2.15**	**2.27**	**2.5**	**2.5**
2.5	2.09	1.99	2.09	2.3	2.8
3.0	**1.81**	**1.76**	**1.81**	**2.0**	**3.3**
4.0	1.45	1.47	1.47	1.6	4.4
5.0	1.22	1.29	1.29	1.4	5.5
6.0	1.05	1.17	1.17	1.3	6.6
7.0	0.94	1.09	1.09	1.2	7.7
8.0	0.84	1.03	1.03	1.1	8.8
9.0	0.77	0.98	0.98	1.1	9.9
10.0	0.71	0.94	0.94	1.0	11.0

*Incorporates 10-percent compliance margin.

We generally set standards by focusing on attaining ambient air quality in broad outdoor areas. Any of the emission standards under consideration would provide large reductions to address this concern. More careful balancing of CO and HC+NOx emission standards would allow us to simultaneously address concerns for individual exposure to elevated levels of CO, NO, and NO_2.

Modeling a scenario of indoor engine operation allows us to evaluate the relative exposure of different pollutants under varying engine calibrations. Since the analysis relates primarily to the relative concentrations of the different pollutants, the conclusions drawn here are relatively insensitive to the simplifying assumptions in the calculations. Calculations are based on a forklift operating for eight hours at 20 hp (on average) in a 40' by 60' room with a 20' ceiling. With a dilution rate of one full air exchange per hour, the effective volume is 432,000 ft^3. This volume of air has a mass of about 14,000 kg (or 500,000 moles). Hydrocarbon emissions are estimated to be 20 percent of the total HC+NOx emissions rate, which is typical for Large SI engines. Similarly, the analysis estimates that 90 percent of NOx emissions are NO, with the remainder being NO_2. Plugging in several values from the candidate combinations of emission standards in Figure 4.2-10 results in a shifting balance of HC+NOx and CO emissions.

Table 4.2-7 shows the calculated resulting ambient ppm levels for three different scenarios and compares these values to the threshold limit value published by the American Conference of Governmental Industrial Hygienists. The scenario with emission standards of 3.0 g/hp-hr HC+NOx and 1.9 g/hp-hr CO shows equal relative protection from NO and CO exposures, with both values somewhat lower than the threshold limit values. The second scenario with emission standards of 2.5 g/hp-hr HC+NOx and 2.5 g/hp-hr CO shows the expected shift to lower ambient NO levels, with CO levels slightly over the threshold limit value. The third scenario with emission standards of 2.0 g/hp-hr HC+NOx and 3.3 g/hp-hr CO shows ambient NO levels decreasing to 14 ppm, with ambient CO up to 34 ppm. We are proposing emission standards of 2.5 g/hp-hr for both HC+NOx and for CO as the most appropriate balance in setting emission standards for these pollutants.

Figure 4.2-10

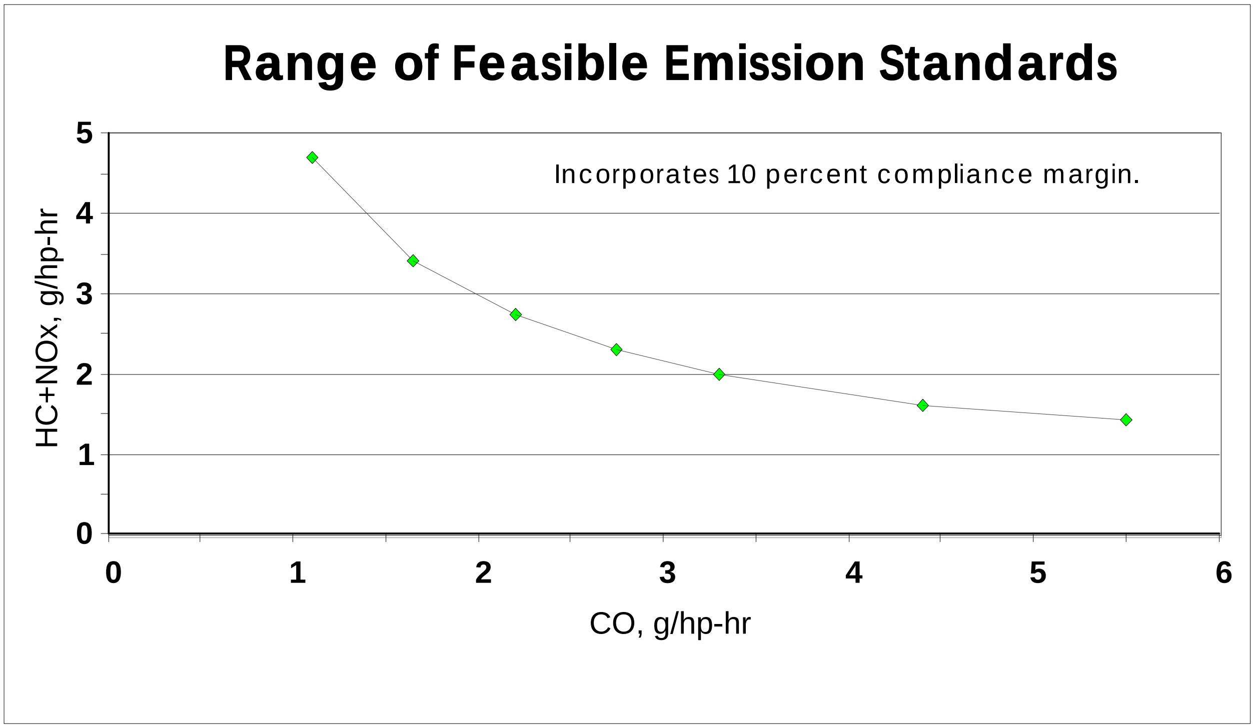


Table 4.2-7
Exposure Scenario for Indoor Operation*

Emission standards, g/hp-hr		Pollutant	Emission factor (g/hp-hr)	Emission rate, g	Emission rate, mol	Ambient ppm	Threshold Limit Value
HC+NOx	CO						
3.0	0.9	NO	2.2	311	10.4	**21**	25
		NO2	0.2	35	0.8	**1.5**	3
		CO	1.9	274	9.8	**20**	25
2.5	2.5	NO	1.8	259	8.6	**17**	25
		NO2	0.2	29	0.6	**1.3**	3
		CO	2.5	360	12.9	**26**	25
2.0	3.3	NO	1.4	207	6.9	**14**	25
		NO2	0.2	23	0.5	**1.0**	3
		CO	3.3	475	17	**34**	25

*Based on emission standards of 3.0 g/hp-hr for HC+NOx and 1.9 g/hp-hr for CO.

4.2.2.7.3 Alternate emission standards

As described in Section 4.2.2.7, we believe that gasoline-fueled engines are most likely to utilize the proposed alternate emission standards, which allow for more stringent NOx+HC emission standards with less stringent CO emission standards. As engines increase their CO emission levels, they are generally capable of achieving lower NOx emission levels. Preliminary data suggest that Large SI engines can meet a 1.0 g/hp-hr HC+NOx emission level when CO emission levels are allowed to increase up to 20 g/hp-hr.

Ongoing testing efforts at SwRI are focused on achieving effective emission control from a gasoline-fueled industrial engine. As we continue this testing, we intend to place emission testing results in the docket as soon as they become available.

4.2.2.7.4 Field-testing emission standards

We are proposing to allow manufacturers to do testing under the in-use testing program using field-testing procedures. This has the potential to substantially reduce the cost of testing. Setting an emission standard for testing engines in the field requires that we take into account all the variability inherent in testing outside the laboratory. As discussed further below, this includes varying engine operation, and a wider range of ambient conditions, and the potential for less accurate or less precise emission measurements and calculations. Also, while the proposed field-testing standards and procedures are designed for testing engines installed in equipment, engines can also be tested on a dynamometer to simulate what would happen in the field. In this case, extra precautionary steps would be necessary to ensure that the dynamometer testing could be characterized as "normal operation." Also, the less stringent field-testing standards would apply to any simulated field-testing on a dynamometer to take emission-measurement variability into account, as described below.

The SwRI test engines also show that Large SI engines are capable of controlling emissions under the wide range of operation covered by the proposed field-testing provisions. A modest amount of additional development would be necessary to address isolated high-emission points uncovered by the testing, but the above discussion makes clear that it would be feasible to resolve these issues well before 2007. Field testing may also include operation at a wider range of ambient conditions than for certification testing. Selecting emission standards for field testing that correspond with the duty-cycle standards requires consideration of the following factors:

- The data presented above show that emissions vary for different modes of engine operation. Manufacturers will need to spend time addressing high-emission points to ensure that engines are not overly sensitive to operation at certain speeds or loads. The data suggest that spark-ignition engines can be calibrated to improve control at the points with the highest emission rates.
- Established correction factors allow for adjustment to account for varying ambient conditions. Allowing adjustment of up to 10 percent would adequately cover any potential increase in emissions resulting from extreme conditions.

- While emission measurements with field-testing equipment allow more flexibility in testing, they are not as precise or as accurate as in the laboratory; the proposed regulations define specifications to limit the error in emission measurements. For most mass-flow and gas analyzer hardware, these tolerance remain quite small. Measurements and calculations for torque values introduce a greater potential for error in determining brake-specific emission levels. The proposed tolerance for onboard torque readings allows for a 15-percent error in understating torque values, which would translate into a 15-percent error in overstating brake-specific emissions.

Taking all these factors into account, we believe it is appropriate to allow for a 40-percent increase in HC+NOx emissions relative to the SwRI measured values to account for the factors listed above. CO emissions are generally somewhat more sensitive to varying engine operation, so a 50-percent adjustment is appropriate for CO. We are therefore proposing field-testing emission standards of 3.5 g/hp-hr THC+NOx and 3.8 g/hp-hr CO.

These same numerical field-testing standards would apply to natural gas engines. Much like for certification, we are proposing to exclude methane measurements from natural gas engines. Since there are currently no portable devices to measure methane (and therefore nonmethane hydrocarbons), we are proposing that the 3.5 g/hp-hr field-testing standard apply only to NOx emissions for natural gas engines.

We would expect to apply the same adjustments to the alternate emission standards to select the appropriate field-testing standard for these engines. As a result, we are proposing alternate field-testing standards of 1.4 g/hp-hr HC+NOx and 31 g/hp-hr CO.

4.2.2.7.5 Evaporative emissions

Several manufacturers are currently producing products with pressurized fuel tanks to comply with Underwriters Laboratories specifications. Most fuel tanks in industrial applications are made of a thick-grade sheet metal or structural steel, so increasing fuel pressures within the anticipated limits poses no risk of bursting or collapsing tanks. For those few applications that use plastic fuel tanks or thinner sheet steel, straightforward technologies such as insulation or a volume-compensating bag would allow for adequate suppression of fuel vapors.

4.2.2.7.6 Conclusions

Manufacturers have been developing emission-control technologies to meet the proposed 2004 emission standards since October 1998, when California ARB adopted the same standards. We expect that manufacturers will add three-way catalysts to their engines and use electronic closed-loop fueling systems. These technologies have been available for industrial engines for many years.

As described above, technology development has shown that these technologies can be optimized to achieve the more stringent emission standards proposed for 2007 and later engines. The testing effort on aged engines with off-the-shelf hardware showed that engines can meet not only the proposed steady-state emission standards, but also the standards that would apply to testing with the proposed transient duty cycles. Similarly, testing over a wide range of engine operation has shown that engines with the these established emission-control technologies can meet the field-testing standards under any normal operation.

4.2.3 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Electronically controlled fuel systems are able to improve management the combustion event, and catalysts can be incorporated into existing equipment designs without compromising the muffling capabilities in the exhaust.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates. We project fuel consumption improvements that will reduce total nationwide fuel consumption by about 300 million gallons annually once the program is fully phased in. While a small number of engines already have these technologies, it seems that the industrial engine marketplace has generally not valued fuel economy highly enough to create sufficient demand for these technologies.

We believe the technology discussed here would have no negative impacts on safety. Electronic fuel injection is almost universally used in cars and trucks in the United States with very reliable performance. In addition, we expect cases of CO poisoning from these engines to decrease as a result of the reduced emission levels.

4.3 Snowmobiles

The following paragraphs summarize the data and rationale supporting the proposed emission standards for snowmobiles, which are listed in the Executive Summary.

4.3.1 Baseline Technology and Emissions

Snowmobiles are equipped with relatively small high-performance two-stroke two and three cylinder engines that are either air- or liquid-cooled. The main emphasis of engine design is on performance, durability, and cost and, because these engines are currently unregulated, they have no emission controls. The fuel system used on these engines are almost exclusively carburetors, although a small number have electronic fuel injection. Two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary 2-stroke engines with a pump that sends two-cycle oil from a separate oil reserve to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. In fact, because performance and durability are such important qualities for snowmobile engines, they all operate with a “rich” air and fuel mixture. That is, they operate with excess fuel, which enhances performance and allows engine cooling which promotes longer lasting engine life. However, rich operation results in high levels of HC, CO, and PM emissions. Also, two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust resulting in high levels of raw HC.

We developed average baseline emission rates for snowmobiles based on the results of emissions testing of 23 snowmobiles.[20] Current average snowmobile emissions rates are 397 g/kW-hr (296 g/hp-hr) CO and 149 g/kW-hr (111 g/hp-hr) HC.

4.3.2 Potentially Available Snowmobile Technologies

A variety of technologies are currently available or in stages of development to be available for use on 2-stroke snowmobiles. These include engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, pulse air, and semi-direct and direct fuel injection. In addition to these 2-stroke technologies, converting to 4-stroke engines may be feasible for some snowmobile types. Each of these is discussed in the following sections.

4.3.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish and tumble would serve to improve the combustion of the intake charge. These modifications have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these things.

4.3.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in snowmobile engines. First, strategies to improve fuel atomization would promote more complete combustion of the fuel/air mixture. Additionally, production tolerances could be improved for more consistent fuel metering. Both of these things would allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ration could be leaned out some. Snowmobile engines are currently calibrated with rich air/fuel ratios for durability reasons. Leaner calibrations would serve to reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration. Small improvements in fuel economy could also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) would also reduce snowmobile engine durability. There are many engine improvements that could be made to regain lost durability that occurs with leaner calibration. These include changes to the cylinder head, pistons, ports and pipes to reduce knock. In addition critical engine components could be made more robust to improve durability.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines could also be employed, possibly with more accuracy, with the use of fuel injection. At least one major snowmobile manufacturer currently employs electronic fuel injection on several of its snowmobile models.

4.3.2.3 Pulse Air

Pulse air injection into the exhaust stream mixes oxygen with the high temperature HC and CO in the exhaust. The added oxygen allows the further combustion of these exhaust constituents between the combustion chamber and tailpipe exhaust. Pulse air can achieve 10 to 40 percent reductions in four-stroke applications, and we expect some modest reductions in two-stroke applications as well.

4.3.2.4 Direct and Semi-direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that emissions from two-stroke engines are high is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft engines. Manufacturers have indicated to us that two-stroke engines equipped with direct fuel injection systems could reduce HC emissions by 70 to 75 percent and reduce CO emissions by 50 to 60 percent. Certification results for 1999 and 2000 model year outboard engines and PWC support the manufacturers projections, as shown in Table 4.3-1. This table shows the paired certification data from some PWC engines in both uncontrolled and direct injection configurations. The percent difference in FEL column refers to the HC + NOx FEL. This is a pretty good surrogate for HC since most of the HC + NOx level is made up of HC, as can be seen from the table.

Table 4.3-1
Certification Levels of Direct Injection vs. Uncontrolled Engines

Mfr	% difference in FEL	size (liter)	power (kw)	FEL (HC + NOx)	HC cert level	CO cert level	Technology
Kawasaki	50%	1.074	95.6	70.0	58.4	148.6	Direct injection, electronic control
		1.073	88.3	140.0	136.76	241.8	none
Arctic Cat	55%	1.104	84.31	75	69.09	148.56	Direct injection
		1.103	88	167	not reported	not reported	none
Bombardier	60%	0.9514	88.85	54.06	45.98	143.0	Direct injection, electronic control
		0.9513	89.5	136.8	136.20	361.30	none
Polaris	70%	1.16	85.26	46.0	37.46	100.4	Direct injection
		1.16	93.25	149.4	not reported	not reported	none

Substantial improvements in fuel economy could also be expected with these technologies. We believe these technologies hold promise for application to snowmobiles. Manufacturers must address a variety of technical design issues for adapting the technology to snowmobile operation, such as operating in colder ambient temperatures and at variable altitude. The several years of lead time give manufacturers time to incorporate these development efforts into their overall research plan as they apply these technologies to snowmobiles.

4.3.2.5 Four-stroke Engines

In addition to the two-stroke technologies just discussed, the use of four-stroke engines in snowmobiles is feasible. One manufacturer has already introduced a four-stroke snowmobile on a limited basis, with wider availability planned, and another is preparing for the introduction of a four-stroke model. Since four-stroke engines do not rely on scavenging of the exhaust gases with the incoming air/fuel mixture, they have inherently lower HC emissions compared to two-strokes (up to 90 percent lower). Somewhat lesser reductions in CO could also be expected. Four-stroke engines have a lower power to weight ratio than two-stroke engines. Thus, they are more likely to be used in snowmobile models where extreme power and acceleration are not the primary selling points. Such models include touring and sport trail sleds, as opposed to high performance sleds such as those used for aggressive trail, cross country, mountain and lake riding.

4.3.3 Test Procedure

We are proposing to largely adopt the snowmobile test procedure developed by Southwest Research Institute in cooperation with the International Snowmobile Manufacturers Association for all snowmobile emissions testing.[21] This test procedure consists of two main parts; the duty cycle that the snowmobile engine would operate over during testing and other testing protocols surrounding the measurement of emissions (sampling and analytical equipment, specification of test fuel, atmospheric conditions for testing, etc.). While the duty cycle we are proposing was developed specifically to reflect snowmobile operation, many of the testing protocols are well established in other EPA emissions programs and have been simply adapted where appropriate for snowmobiles.

The snowmobile duty cycle was developed by instrumenting several snowmobiles and operating them in the field in a variety of typical riding styles, including aggressive (trail), moderate (trail), double (trail with operator and one passenger), freestyle (off-trail), and lake driving. A statistical analysis of the collected data produced the five mode steady-state test cycle shown in Table 4.3-2.

Table 4.3-2
Proposed Snowmobile Engine Test Cycle

Mode	1	2	3	4	5
Normalized Speed	1	0.85	0.75	0.65	Idle
Normalized Torque	1	0.51	0.33	0.19	0
Relative Weighting (%)	12	27	25	31	5

We believe this duty cycle is representative of typical snowmobile operation, and is therefore appropriate for use in demonstrating compliance with the proposed snowmobile emission standards.

The other testing protocols we are proposing are largely derived from our regulations for marine outboard and personal watercraft engines.[22] The testing equipment and procedures from that regulation are largely appropriate for snowmobiles. However, unlike snowmobiles, outboard and personal watercraft engines tend to operate in fairly warm ambient temperatures. Thus, some provision needs to be made in the snowmobile test procedure to account for the colder ambient temperatures typical of snowmobile operation. Since snowmobile carburetors are jetted for specific ambient temperatures and pressures, we could take one of two general approaches. The first is to require testing at ambient temperatures typical of snowmobile operation, with appropriate jetting. A variation of this option is to simply require that the engine inlet air temperature be representative of typical snowmobile operation, without requiring that the entire test cell be at that temperature. The second is to allow testing at higher temperatures than typically experienced during snowmobile operation, with jetting appropriate to the warmer ambient temperatures.

We are proposing that snowmobile engine inlet air temperature be between -15°C and -5°C (5°F and 23°F), but that the ambient temperature in the test cell not be required to be refrigerated. We believe that this approach strikes an appropriate balance between the need to test at conditions that are representative of actual use, and the fact that simply cooling the inlet air would be significantly less costly than requiring a complete cold test cell.

4.3.4 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Four-stroke engines can have considerably lower sound levels than two-stroke engines. Electronically controlled fuel systems are able to improve management of the combustion event which can help lower noise levels.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for two-stroke engines as well as for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke snowmobile is 12 miles per gallon (mpg). Average mileage for a four-stroke snowmobile is 18 mpg and up to 20 mpg for a two-stroke with direct injection. We project that these fuel consumption benefits will reduce total nationwide fuel consumption by more than 50 million gallons annually once the program is fully phased in.

We believe the technology discussed here would have no negative impacts on safety. Electronic fuel injection is almost universally used in cars, trucks and highway motorcycles in the United States with very reliable performance.

4.3.5 Conclusion

4.3.6.1 2006 Standards

We expect that the proposed 2006 model year snowmobile emission standards will largely be met through a combination of engine modifications and carburetion improvements. However, the other technologies discussed have the potential to reduce emissions beyond what could be expected from engine modifications and carburetion improvements. These other technologies also have potential benefits beyond emission reductions (e.g., improved fuel economy, reliability and performance, reduced noise). We expect that as snowmobile manufacturers develop and refine these other technologies they will find their way into the marketplace in certain applications where their non-emissions benefits would outweigh their cost.

4.3.6.2 2010 Standards

There are a number of different technology mixes which could be used to meet the proposed 50 percent average reductions in HC and CO. The Table 4.3-3 provided below presents the approach we used for purposes of further analysis. The average reduction level at the bottom of the table represents average reductions for a manufacturer’s entire fleet which already incorporates compliance margin consideration, since each engine family FEL will have a unique compliance margin. The percent reduction presented in the table are based on CO, since it is likely to be the pollutant most difficult to control. Larger HC reductions would be achieved with these technologies. Obviously, a manufacturer could change the technology mix based on cost and performance considerations. For example, the percent of direct injection two-stroke engine could be increased thus allowing fewer four-stroke or more modified two-stroke engines (e.g., calibration & engine modifications). We expect the manufacturers to select the most technically attractive and cost-effective approach which meet their perceived customer needs. Clearly there are options available to accomplish this goal.

Table 4.3-3
Potential Snowmobile Technology Mix for 2010

Technology	Percent Reduction	Percent Use to Meet Standard	Total Percent Reduction
Carburetor/EFI Recalibration + Engine Modifications + Pulse Air Injection	35%	50%	0.175
Direct Injection	70%	40%	0.280
Four-Stroke	50%	10%	0.050
Average Reduction			**0.505**

4.4 All-Terrain Vehicles

The following paragraphs summarize the data and rationale supporting the proposed emission standards for ATVs, which are listed in the Executive Summary.

4.4.1 Baseline Technology and Emissions

ATVs have been in existence for many years, but have only become popular over the last 25 years. Some of the earliest and most popular ATVs were three-wheeled off-highway motorcycles with large balloon tires. Due to safety concerns, the three-wheeled ATVs were phased-out in the mid-1980s and replaced by the current and more popular vehicle known as "quad runners" or simply "quads." Quads resemble the earlier three-wheeled ATVs except the single front wheel was replaced with two wheels that are controlled by a steering system. The ATV steering system uses motorcycle handlebars, but otherwise looks and operates like an automotive design. The operator sits on and rides the quad much like a motorcycle. The engines used in quads tend to be very similar to those used in off-highway motorcycles - relatively small single cylinder two- or four-stroke engines that are either air- or liquid-cooled. Recently, some manufacturers have introduced ATVs equipped with larger four-stroke two-cylinder V-twin engines. Quads are typically divided into two types: utility and sport. The utility quads are designed for recreational use but have the ability to perform many utility functions such as plowing snow, tilling gardens, and mowing lawns to name a few. They are typically heavier and equipped with relatively large four-stroke engines and automatic transmissions with reverse gear. Sport quads are smaller and designed primarily for recreational purposes. They are equipped with two- or four-stroke engines and manual transmissions.

There are two other types of ATVs, although they are not nearly as common as quad runners. Both types of vehicles are equipped with six wheels. The first type looks similar to a large golf cart, with a bed for hauling cargo much like a pick-up truck. These ATVs are typically manufactured by the same companies that make quad runners and use similar engines. The other type of six-wheeled ATV is an amphibious unit that can operate in water as well as on land. These ATVs are typically equipped with small spark-ignition gasoline-powered engines similar to those found in lawn and garden tractors, rather than the motorcycle engines used in quads, although some also use large SI engines as well.

Although ATVs are not currently regulated federally, they are regulated in California. The California ATV standards are based on the FTP cycle just like highway motorcycles, however, they allow manufacturers to optionally certify to a steady-state engine cycle (SAE J1088) and meet the California non-handheld small SI utility engine standards. Manufacturers have felt that these standards are unattainable with two-stroke engine technology. Therefore, all of the ATVs certified in California are equipped with four-stroke engines. California ultimately allowed manufacturers to sell uncertified engines as long as those ATVs and motorcycles equipped with these engines were operated exclusively on restricted public lands and at specified times of the year. This allowed manufacturers to continue to manufacture and sell two-stroke ATVs in California. Thus, the main emphasis of ATV engine design federally, and for two-stroke powered ATVs in California, is on performance, durability, and cost. Although some manufacturers offer some of their California models nationwide, most ATVs sold federally have no emission controls.

ATVs predominantly use four-stroke engines (e.g., 80 percent of all sales are four-stroke). The smaller percentage of two-stroke engines are found primarily in the small engine displacement "youth" models. Of the seven major ATV manufacturers, only two make two-stroke ATVs for adults. These models are either inexpensive entry models or high-performance sport models. The fuel system used on ATVs, whether two- or four-stroke, are almost exclusively carburetors, although at least one manufacturer has introduced a four-stroke ATV with electronic fuel injection. Although ATVs are mostly four-stroke equipped, they still can have relatively high levels of HC and extremely high levels of CO, because many of them operate with a "rich" air and fuel mixture, which enhances performance and allows engine cooling which promotes longer lasting engine life. This is also true for two-stroke equipped ATVs. Rich operation results in high levels of HC, CO, and PM emissions. In addition, two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary 2-stroke engines with a pump that sends two-cycle oil from a separate oil reserve to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. Because two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust, lubricating oil particles are also released into the atmosphere, becoming HC particles or particulate matter (PM). The scavenging losses also result in high levels of raw HC. This is in contrast to four-stroke engines that use the crankcase as an oil sump and a pump to distribute oil throughout the engine, resulting in virtually no PM..

We tested five adult four-stroke and two youth two-stroke ATVs over the FTP. Tables 4.4-1 and 4.4-2 shows that the HC emissions for the four-stroke ATVs is significantly lower than for the two-stroke ATVs, whereas the NOx emissions from the two-strokes were considerably lower. Although the two-stroke ATVs tested were youth models, it can be argued that the emissions from these two models are lower than what could be expected from larger engines, since smaller displacement engines typically generate less emissions. The CO emissions were also lower for the two-stroke ATVs. The four-stroke ATVs that we tested that had high levels of CO happened to be 50-state certified vehicles, meaning they are California vehicles sold nationwide. Because there are California standards for HC+NOx, manufacturers have tended to calibrate the ATVs even richer then normal to meet the NOx standard. Since the CO standard in California is relatively high, these ATVs can run rich and still meet the CO standards.

Table 4.4-1
Four-Stroke ATV Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Kawasaki	Bayou	1989	280 cc	1.17	14.09	0.640
Honda	300EX	1997	298 cc	1.14	34.60	0.155
Polaris	Trail Boss	1998	324 cc	1.56	43.41	0.195
Yamaha	Banshee	1998	349 cc	0.98	19.44	0.190
Polaris	Sportsman	2001	499 cc	2.68	56.50	0.295
Average				1.51	33.61	0.295

Table 4.4-2
Two-Stroke ATV Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Suzuki	LT80	1998	79 cc	7.66	24.23	0.047
Polaris	Scrambler	2001	89 cc	38.12	25.08	0.057
Average				22.89	24.66	0.052

4.4.2 Potentially Available ATV Technologies

A variety of technologies are currently available or in stages of development to be available for use on two-stroke ATVs, such as engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, and semi-direct and direct fuel injection. However, it is our belief that manufacturers will choose to convert their two-stroke engines to four-stroke applications, because of the cost and complexity of the above mentioned technologies necessary to make a two-stroke engine meet our proposed standards. For our proposed phase 1 standards, we believe that a four-stroke engine with minor improvements to carburetion and enleanment strategies will be all that is required. For our proposed phase 2 standards, we believe the use of a four-stroke engine with improved carburetion or possible use of electronic fuel injection, enleanment strategies, possible engine modifications, secondary air and/or possibly the use of a oxidation catalyst will be necessary. Each of these is discussed in the following sections.

4.4.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke and four-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications for two-stroke engines that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish and tumble would serve to improve the combustion of the intake charge for both two- and four-stroke engines. These modifications for two-stroke engines have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these things, but would be insufficient alone to meet our proposed phase 1 standards.

4.4.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in ATV engines. First, strategies to improve fuel atomization would promote more complete combustion of the fuel/air mixture. Additionally, production tolerances could be improved for more consistent fuel metering. Both of these things would allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ratio could be leaned out some. ATV engines are currently calibrated with rich air/fuel ratios for durability and performance reasons. Leaner calibrations would serve to reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration. Small improvements in fuel economy could also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) would also reduce ATV engine durability. There are many engine improvements that could be made to regain lost durability that occurs with leaner calibration. These include changes to the cylinder head, pistons, pipes and ports for two-stroke and valves for four-stroke, to reduce knock. In addition critical engine components could be made more robust to improve durability.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines could also be employed, possibly with more accuracy, with the use of fuel injection. At least one ATV manufacturer currently employs electronic fuel injection on one of its ATV models.

4.4.2.3 Direct and Semi-Direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that two-stroke engines have such high levels of HC emissions is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft engines and some are showing upwards of 70 percent reductions in emissions. Direct injection is also being used by some motorcycle manufacturers (e.g., Aprilla) on small mopeds, scooters, and motorcycles to meet emission standards for two-strokes in Europe and Asia. Substantial improvements in fuel economy could also be expected with these technologies. However, there are some issues with ATV operation (larger displacement engines that experience more transient operation than watercraft and small mopeds) that make the application of the direct injection technologies somewhat more challenging for ATVs than for personal watercraft and small displacement scooters. The biggest obstacle for this technology is that the many of the two-stroke equipped ATVs are youth models which emphasize low price. Direct injection is relatively expensive and is currently not considered to be cost effective for these engines.

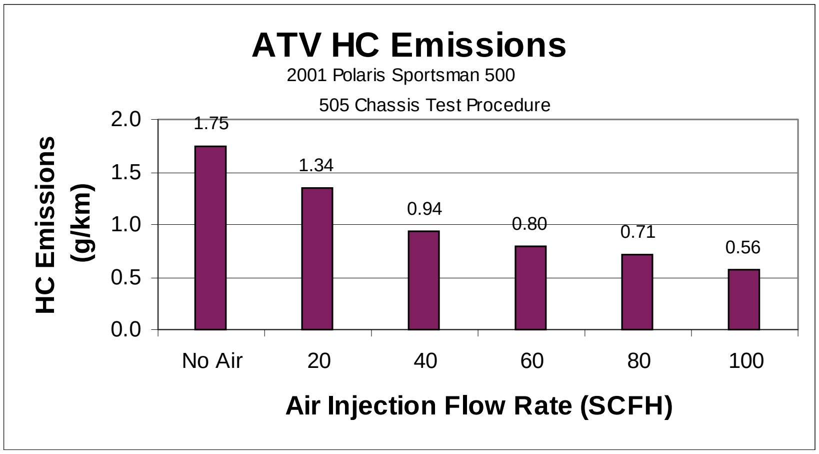
4.4.2.4 Four-Stroke Engines

Since 80 percent of all ATVs sold each year are four-stroke, there is no question about the feasibility of using four-stroke technology for ATVs. The ATV models that are currently equipped with two-stroke engines tend to be small-displacement youth models, entry-level adult ATVs and high-performance adult sport ATVs. While most youth ATVs are equipped with two-stroke engines, there are several manufactures who offer four-stroke models. Youth ATVs are regulated by the Consumer Product Safety Commission (CPSC). Although the regulations are voluntary, manufactures take them very seriously, and one of the their requirements is that youth ATV speeds be governed. For “Y6" ATVs (i.e., age 6 and up) the maximum speed is 15 miles per hour (mph) and for “Y12" ATVs (i.e., age 12 and up), the maximum speed is 30 mph. Some manufacturers have argued that because of these speed constraints, they need to use light-weight two-stroke engines, which have higher power-to-weight ratios than four-stroke engines, in order to have sufficient power to operate the ATV. As mentioned earlier, some manufacturers already use four-stroke engines in these applications without any problem. The power required to meet the maximum speed limits for these little ATVs is low enough that a four-stroke engine is more than adequate. The real issue appears to be cost. Manufacturers argue that youth ATVs are price sensitive and that minor increases in cost would be undesirable. Four-stroke engines are more expensive than similarly powered two-stroke engines. This appears to be the issue with entry-level adult ATVs as well. Those manufacturers that offer two-stroke entry-level ATVs, also offer similar entry-level machines with four-stroke engines. The argument is that consumers of their product like having the ability to choose between engine types.

Adult sport ATVs equipped with two-stroke engines were at one time considered the only ATVs that were capable of providing true high-performance. However, advancements in four-stroke engine technology for ATVs and off-highway motorcycles have now made it possible for larger displacement high-powered four-stroke engines to equal, and in some cases surpass, the performance of the high-powered two-stroke engines. Again, the argument for two-stroke engines appears to be a matter of choice for consumers. However, since only two manufacturers produce two-stroke adult ATVs, we believe that the relatively low sales volumes for these models will make it cost prohibitive to reduce two-stroke emissions to the levels necessary to meet our proposed phase I standards.

Conversion from two-stroke to four-stroke engine technology will also result in improvements to fuel consumption and engine durability. These benefits could be especially valuable to consumers who purchase utility ATVs.

4.4.2.5 Air Injection



Secondary pulse air injection involves the introduction of fresh air into the exhaust pipe immediately after the gases exit the engine. The extra air causes further combustion to occur as the gases pass through the exhaust pipe, thereby controlling more of the hydrocarbons that escape the combustion chamber. This type of system is relatively inexpensive and uncomplicated because it does not require an air pump; air is drawn into the exhaust through a one-way reed valve due to the pulses of negative pressure inside the exhaust pipe. Secondary pulse-air injection is one of the most effective non-catalytic, emissions control technologies; compared to engines without the system, reductions of 10-40% for HC are possible with pulse-air injection.

This technology is fairly common on highway motorcycles and is used on some off-highway motorcycle models in California to meet the California off-highway motorcycle and ATV emission standards. We believe that secondary air injection will not be necessary to meet our proposed phase 1 standards, but will be a viable technology for meeting our proposed phase 2 emission standards. Secondary air injection can also be used in conjunction with an oxidation catalyst to achieve even further reductions. We are planning to test several four-stroke ATVs with secondary air injection. Initial test results for a 2001 Polaris Sportsman 500 four-stroke ATV indicate that secondary air injection could result in up to a 70 percent reduction in HC emissions and a 50 percent reduction in CO emissions from baseline four-stroke ATV emission levels.

Figure 4.4-1

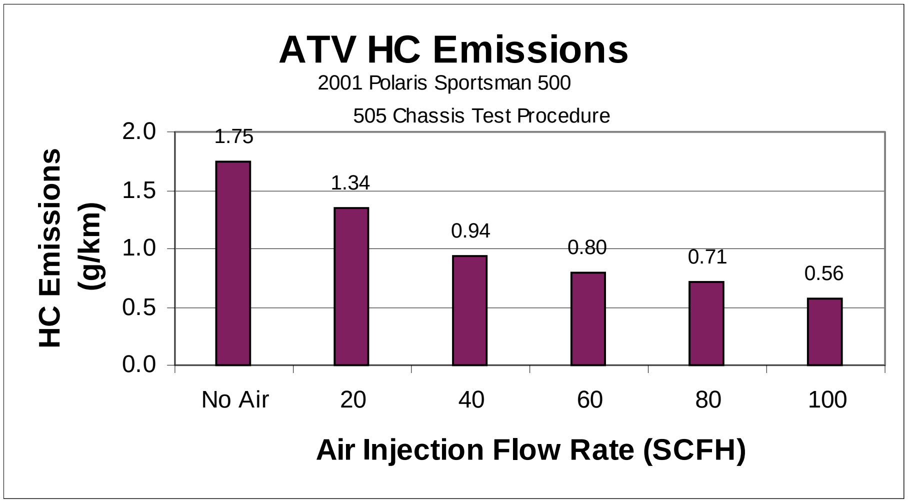
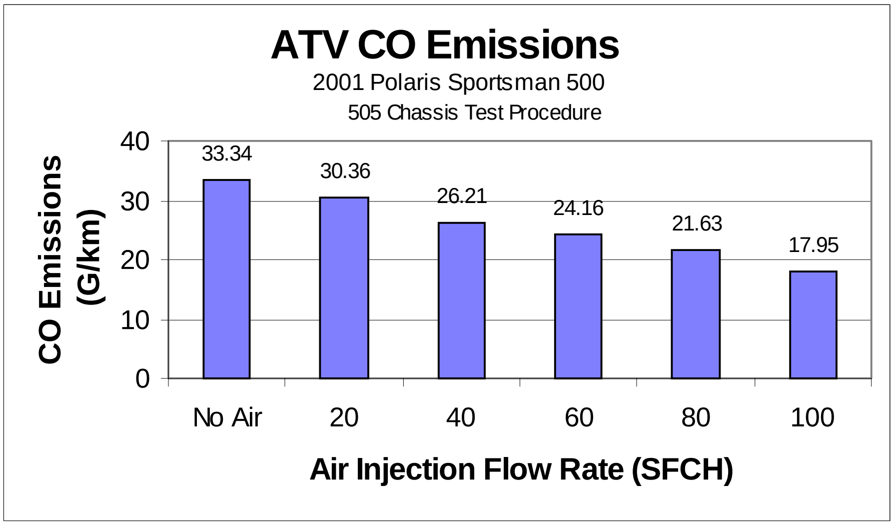


Figure 4.4-2



4.4.2.6 Catalyst Technology

Catalyst technology may be necessary for some ATV models to meet our proposed phase-2 emission standards. Depending on the model, the respective engine and it's unique characteristics and the manufacturers preference, manufacturers may choose to use a two-way or oxidation catalyst or a three-way catalyst. If NOx emissions are inherently low for a given engine, a manufacturer may decide to use an oxidation catalyst. If high NOx levels are a concern, the manufacturer may choose to use a three-way catalyst instead. Oxidation catalysts typically use platinum and/or palladium to oxidize HC and CO emissions. Because some ATV engines operate so rich, it may be necessary to also use secondary air injection in conjunction with an oxidation catalyst in order to provide adequate oxygen for oxidation to occur.

Three-way catalytic converters traditionally utilize rhodium and platinum/palladium as the catalytic material to control the emissions of all three major pollutants (HC, CO, and NOx). Although this type of catalyst is very effective at converting exhaust pollutants, rhodium, which is primarily used to reduce NOx to nitrogen and oxygen, tends to thermally deteriorate at temperatures significantly lower than platinum. Recent advances in palladium and tri-metal (i.e., palladium-platinum-rhodium) catalyst technology, however, have improved both the light-off performance and high temperature durability over previous catalysts. In addition, other refinements to catalyst technology, such as higher cell density substrates and adding a second layer of catalyst washcoat to the substrate (dual-layered washcoats), have further improved catalyst performance from just a few years ago.

Typical cell densities for conventional catalysts used in motorcycles are less than 300 cells per square inch (cpsi). To meet our proposed phase 2 standards, we expect manufacturers to use catalysts with cell densities of 100 to 200 cpsi. If catalyst volume is maintained at the same level (we assume volumes of up to 50% of engine displacement), using a higher density catalyst effectively increases the amount of surface area available for reacting with pollutants. Catalyst manufacturers have been able to increase cell density by using thinner walls between each cell without increasing thermal mass (and detrimentally affecting catalyst light-off) or sacrificing durability and performance.

We have tested a 2001 model year Polaris Sportsman 500 ATV. It is a large utility ATV equipped with a 500 cc four-stroke engine and is one of the largest ATV models currently offered in the market. We chose this model to demonstrate catalyst viability because it had the highest baseline emissions of any of the ATVs we tested, and it is a California certified vehicle that is sold nationwide. We tested the Polaris with three different catalysts. Two of the catalysts were three-way catalysts with metal substrates and cell densities of 200 cpsi. One of the catalyst's had a Pt/Rh washcoat, while the other used a Pd-only washcoat. The third catalyst was an oxidation catalyst with a ceramic substrate and a cell density of 400 cpsi. Table 4.4-3 shows that the use of either an oxidation or three-way catalyst can significantly reduce emissions from an ATV. This particular ATV had baseline HC and CO emissions that were 77% higher for HC and 68% higher for CO than the average of the baseline levels of all of the ATVs we tested (see above in Table 4.4-1). We measured air/fuel ratio during testing and found this vehicle to operate extremely rich. We plan to test the ATV with a leaner carburetor setting and with secondary air injection. We anticipate that either one or perhaps both of these strategies would result in even further emission reductions. We also measured exhaust backpressure and found that none of the catalysts tested resulted in a significant increase in backpressure, which could correspond to reduced engine performance.

Although the test results for the Polaris did not meet our proposed phase 2 standards, we are confident that the data illustrate that the use of a catalytic converter can achieve these levels, since the percent reductions from baseline levels with the catalysts were approximately 52% for HC and 38% for CO. These levels of reduction when applied to the average baseline emissions from our test fleet would result in emission levels at or below our proposed phase 2 standards.

Table 4.4-3
Polaris Sportsman 500 Emissions with Various Catalysts

Catalyst	HC	CO	NOx	HC+NOx
Baseline	2.68	56.50	0.30	2.98
TWC (Pd-only)	1.27	35.27	0.05	1.32
TWC (Pt/Rh)	1.29	32.60	0.04	1.33
Oxidation	1.38	28.87	0.02	1.40

Increased precious metal loading (up to a certain point) will reduce exhaust emissions because it increases the opportunities for pollutants to be converted to harmless constituents. The extent to which precious metal loading is increased will be dependent upon the precious metals used and other catalyst design parameters. We believe recent developments in palladium/rhodium catalysts are very promising since rhodium is very efficient at converting NOx, and catalyst suppliers have been investigating methods to increase the amount of rhodium in catalysts for improved NOx conversion.

Double layer technologies allow optimization of each individual precious metal used in the washcoat. This technology can provide reduction of undesired metal-metal or metal-base oxide interactions while allowing desirable interactions. Industry studies have shown that durability and pollutant conversion efficiencies are enhanced with double layer washcoats. These recent improvements in catalysts can help manufacturers meet the proposed phase 2 standards at reduced cost relative to older three-way catalysts.

New washcoat formulations are now thermally stable up to 1050 ^{o}C. This is a significant improvement from conventional washcoats, which are stable only up to about 900 ^{o}C. With the improvements in light-off capability, catalysts may not need to be placed as close to the engine as previously thought. However, if placement closer to the engine is required for better emission performance, improved catalysts based on the enhancements described above would be more capable of surviving the higher temperature environment without deteriorating. The improved resistance to thermal degradation will allow closer placement to the engines where feasible, thereby providing more heat to the catalyst and allowing them to become effective quickly.

It is well established that a warmed-up catalyst is very effective at converting exhaust pollutants. Recent tests on advanced catalyst systems in automobiles have shown that over 90% of emissions during the Federal Test Procedure (FTP) are now emitted during the first two minutes of testing after engine start up. Similarly, the highest emissions from a motorcycle occur shortly after start up. Although improvements in catalyst technology have helped reduce catalyst light-off times, there are several methods to provide additional heat to the catalyst. Retarding the ignition spark timing and computer-controlled, secondary air injection have been shown to increase the heat provided to the catalyst, thereby improving its cold-start effectiveness.

Improving insulation of the exhaust system is another method of furnishing heat to the catalyst. Similar to close-coupled catalysts, the principle behind insulating the exhaust system is to conserve the heat generated in the engine for aiding catalyst warm-up. Through the use of laminated thin-wall exhaust pipes, less heat will be lost in the exhaust system, enabling quicker catalyst light-off. As an added benefit, the use of insulated exhaust pipes will also reduce exhaust noise. Increasing numbers of manufacturers are expected to utilize air-gap exhaust manifolds (i.e., manifolds with metal inner and outer walls and an insulating layer of air sandwiched between them) for further heat conservation for highway motorcycles, although this may prove to be overkill for ATV applications.

4.4.3 Test Procedure

For ATVs, we propose that the current highway motorcycle test procedure be used for measuring emissions. The highway motorcycle test procedure is the same test procedure as used for light-duty vehicles (i.e., passenger cars and trucks) and is referred to as the Federal Test Procedure (FTP). The FTP for a particular class of engine or equipment is actually the aggregate of all of the emissions tests that the engine or equipment must meet to be certified. However, the term FTP has also been used traditionally to refer to the exhaust emission test based on the Urban Dynamometer Driving Schedule (UDDS), also referred to as the LA4 (Los Angeles Driving Cycle #4). The UDDS is a chassis dynamometer driving cycle that consists of numerous “hills” which represent a driving event. Each hill includes accelerations, steady-state operation, and decelerations. There is an idle between each hill. The FTP consists of a cold start UDDS, a 10 minute soak, and a hot start. The emissions from these three separate events are collected into three unique bags. Each bag represents one of the events. Bag 1 represents cold transient operation, bag 2 represents cold stabilized operation, and bag 3 represents hot transient operation.

Highway motorcycles are divided into three classes based on engine displacement, with class I (50 to 169 cc) being the smallest and class 3 (280 cc and over) being the largest. The highway motorcycle regulations allow class I motorcycles to be tested on a less severe UDDS cycle than the class II and III motorcycles. This is accomplished by reducing the acceleration and deceleration rates on some the more aggressive “hills.” We propose that this same class/cycle distinction be allowed for ATVs. In other words, ATVs with an engine displacement between 50 and 279 cc (class I and II) would be tested over the class I highway motorcycle FTP test cycle. ATVs with engine displacements greater than 280 cc would be tested over the class III highway motorcycle FTP test cycle. Some manufacturers have noted that they do not currently have chassis-based test facilities capable of testing ATVs. Manufacturers have noted that requiring chassis-based testing for ATVs would require them to invest in additional testing facilities which can handle ATVs, since ATVs do not fit on the same roller(s) as motorcycles used in chassis testing. Some manufacturers also have stated that low pressure tires on ATVs would not stand up to the rigors of a chassis dynamometer test. California provides manufacturers with the option of certifying ATVs using the engine-based, utility engine test procedure (SAE J1088), and most manufacturers use this option for certifying their ATVs. Manufacturers have facilities to chassis test motorcycles and therefore California does not provide an engine testing certification option for motorcycles.

We have tested numerous ATVs over the FTP and have found that several methods can be used to test ATVs on chassis dynamometers. The most practical method for testing an ATV on a motorcycle dynamometer is to disconnect one of the drive wheels and test with only one drive wheel in contact with the dynamometer. For chassis dynamometers set-up to test light-duty vehicles, wheel spacers or a wide axle can be utilized to make sure the drive wheels fit the width of the dynamometer. We have found that the low pressure tires have withstood dynamometer testing without any problems.

We acknowledge that a chassis dynamometer could be very costly to purchase and difficult to put in place in the short run, especially for some smaller manufacturers. Therefore, we are proposing that for the model years 2006 thru 2009, ATV manufacturers would be allowed the option to certify using the J1088 engine test cycle per the California off-highway motorcycle and ATV program. After 2009, this option would end and the FTP would be the required test cycle. If manufacturers can develop an alternate transient test cycle (engine or chassis) that shows correlation with the FTP or demonstrates representativeness of actual ATV operation greater than the FTP, then we would consider allowing the option of an alternative test cycle in place of the FTP.

4.4.4 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Virtually all ATVs are equipped sound suppression systems or mufflers. The four-stroke engines used in ATVs are considerably more quiet than two-stroke engines. Electronically controlled fuel systems are able to improve management of the combustion event which can further help lower noise levels.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke ATV is 20-25 mpg, while the average four-stroke ATV gets 45-50 mpg.

We believe the technology discussed here would have no negative impacts on safety. Four-stroke engine technology has been utilized on ATVs for numerous years without any incident. Secondary air and catalysts have been utilized in highway motorcycles and lawn and garden equipment without any safety concerns.

4.4.5 Conclusion

We expect that the proposed phase 1 ATV emission standards will largely be met through the conversion of two-stroke engines to four-stroke engines with some minor carburetor calibration modifications and air-fuel ratio enleanment. Certification data from California’s off-highway motorcycle and ATV program, as well as data from our own testing suggest that four-stroke engines with some minor fuel system calibration modifications will be capable of meeting our proposed emission standards. For our proposed phase 2 ATV emission standards, we expect manufacturers to use four-stroke engine technology with a possible combination of engine modifications, carburetion improvements, secondary air injection and/or catalyst aftertreatment. These technologies have been utilized in a number of different applications, such as highway motorcycles, personal watercraft, lawn and garden equipment, and small scooters. Preliminary testing performed by us and other research firms have also shown that these are viable technologies capable of meeting our proposed phase 2 standards. However, the other technologies discussed have the potential to reduce emissions beyond what could be expected from engine modifications and carburetion improvements. These other technologies also have potential benefits beyond emission reductions (e.g., improved fuel economy, reliability and performance, and reduced noise). We expect that as ATV manufacturers develop and refine these other technologies, they will find their way into the marketplace in certain applications where their non-emission benefits would outweigh their cost.

4.7 Off-Highway Motorcycles

The following paragraphs summarize the data and rationale supporting the proposed emission standards for off-highway motorcycles, which are listed in the Executive Summary.

4.7.1 Baseline Technology and Emissions

Off-highway motorcycles are similar in appearance to highway motorcycles (which are discussed in section 4.8.), but there are several important distinctions between the two types of machines. Off-highway motorcycles are not street-legal and are primarily operated on public and private lands over trails and open land. Off-highway motorcycles tend to be much smaller, lighter and more maneuverable than their larger highway counterparts. They are equipped with relatively small-displacement single- cylinder two- or four-stroke engines ranging from 50 to 650 cubic centimeters (cc). The exhaust systems for off-highway motorcycles are distinctively routed high on the frame to prevent damage from brush, rocks, and water. Off-highway motorcycles are designed to be operated over varying surfaces, such as dirt, sand, and mud, and are equipped with knobby tires which provide better traction in off-road conditions. Unlike highway motorcycles, off-highway motorcycles have fenders mounted far from the wheels and closer to the rider to keep dirt and mud from spraying the rider and clogging between the fender and tire. Off-highway motorcycles are also equipped with a more advanced suspension system than those for highway motorcycles. This allows the operator to ride over obstacles and make jumps safely.

Thirty percent of off-highway motorcycle sales are competition motorcycles. The vast majority of competition off-highway motorcycles are two-strokes. The CAA requires us to exempt from our regulations vehicles used for competition purposes. The off-highway motorcycles that remain once competition bikes are excluded are recreational trail bikes and small-displacement youth bikes. The majority of recreational trail bikes are equipped with four-stroke engines. Youth off-highway motorcycles are almost evenly divided between four-stroke and two-stroke engines.

The fuel system used on off-highway motorcycles, whether two- or four-stroke, are almost exclusively carburetors, although at least one manufacturer has introduced a four-stroke off-highway motorcycle with electronic fuel injection. Although many off-highway motorcycles are four-stroke equipped, they still can have relatively high levels of HC and extremely high levels of CO, because many of them operate with a “rich” air and fuel mixture, which enhances performance and allows engine cooling which promotes longer lasting engine life. This is also true for two-stroke equipped off-highway motorcycles. Rich operation results in high levels of HC, CO, and PM emissions. In addition, two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary two-stroke engines with a pump that sends two-cycle oil from a separate oil reserve to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. Because two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust, lubricating oil particles are also released into the atmosphere, becoming HC particles or particulate matter (PM). The scavenging losses also result in high levels of raw HC. This is in contrast to four-stroke engines that use the crankcase as an oil sump and a pump to distribute oil throughout the engine, resulting in virtually no PM.

We tested six high-performance two-stroke motorcycles and four high-performance four-stroke motorcycles over the FTP. Tables 4.7-1 and 4.7-2 shows that the HC emissions for the four-stroke bikes is significantly lower than for the two-stroke bikes, whereas the NOx emissions from the two-strokes were considerably lower. The CO levels were also considerably lower for the four-stroke bikes.

Table 4.7-1
Four-Stroke Off-Highway Motorcycles Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Yamaha	WR250F	2001	249 cc	1.46	26.74	0.110
Yamah	WR400F	1999	398 cc	1.07	20.95	0.155
KTM	400EXC	2001	398 cc	1.17	28.61	0.050
Husaberg	FE501	2001	498 cc	1.30	25.81	0..163
Average				1.25	25.52	0.109

Table 4.7-2
Two-Stroke Off-Highway Motorcycles Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
KTM	125SX	2001	124 cc	33.77	31.00	0.008
KTM	125SX	2001	124 cc	61.41	32.43	0.011
KTM	200EXC	2001	198 cc	53.09	39.89	0.025
KTM	250SX	2001	249 cc	62.89	49.29	0.011
KTM	250EXC	2001	249 cc	59.13	40.54	0.016
KTM	300EXC	2001	398 cc	47.39	45.29	0.012
Average				52.95	39.74	0.060

4.7.2 Potentially Available Off-Highway Motorcycle Technologies

A variety of technologies are currently available or in stages of development to be available for use on two-stroke off-highway motorcycles, such as engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, and semi-direct and direct fuel injection. However, it is our belief that manufacturers will choose to convert their two-stroke engines to four-stroke applications, because of the cost and complexity of the above mentioned technologies necessary to make a two-stroke engine meet our proposed standards. For our proposed standards, we believe that a four-stroke engine with minor improvements to carburetion and enleanment strategies will be all that is required. Each of these is discussed in the following sections.

4.7.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke and four-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications for two-stroke engines that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish and tumble would serve to improve the combustion of the intake charge for both two- and four-stroke engines. These modifications for two-stroke engines have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these things, but would be insufficient alone to meet our proposed standards.

4.7.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in off-highway motorcycle engines. First, strategies to improve fuel atomization would promote more complete combustion of the fuel/air mixture. Additionally, production tolerances could be improved for more consistent fuel metering. Both of these things would allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ratio could be leaned out some. Off-highway motorcycle engines are currently calibrated with rich air/fuel ratios for durability and performance reasons. Leaner calibrations would serve to reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration. Small improvements in fuel economy could also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) would also reduce off-highway motorcycle engine durability. There are many engine improvements that could be made to regain lost durability that occurs with leaner calibration. These include changes to the cylinder head, pistons, pipes and ports for two-stroke and valves for four-stroke, to reduce knock. In addition critical engine components could be made more robust to improve durability.

Carburetion improvements alone will not allow manufacturers to meet our proposed standards, especially for two-stroke engines. Carburetion improvements with four-stroke engines may be necessary.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines could also be employed, possibly with more accuracy, with the use of fuel injection. At least one off-highway motorcycle manufacturer currently employs electronic fuel injection on one of its models.

4.7.2.3 Direct and Semi-Direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that two-stroke engines have such high levels of HC emissions is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft engines and some are showing upwards of 70 percent reductions in emissions. Direct injection is also being used by some motorcycle manufacturers (e.g., Aprilla) on small mopeds, scooters, and motorcycles to meet emission standards for two-strokes in Europe and Asia. Substantial improvements in fuel economy could also be expected with these technologies. However, there are some issues with off-highway motorcycle operation (larger displacement engines that experience more transient operation than watercraft and small mopeds) that make the application of the direct injection technologies somewhat more challenging for motorcycles than for personal watercraft and small displacement scooters. The biggest obstacle for this technology is that the many of the two-stroke equipped off-highway motorcycles are youth models which emphasize low price. Direct injection is relatively expensive and is currently not considered to be cost effective for these engines.

4.7.2.4 Four-Stroke Engines

We expect that the conversion of off-highway motorcycle models utilizing two-stroke engines to four-stroke engines will be the main method of achieving our proposed off-highway motorcycle standards. As with ATVs, the question of feasibility for four-stroke engines in off-highway motorcycles is moot, since more than half of the existing off-highway models are already four-stroke and, in some cases, have been for a long time. Honda has used four-stroke engines in all of their off-highway motorcycles (except for their competition motocross bikes) for over thirty years. In fact, over the last 5 to 10 years, the trend has been to slowly replace two-stroke models with four-stroke engines. Although the California emission standards have had some impact on this, it has been minor. Four-stroke engines are more durable, reliable, quieter and get far better fuel economy than two-stroke engines. But probably the single most important factor in the spread of the four-stroke engine has been major advances in weight reduction and performance.

Four-stroke engines typically weigh more than two-stroke engines because they need a valve-train system, consisting of intake and exhaust valves, camshafts, valve springs, valve timing chains and other components, as well as storing lubricating oil in the crankcase. Since a four-stroke engine produces a power-stroke once every four revolutions of the crankshaft, compared to a two-stroke which produces one once every two revolutions, a four-stroke engine of equal displacement to a two-stroke engine produces less power, on the average of 30 percent less. So in the past, off-highway motorcycles that used four-stroke engines tended to use very heavy, large displacement engines, but yet had average power and performance. However, recent breakthroughs in technologies have allowed manufacturers to design off-highway motorcycles that use lighter and stronger materials for the engine and the motorcycle frame. The advanced four-stroke technologies, such as multiple valves, used in some of the high-performance four-stroke highway motorcycles, have found their way onto off-highway motorcycles, resulting in vastly improved performance. The newer four-stroke bikes also tend to have an engine power band or range that is milder of more forgiving than a typical two-stroke bike. Two-stroke bikes tend to run poorly at idle and during low load situations. They also typically generate low levels of torque at low to medium speeds, whereas four-stroke bikes traditionally generate a great deal of low-end and mid-range torque. This is important to off-highway motorcycle riders because it is common when riding off-highway motorcycles on trails or other surfaces to come across obstacles that require slower maneuverability. A two-stroke engine that idles poorly and has poor low-end torque can easily stall during these maneuvers, whereas a four-stroke bike excels under these conditions. Current sales figures, as well as articles in off-highway motorcycle trade magazines, indicate that four-stroke off-highway motorcycles are more popular than ever, and the public is buying them as fast as they can build them.

4.7.2.5 Air Injection

Secondary pulse air injection involves the introduction of fresh air into the exhaust pipe immediately after the gases exit the engine. The extra air causes further combustion to occur as the gases pass through the exhaust pipe, thereby controlling more of the hydrocarbons that escape the combustion chamber. This type of system is relatively inexpensive and uncomplicated because it does not require an air pump; air is drawn into the exhaust through a one-way reed valve due to the pulses of negative pressure inside the exhaust pipe. Secondary pulse-air injection is one of the most effective non-catalytic, emissions control technologies; compared to engines without the system, reductions of 10-40% for HC are possible with pulse-air injection.

This technology is fairly common on highway motorcycles and is used on some off-highway motorcycle models in California to meet the California off-highway motorcycle and ATV emission standards. We believe that secondary air injection should not be necessary to meet our proposed standards, however, some manufacturers may choose to use it on some four-stroke engine models.

4.7.3 Test Procedure

For off-highway motorcycles, we propose that the current highway motorcycle test procedure be used for measuring emissions. The highway motorcycle test procedure is the same test procedure as used for light-duty vehicles (i.e., passenger cars and trucks) and is referred to as the Federal Test Procedure (FTP). The FTP for a particular class of engine or equipment is actually the aggregate of all of the emissions tests that the engine or equipment must meet to be certified. However, the term FTP has also been used traditionally to refer to the exhaust emission test based on the Urban Dynamometer Driving Schedule (UDDS), also referred to as the LA4 (Los Angeles Driving Cycle #4). The UDDS is a chassis dynamometer driving cycle that consists of numerous "hills" which represent a driving event. Each hill includes accelerations, steady-state operation, and decelerations. There is an idle between each hill. The FTP consists of a cold start UDDS, a 10 minute soak, and a hot start. The emissions from these three separate events are collected into three unique bags. Each bag represents one of the events. Bag 1 represents cold transient operation, bag 2 represents cold stabilized operation, and bag 3 represents hot transient operation.

Highway motorcycles are divided into three classes based on engine displacement, with class I (50 to 169 cc) being the smallest and class 3 (280 cc and over) being the largest. The highway motorcycle regulations allow class I motorcycles to be tested on a less severe UDDS cycle than the class II and III motorcycles. This is accomplished by reducing the acceleration and deceleration rates on some the more aggressive "hills." We propose that this same class/cycle distinction be allowed for off-highway motorcycles. In other words, off-highway motorcycles with an engine displacement between 50 and 279 cc (class I and II) would be tested over the class I highway motorcycle FTP test cycle. Off-highway motorcycles with engine displacements greater than 280 cc would be tested over the class III highway motorcycle FTP test cycle.

4.7.4 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Virtually all recreational off-highway motorcycles are equipped with sound suppression systems or mufflers. The four-stroke engines used in off-highway motorcycles are considerably more quiet than the two-stroke engines used.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke off-highway motorcycle is 20-25 mpg, while the average four-stroke off-highway motorcycle gets 45-50 mpg.

We believe the technology discussed here would have no negative impacts on safety. Four-stroke engine technology has been utilized on off-highway motocycles for numerous years without any incident. Secondary air and catalysts have been utilized in highway motorcycles and lawn and garden equipment without any safety concerns.

4.7.5 Conclusion

We expect that the proposed off-highway motorcycle emission standards will largely be met through the conversion of two-stroke engines to four-stroke engines with some minor carburetor calibration modifications and air-fuel ratio enleanment. Four-stroke engines are common in many off-highway motorcycles and have been used for many years. Certification data from California's off-highway program, as well as data from our own testing suggest that four-stroke engines with some minor fuel system calibration modifications will be capable of meeting our proposed emission standards. We believe the current sales volumes of two-stroke off-highway motorcycles, combined with the cost to modify two-stroke engines for significant emission reductions, will discourage the use of two-stroke engine technology.

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CHAPTER 5: Estimated Costs

This chapter describes our approach to estimating the cost of complying with emission standards. We start with a general description of the approach to estimating costs, then describe the technology changes we expect and assign costs to them. We also present an analysis of the estimated aggregate cost to society.

5.1 Methodology

We developed the costs for individual technologies using information provided by ICF, Incorporated and Arthur D. Little, as cited below. The technology characterization and cost figures reflect our current best judgment based on engineering analysis, information from manufacturers, and the published literature. The analysis combines cost figures including markups to the retail level.

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 the engine manufacturers' overhead and profit.[1] For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. All costs are in 2001 dollars.

The analysis presents an estimate of costs that would apply in the first year of new emission standards and the corresponding long-term costs. Long-term costs decrease due to two principal factors. First, fixed costs are assessed for five years, after which they are fully amortized and are therefore no longer part of the cost calculation. Second, manufacturers are expected to learn over time to produce the engines with the new technologies at a lower cost. Because of relatively low sales volumes, manufacturers are less likely to put in the extra R&D effort for low-cost manufacturing. As production starts, assemblers and production engineers will then be expected to find significant improvements in fine-tuning the designs and production processes. Consistent with analyses from other programs, we reduce estimated variable costs by 20 percent beginning with the third year of production and an additional 20 percent beginning with the sixth year of production.[2] We believe it is appropriate to apply this factor here, given that the industries are facing emission regulations for the first time and it is reasonable to expect learning to occur with the experience of producing and improving emission-control technologies.

Many of the engine technologies available to manufacturers to control emissions also have the potential to significantly improve engine performance. This is clear from the improvements in automotive technologies. As cars have continually improved emission controls, they have also greatly improved fuel economy, reliability, power, and a reduced reliance on regular maintenance. Similarly, the fuel economy improvements associated with converting from two-stroke to four-stroke engines is well understood. We attempt to quantify these expected improvements, as we describe for each type of engine below.

Even though the analysis does not reflect all the possible technology variations and options that are available to manufacturers, we believe the projections presented here provide a cost estimate representative of the different approaches manufacturers may ultimately take. We expect manufacturers in many cases to find and develop approaches to achieve the emission standards at a lower cost than we describe in this analysis.

5.2 Cost of Emission Controls by Engine/Vehicle Type

5.2.1 Recreational Marine Diesel Engines

We have developed cost estimates for diesel engine technologies for several different applications in a series of reports.[3,4,5] This analysis adapts these existing cost estimates for recreational marine diesel engines with separate estimates for three different sizes of engines.

Recreational marine diesel engines invariably have counterpart engine models used for commercial application. Manufacturers will design, certify, and manufacture these commercial models to meet emission standards. The analysis projects that manufacturers will comply with the new emission standards generally by applying the same technologies for both commercial and recreational engines. The remaining effort to meet emission standards with the recreational models would be limited to applying new or improved hardware and conducting sufficient R&D to integrate the new technologies into marketable products. The analysis therefore does not consider fixed costs to develop the individual technologies separately.

One area where recreational engine designs differ is in turbocharging and aftercooling. To reach peak performance, recreational engines typically already use optimized turbochargers and seawater aftercooling, which offer the greatest potential for controlling NOx emissions.

We estimate the total cost impact of new emission standards by considering the cost of each of the anticipated technologies. The following paragraphs describe these technologies and their application to recreational marine engines. The analysis then combines these itemized costs into a composite estimate for the range of marine engines affected by the rulemaking.

Table 5.2.1-1 also includes information on product offerings and sales volumes, which is needed to calculate amortized fixed costs for individual engines. Estimated sales and product offerings were compiled from the PSR database based on historical 1997 information.

Table 5.2.1-1
Recreational Marine Diesel Engine Categories for Estimating Costs

Engine Power Ranges (kW)	Nominal Engine Power (kW)	Annual Sales	Models	Average Sales per Model
37 - 225	100	3,700	17	216
225 - 560	400	6,700	15	448
560 +	750	1,000	6	173

Manufacturers are expected to develop engine technologies not only to reduce emissions, but also to improve engine performance. While it is difficult to take into account the effect of ongoing technology development, EPA is concerned that assessing the full cost of the anticipated technologies as an impact of new emission standards would inappropriately exclude from consideration the expected benefits for engine performance, fuel consumption, and durability.[1] Short of having sufficient data to predict the future with a reasonable degree of confidence, we face the need to devise an alternate approach to quantifying the true impact of the new emission standards. As an attempt to take this into account, we present the full cost of the control technologies in this chapter, then apply a discount to some of these costs for calculating the cost-per-ton of the proposed emission standards, as described in Chapter 7.

5.2.1.1 Fuel Injection Improvements

All engines are expected to see significant improvements in their fuel injection systems. The smaller engines will likely undergo incremental improvements to existing unit injector designs. The analysis projects that engines rated over 600 kW will use common rail injection technology, which greatly increases the flexibility of tailoring the injection timing and profile to varying modes of operation. Better control of injection timing and increased injection pressure contribute to reduced emissions. Table 5.2.1-2 shows the estimated costs for these fuel injection improvements.

Table 5.2.1-2
Fuel Injection Improvements

	100 kW	400 kW	750 kW
Component costs	$63	$98	$205
Assembly, markup, and warranty	$32	$46	$59
Composite Unit Cost	$95	$144	$264

5.2.1.2 Engine Modifications

Manufacturers will be optimizing basic engine parameters to control emissions while maintaining performance. Such variables include routing of the intake air, piston crown geometry, and placement and orientation of injectors and valves. Most of these variables affect the mixing of air and fuel in the combustion chamber. Small changes in injection timing are also considered in this set of modifications. We expect, however, that manufacturers will complete this work for commercial marine diesel engines, so that the remaining effort will be focused on fine-tuning designs for turbocharger matching and other calibration-related changes. Fixed costs are amortized over a five-year period, using the sales volumes developed in Table 5.2.1-1, with

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[1] While EPA does not anticipate widespread, marked improvements in fuel consumption, small improvements on some engines may occur.

forward discounting incorporated to account for manufacturers incurring these costs before the emission standards begin to apply. Table 5.2.1-3 shows the estimated per-engine costs for these modifications. These costs include the consideration manufacturers must give to offsetting any crankcase emissions routed to the exhaust. There is no estimated long-term cost to the engine modifications because manufacturers can fully recover the fixed costs, and we don't expect any increase in variable costs as a result of these improvements.

Table 5.2.1-3
Engine Modifications

	100 kW	400 kW	750 kW
Total fixed costs	$200,000	$200,000	$200,000
Fixed cost per engine	$244	$122	$244
Composite Unit Cost	$244	$122	$244

5.2.1.3 Certification and Compliance

We have significantly reduced certification requirements in recent years, but manufacturers are nevertheless responsible for generating a minimum amount of test data and other information to demonstrate compliance with emission standards. Table 5.2.1-4 lists the expected costs for different sizes of engines, including the amortization of those costs over five years of engine sales. Estimated certification costs are based on two engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information.

Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. Since these engines are currently not subject to any emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years.

Costs for production line testing are summarized in Table 5.2.1-5. These costs are based on testing 1 percent of total estimated sales, then distributing costs over the fleet. Listed costs for engine testing presume no need to build new test facilities, since we are proposing to waive production-line testing requirements for small-volume production. Few manufacturers, if any, will therefore need to build new test facilities.

Table 5.2.1-4
Certification

	100 kW	400 kW	750 kW
Total fixed costs	$30,000	$30,000	$40,000
Fixed cost per engine	$77	$93	$859
Composite Unit Cost	$37	$18	$49

Table 5.2.1-5
Costs for Production Line Testing

	100 kW	400 kW	750 kW
Cost per test	$10,000	$10,000	$15,000
Testing rate	1 %	1 %	1 %
Cost per engine	$100	$100	$150

5.2.1.4 Total Engine Costs

These individual cost elements can be combined into a calculated total for new emission standards by assessing the degree to which the different technologies will be deployed. As shown in Table 5.2.1-6, estimated costs for complying with the proposed emission standards increase with increasing power ratings. We expect each of the listed technologies to apply to all the engines that need to meet the new emission standards. Estimated price impacts range from $400 to $700 for the different engine sizes.

Characterizing these estimated costs in the context of their fraction of the total purchase price and life-cycle operating costs is helpful in gauging the economic impact of the new standards. The estimated first-year cost increases for all engines are at most 2 percent of estimated engine prices, with even lower long-term effects, as described above.

Table 5.2.1-6
Diesel Engine Costs

	100 kW	400 kW	750 kW
Fuel injection upgrade	$95	$144	$264
Engine modifications	$244	$122	$244
Certification + PLT	$137	$118	$199
Total Engine Cost	$475	$384	$707

5.2.1.5 CI Marine Aggregate Costs

The above analyses developed incremental per-vessel cost recreational marine diesel engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for proposed emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold. Table 5.2.1-7 presents a summary of this analysis. As shown in the table, aggregate net costs stay between $2 million and $4 million.

Table 5.2.1.-7
Summary of Annual Aggregate Costs for Marine CI Engines (millions of dollars)

	2006	2010	2015	2020	2025
Total Costs	$3.0	$3.7	$2.2	$2.5	$2.7

To project annual sales, we started with the 1998 population estimates presented in Chapter 6. We then used the engine turnover rates and growth estimates to calculate annual sales. Table 5.2.1.-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.1.-8
Estimated Annual Sales of Recreational Marine Diesel Engines

Engine Power Range (kW)	1999	2006	2010	2020
37 - 225	5,160	6,330	7,000	8,700
225 - 560	1,580	1,900	2,140	2,660
560 +	180	220	240	300

To calculated annual aggregate costs, the sales estimates have been multiplied by the per-unit costs discussed above. These calculations take into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.2 Large Industrial Spark-Ignition Engines

We estimated the cost of upgrading LPG-fueled and gasoline-fueled and gasoline-fueled Large SI engines. We developed the costs for individual technologies in cooperation with ICF, Incorporated and Arthur D. Little.[6] The analysis combines these individual figures into a total estimated cost for each type of engine, including markups to the retail level. A composite cost based on the mix of engine types provides an estimated industry-wide estimate of the per-engine cost impact.

Gasoline-fueled Large SI engines continue to rely on traditional carburetor designs rather than incorporating the automotive technology innovations introduced to address emission controls. Since natural gas- and LPG-fueled engines use comparable technologies, the analysis presents a single set of costs for both fuels.

The anticipated technology development is generally an outgrowth of automotive technologies. Over the last thirty years, engineers in the automotive industry have made great strides in developing new and improved approaches to achieve dramatic emission reductions with high-performing engines. In more recent years, companies have started to offer these same technologies for industrial applications. Fundamental to this technology development is the electronically controlled fuel system and catalytic converters.

Electronically controlled fuel systems allow manufacturers to more carefully meter fuel into the combustion chambers. This gives the design engineer an important tool to better control power and emission characteristics over the whole range of engine operation. Careful control of air-fuel ratio is also essential for effective catalyst conversion. The catalyst converts the pollutants in the exhaust stream to harmless gases. We also consider development time to redesign the combustion chamber and intake air routing, as well as to combine the new control technologies and optimize engine calibrations. We include these efforts under the total R&D costs for each engine.

Gasoline engines can use either throttle-body or port-fuel injection. Manufacturers can likely reach the targeted emission levels using simpler throttle-body systems. However, the performance advantages and the extra assurance for full-life emission control from the more advanced port-fuel injection systems offer a compelling advantage. The analysis therefore projects that all gasoline engines will use port-fuel injection. The analysis does not take into account the performance advantages of port-fuel injection and therefore somewhat overestimates the cost impact of adopting new emission standards.

Gaseous-fuel engines have very different fuel metering systems due to the fact that LPG and natural gas evaporate readily at typical ambient temperatures and pressures. Manufacturers of these engines face a choice between continuing with conventional mixer technology and upgrading to injection systems. We are aware that manufacturers are researching gaseous injection systems, but we believe mixer technology will be sufficient to meet the proposed standards. All the data supporting the feasibility of emission standards for LPG engines is based on engines using mixer technology.

5.2.2.1 Engine Technology

Tables 5.2.2-1 and 5.2.2-2 show the estimated costs of upgrading each of the engine types. The cost figures are in the form of retail-price equivalent for an individual engine. The tables include individual cost estimates of the various components involved in converting a baseline engine to comply with emission standards. The cost of the catalyst is based on a precious metal loading of 2.8 g/liter (primarily palladium, with small amounts of platinum and rhodium) and a catalyst volume 60 percent of total engine displacement.

The analysis incorporates a cost for potential warranty claims related to the new technologies by adding 5 percent of the increase in hardware costs. The industry has gained enough experience with electronic fuel systems that we expect a relatively low rate of warranty claims for them. Catalysts have been used for many years, but not in Large SI applications, so these technologies may cause a somewhat higher rate of warranty claims.

Even without EPA emission standards, manufacturers will conduct the research and development needed to meet the 2004 emission standards in California. The R&D impact of new EPA standards is therefore limited to the additional burden of complying with the proposed 2007 requirements. Estimated costs for research and development are $175,000 for each engine family. This is based on about six months of time for an engineer and a technician on each fuel type for each engine family. We would expect initial efforts to require greater efforts, but cumulative learning would reduce per-family development costs for subsequent models. These fixed costs are increased by 7 percent to account for forward discounting, since manufacturers incur these costs before the new standards apply. Redesigning the first engine model will likely require significantly more time than this, but we expect the estimated level of R&D to be appropriate as an average level for the range of models in a manufacturer’s product line.

While there is no separate item in the following cost tables for positive-crankcase ventilation, the analysis takes these costs into account indirectly through the increased cost for the intake manifold and the overall development cost per engine family.

Table 5.2.2-1
Estimated Costs for an LPG-fueled Large SI Engine

	Baseline	Controlled
Hardware Cost to Manufacturer		
Regulator/throttle body	$50	$65
Intake manifold	$37	$37
Fuel filter w/ lock-off system	$15	$15
LPG vaporizor	$75	$75
Governor	$40	$60
Converter temperature control valve		$15
Oxygen sensor		$19
ECM		$100
Wiring/related hardware		$45
Fuel system total	$217	$431
Catalyst/muffler		$229
Muffler	$45	$0
Total Hardware Cost	$262	$660
Markup @ 29%	$76	$191
Warranty markup @5%		$20
Total component costs	$338	$871
Fixed Cost to Manufacturer		
R&D costs	$0	$175,000
Units/yr.	2,000	2,000
Amortization period (7 % discounting)	5	5
Fixed cost/unit	$0	$26
Total Costs	$338	$897
Incremental Total Cost		$559

Table 5.2.2-2
Estimated Per-Engine Costs for Gasoline-Fueled Large SI Engines

	Baseline	Controlled
Hardware Cost to Manufacturer		
Carburetor	$51	$0
Injectors (each)		$17
Number of injectors		4
Pressure Regulator		$11
Fuel filter	$3	$4
Intake manifold	$35	$50
Fuel rail		$13
Throttle body/position sensor		$60
Fuel pump	$15	$30
Oxygen sensor		$19
ECM		$150
Governor	$40	$60
Air intake temperature sensor		$5
Manifold air pressure sensor		$11
Injection timing sensor		$12
Wiring/related hardware		$45
Fuel system total	$144	$538
Catalyst/muffler		$229
Muffler	$45	
Total Hardware Cost	$189	$767
Markup @ 29%	$55	$222
Warranty markup @5%		$29
Total Component Costs	$244	$1,018
Fixed Cost to Manufacturer		
R&D Costs	$0	$175,000
Units/yr.		1,750
Amortization period (7 % discounting)		5
Fixed cost/unit	$0	$30
Total Costs	$244	$1,048
Incremental Total Cost		$805

In addition to these estimated costs for addressing exhaust emissions, we have analyzed the costs associated with reducing evaporative emissions from gasoline-fueled engines and vehicles. This effort consists of three primary areas—permeation, diurnal, and boiling.

To reduce permeation losses, we expect manufacturers to upgrade plastic or rubber fuel lines to use automotive-grade materials. These fuel lines are readily available at a cost premium of about $0.25 per linear foot. If an installed engine has an average of four feet of fuel line, this translates into an increased cost of $1 per engine.

The standard related to diurnal emissions can be met with a fuel cap that seals the fuel tank, relieving pressure as needed to prevent the tank from bursting or collapsing. The estimated cost of upgrading to such a fuel cap is $8, based on the aftermarket cost of comparable automotive fuel caps.

Many Large SI engines are installed in equipment in a way that poses little or no risk of fuel boiling during engine operation. A few models are configured in a way that causes this to be a possibility, at least under extreme conditions. Preventing fuel boiling is primarily a matter of isolating the fuel tank from heat sources, such as the engine compartment and the exhaust pipe. Some additional material may be needed to reduce heat exposure, such as a simple metal shield or a fiberglass panel. Given several years to redesign engines and equipment, we believe that manufacturers can readily incorporate such changes into their ongoing R&D programs. To account for several hours of engineering effort and a small amount of material, we estimate that these costs averaged over the whole set of gasoline-fueled engines will come to about $1 per engine.

5.2.2.2 Operating Cost Savings

Introducing electronic closed-loop fuel control will significantly improve engine operation, with corresponding cost savings, in three areas— reduced fuel consumption, less frequent oil changes and tuneups, and delayed time until rebuild.

It may also be appropriate to quantify the benefit of longer total engine lifetimes. For example, passenger cars with low-emission engine technologies last significantly longer than they did before manufacturers developed and applied these technologies. In addition, engine performance (responsiveness, reliability, engine warm-up, etc.) will also improve with the new technologies. However, these benefits are more difficult to quantify and the analysis therefore does not take them into account.

Fuel consumption rates will improve as manufacturers no longer design engines for operation in fuel-rich conditions. Some current systems already operate at somewhat leaner air-fuel ratios than in previous years, but even in these cases, engines generally revert to richer mixtures when accelerating. Closed-loop fuel systems generally operate close to stoichiometry, which improves the engine's efficiency of converting the fuel energy into mechanical work. Information in the docket, including development testing, engineering projections, and user testimony, leads to an estimated 20-percent reduction in fuel consumption rates.[7,8,9] Table 5.2.2-3 shows the value of the estimated fuel savings. These values and calculations are based on our NONROAD emissions model.

Table 5.2.2-3
Estimated Fuel Savings from Large SI Engines

	LPG	Gasoline	Natural gas
Horsepower	66	52	65
Load factor	0.39	0.58	0.49
Annual operating hours, hr/yr	1,365	537	1,161
Lifetime, yr	12	12	13
Baseline bsfc, lb/hp-hr	0.507	0.605	0.507
Improved bsfc, lb./hp-hr	0.406	0.484	0.406
Fuel density	4.2 lb./gal	6.1 lb./gal	0.05 .g./ft^3
Fuel cost	$0.60/gal	$1.10/gal	$2.17/1000 ft^3
Annual fuel saved (gal/yr)	845	321	—
Annual fuel savings ($/yr)	$507	$353	$160
Lifetime Fuel Savings (NPV)	$4,333	$3,038	$1,427

In addition to the fuel savings, we expect Large SI engines to see significant improvements in reliability and durability. Open-loop fueling systems in uncontrolled engines are prone to drifting calibrations as a result of varying fuel quality, wear in engine components, changing ambient conditions, and other factors. Emission-control systems that operate with a feedback loop to compensate for changing conditions for a near-constant air-fuel ratio significantly reduces the following problems.

-incomplete (and eventually unstable) combustion
-absorption of fuel in lubricating oil
-deposits on valves, spark plugs, pistons, and other engine surfaces
-increased exhaust temperatures

Automotive engines clearly demonstrate that modern fuel systems reduce engine wear and the need for repairs.

This analysis incorporates multiple steps to take these anticipated improvements into account. First, oil change intervals are estimated to increase by 15 percent. Reduced fuel loading in the oil (and other improvements such as piston ring design) can significantly extend its working life. Similarly, tune-up intervals are estimated to increase by 15 percent. This results largely from avoiding an accumulation of deposits on key components, which allows for longer operation between regularly scheduled maintenance. Third, we estimate that engines will last 15 percent longer before needing overhaul. The reduced operating temperatures and generally reduced engine wear associated with closed-loop fuel systems account for this extended lifetime to rebuild. These quantitative estimates of maintenance-related savings are derived from observed changes in automotive performance when upgrading from carburetion to fuel injection. Table 5.2.2-4 summarizes the details of the methodology for converting these maintenance improvements into estimated cost savings over the lifetime of the engines.

Table 5.2.2-4
Maintenance

	LPG/ natural gas	Gasoline
Baseline oil change interval (hrs)	200	150
Improved oil change interval (hrs)	230	172.5
Cost per oil change ($)	$30	$30
Baseline tune-up interval (hrs)	400	400
Improved tune-up interval (hrs)	460	460
Cost per tune-up ($)	$75	$75
Baseline rebuild interval (hrs)	7,000	5,000
Improved rebuild interval (hrs)	8,050	5,750
Rebuild cost ($)	$800	$800
Baseline lifetime maintenance cost	$2,902	$2,573
Improved lifetime maintenance cost	$2,681	$2,354
Lifetime maintenance savings (NPV)	$221	$219

These large estimated fuel and maintenance savings relative to the estimated incremental cost of producing low-emitting engines raise the question of why normal market forces have failed to induce manufacturers to design and sell engines with emission-control technologies on the basis of the expected performance improvements. Since forklifts are the strongly dominant application using Large SI engines, this question effectively applies specifically to forklifts. We have observed that forklift users generally see their purchase as an expense that doesn't add value to a companies product, whether that applies to manufacturing, warehouse, or retail facilities. While operating expenses require no internal justification or decision-making process, purchasing new equipment involves extensive review and oversight by managers who are very sensitive to capital expenditures. This is reinforced by an April 2000 article in a trade publication, which quotes an engineering estimate of 20- to 40-percent improvement in fuel economy while stating that it is unclear whether purchasers will tolerate any increase in the cost of the product.[10] Market theory would predict that purchasers would select products with technologies that result in the lowest net cost (with some appropriate discount for costs incurred over time). It seems that companies have historically focused on initial costs to the exclusion of potential cost savings over time, which would account for the lack of emission-control technologies on current sales of Large SI engines.

This priority given to initial cost therefore affects the competitive decisions of engine manufacturers, who will be less willing to provide a more costly product than its competitors, even if the product would eventually provide substantial savings to the purchaser. Also, the initial costs of changing designs and using new technologies can serve as a deterrent to including newer cost-efficient technologies in established engine types.

In addition to the engine improvements described above, the costs associated with controlling evaporative emissions would be offset by savings from retaining more fuel that can be used to power the engine.

5.2.2.3 Compliance Costs

We estimate that certification costs come to $70,000 per engine family. We expect manufacturers to combine similar engines using different fuels in the same family. This expands the size of engine families, but calls for several tests to complete the certification process for each family. This includes six engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information. Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. This cost is therefore amortized over five years of engine sales, with an assumed volume of 3,000 engines per year from each engine family. This engine-family sales volume is larger than those presented for amortizing fixed costs above, because engine families will include multiple fuel types. The resulting cost for certification is $6 per engine. Since these engines are currently not subject to any EPA emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years. Since manufacturers already need to submit data for California certification, they will incur most of these costs independent of EPA requirements.

The proposal includes a requirement to do production-line testing on a quarterly basis. Manufacturers with sustained, good test results can greatly reduce testing rates. Manufacturers must generate and submit this test data to comply with the requirements adopted by California ARB. The EPA requirement for production-line testing therefore adds no test burden to manufacturers. Even with a transient duty cycle for certification, we are proposing to allow manufacturers to use only steady-state test procedures a the production line. We therefore fully expect that manufacturers will only need to send the “California” test data to EPA to satisfy requirements for production-line testing. The analysis therefore includes no cost for additional routine testing of production engines. In fact, the proposal includes a provision that would allow manufacturers to pursue alternate methods to show that production engines comply with emission standards, which may lead to lower testing costs.

The proposal allows us to select up to 25 percent of a manufacturers’s engine families for in-use testing. This means that a manufacturer would need to have eight engine families for us to be able to select two engine families in a given year. Since this is likely to be a rare scenario, we project an annual testing rate of one engine family per year for each manufacturer to assess the cost of the in-use testing program. The analysis includes the cost of testing in-use engines on a dynamometer, which requires:

- engine removal and replacement ($4,000)
- transport ($1,000)
- steady-state and transient testing ($15,000)

Testing six engines and adding costs for administration and reporting of the testing program leads to a total cost of about $125,000 for an engine family. These costs can be spread over a manufacturer’s total annual sales, which averages about 15,000 units for most companies. The resulting cost per engine is about $8.

As with production-line testing, we would expect in-use emission testing to simultaneously satisfy California ARB and EPA requirements. In certain circumstances, however, we may use our discretion to direct a manufacturer to do in-use testing on an engine family separately from California ARB. Since we expect this to be the exception, this analysis likely overestimates the cost impact of adopting federal requirements to do in-use testing. In fact, manufacturers may reduce their compliance burden with the optional field-testing procedures we are proposing. Table 5.2.2-5 shows the estimated costs from the various compliance programs.

Table 5.2.2-5
Cost of Compliance Programs

Compliance Program Element	Estimated Per-Engine Costs
Certification	$6
In-use testing	$8
Total	$14

5.2.2.4 Total Costs

Table 5.2.2-6 presents the combined cost figures for the different engine types and calculates a composite cost based on their estimated distribution. The estimated 2004 costs are based on the adding component costs and compliance costs. No R&D cost is estimated for manufacturers to do additional development work beyond what is necessary to comply with California ARB standards. Conversely, the estimated 2007 costs are based on R&D (and ongoing compliance costs), with no anticipated increase in component costs, except those related to reducing evaporative emissions. The estimated cost of complying with the proposed emission standards is sizable, but the lifetime savings from reduced operating costs nevertheless more than compensate for the increased costs

Table 5.2.2-6
Estimated First-Year Cost Impacts of New Emission Standards

Standards	Engine Type	Sales Mix of Engine Types	Increased Production Cost per Engine*	Lifetime Operating Costs per Engine (NPV)
2004	LPG	68%	$550	$-4,550
	natural gas	9%	$550	$-1,650
	gasoline	23%	$790	$-3,260
	Composite	—	$600	$-3,985
2007	LPG	68%	$40	—
	natural gas	9%	$40	—
	gasoline	23%	$55	**
	Composite	—	$45	—

*The estimated long-term costs decrease by about 35 percent.
**Gasoline-fueled engines would experience fuel savings due to evaporative emission control, but these are not quantified here.

5.2.2.5 Large SI Aggregate Costs

The above analyses developed incremental per-vessel cost estimates for Large SI engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for proposed emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the engines are operated over their lifetimes. Table 5.2.2-7 presents a summary of this analysis. As shown in the table, aggregate net costs generally range from $75 million to $90 million. Net costs decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used. Fuel savings are projected to more than offset the costs of the program starting by the second year of the program.

Table 5.2.2.-7
Summary of Annual Aggregate Costs and Fuel Savings for Large SI Engines
(millions of dollars)

	2004	2005	2010	2015	2020
Total Costs	$88	$90	$73	$76	$84
Fuel Savings	($49)	($96)	($313)	($431)	($490)
Net Costs	$38	($7)	($240)	($355)	($406)

To project annual sales, we started with the number of model year 2000 engines estimated by the NONROAD model for the 2000 calendar year. We then applied a growth rate of 3 percent of year 2000 sales (increasing by 3,900 units annually) to estimate future sales. Table 5.2.2.-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.2.-8
Estimated Annual Sales of Large SI Engines

2000	2004	2010	2020
130,000	145,600	169,000	208,000

To calculated annual aggregate costs, the sales estimates have been multiplied by the per-unit costs. Annual fuel savings have been calculated based on the reduction in fuel consumption expected from the proposed standards (as described in section 5.2.2.2 of this chapter) as calculated by the NONROAD model. The model takes into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.3 Recreational Vehicles

5.2.3.1 Technologies and Estimated Costs

We estimated costs separately for snowmobiles, ATVs, and off-highway motorcycles. Individual technology costs were developed in cooperation with EPA by ICF Incorporated and Arthur D. Little - Acurex Environmental.[11] Costs were prepared for a typical engine that falls within the displacement ranges noted below. Costing out multiple engine sizes allowed us to estimate any differences in costs for smaller vs. larger engines. The costs include a mark-up to the retail level. This Chapter also provides a brief overview of the technologies, with more information provided in Chapter 4. Costs are provided for both the baseline technology and the new technology (e.g., a two-stroke engine and a four-stroke engine), with the cost of the change in technology being the increment between the two costs.

The R&D costs shown are average costs. The first engine line R&D cost is expected to be significantly higher but the costs would be distributed across the manufacturer's entire product line.[12] To account for any additional warranty cost associated with a change in technology, we have added 5 percent of the incremental hardware cost.[13]

As noted in section 5.1, fixed costs are spread over the first five years of sales for purposed of the cost analysis, with the exception of new facility costs for ATV testing which are spread over 10 years. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used at least that long. We estimated that R&D and facility costs would be incurred three years prior to production on average and tooling and certification costs would be incurred one year prior to production. These fixed costs were then increased seven percent for each year prior to the start of production to reflect the time value on money.

To approximate average annual sales per engine line, we divided the total annual unit sales by estimated total number of engines lines industry-wide.[m] Based on limited sales data from individual manufacturers provided to EPA on a confidential basis, there appears to be a large distinction in sales volume between small engine and large engine displacements for ATVs. The cost analysis accounts for this difference by using a larger annual sales rate per engine line for large ATVs, as shown below.

As noted below, the fuel savings over the life of the vehicle due to some of the projected technology changes can be substantial and in some cases are projected to offset the cost of the emissions controls. As discussed below, these fuel savings would occur because 2-stroke powerplants are inefficient and the changes needed to reduce hydrocarbons also improve fuel

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[m] Based on publicly available product information for the large manufacturers, we estimated 32 engine lines for snowmobiles, 43 lines for ATVs, and 42 lines for off-highway motorcycles.

consumption. Because the fuel savings can outweigh up front costs, one might question why manufacturers continue to use 2-stroke engines. Manufacturers have not made these changes in the absence of emissions standards for several likely reasons. Many customers generally do not place a high value on fuel economy compared to initial cost and engine simplicity. Manufacturers have built a customer base over many years using 2-stroke technology. The engines are relatively simple and the production costs are relatively low because the manufacturers have been building the engines for many years. To capture the fuel economy benefits, manufacturers would have to invest substantially in R&D and more complex powerplants in the face of uncertainty with regard to market acceptance of the new product. Such a move could also lower profits per vehicle. Considering all these factors, manufacturers choose to focus improvements in other areas such as increasing horsepower and overall vehicle design.

Snowmobiles

Snowmobiles are currently almost exclusively powered by carbureted 2-stroke engines. We are basing the cost analysis for Phase 1 standards on the use of engine modifications, carburetor improvements, and recalibration. Manufacturers are likely to be able to meet standards by leaning out the air/fuel mixture, improving carburetors for better fuel control and less production variation, and modifying the engine to withstand higher temperatures and potential misfire episodes attributed to enleanment. Engine modifications are also likely to be made to improve air/fuel mixing and combustion. A small number of models are equipped with electronic fuel injection and these models would not have carburetor improvement costs associated with them. Tables 5.2.3.-1 and 5.2.3.-2 provide estimates of variable and fixed costs associated with the technologies that form the basis of our cost analysis for Phase 1. Recalibration work is included as part of the R&D for the technologies. The incremental cost per unit for engine modifications is estimated to be $17 to $24, with modifications to the carburetor estimated to cost an additional $18 to $24 per engine.

Table 5.2.3.-1. Snowmobile Engine Modification Costs for Two-Stroke Engines

	< 500 cc		> 500 cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Improved Pistons	$10	$12	$12	$15
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$20	$24	$36	$45
Labor @ $28 per hour	$6	$6	$8	$8
Labor Overhead @ 40%	$2	$2	$3	$3
Manufacturer Mark-up @ 29%	$6	$7	$10	$13
Warranty Mark-up @ 5%		$0		$0
Total Component Costs	$34	$39	$57	$69
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4600	4600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	$0	$12	$0	$12
Total Costs	$34	$51	$57	$81
Incremental Total Cost		$17		$24

Table 5.2.3-2. Modified Carburetor Costs for Snowmobiles

	< 500 cc		> 500 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Carburetor	$60	$65	$60	$65
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$120	$130	$180	$195
Labor @ $28 per hour	$1	$1	$2	$2
Labor Overhead @ 40%	$1	$1	$1	$1
Manufacturer Mark-up @ 29%	$35	$38	$53	$57
Warranty Mark-up @ 5%		$1		$1
Total Component Costs	**$157**	**$171**	**$236**	**$256**
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$61,875	$0	$61,875
Tooling Costs	$0	$5,000	$0	$5,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$4**	**$0**	**$4**
Total Costs	**$157**	**$175**	**$236**	**$260**
Incremental Total Cost		**$18**		**$24**

Manufacturers may use an expanded mix of technologies to meet Phase 1 standards. If manufacturers are successful in developing and deploying advanced technologies for snowmobiles such as 4-stroke engines and 2-stroke direct injection in the Phase 1 time frame, the mix of technologies for Phase 1 would be somewhat different. These technologies paths would provide much lower CO and HC emissions, as discussed in Chapter 4. Although these technologies would increase the cost of the engines, they would also potentially provide the consumer with greatly improved fuel economy, reliability, and in the case of direct injection, performance. For these reasons, we would expect manufacturers to continue to develop these advanced technologies and implement them when they are ready.

The cost analysis for the Phase 2 standards is based primarily on the use of direct fuel injection 2-stroke engines and 4-stroke engines for a portion of the fleet. We would expect that by the 2010 time frame these two technologies will be developed and able to be used on a significant fraction of the fleet. For cost purposes, we are projecting that 4-stroke engines are likely to be equipped with electronic fuel injection systems to optimize emissions and overall performance of these engines. Therefore we are including electronic fuel injection costs for 4-strokes. Tables 5.2.3.-3 through 5.2.3.-6 provide costs for direct injection systems (both air assisted direct injection and pump assisted direct injection) and for converting from a 2-stroke to 4-stroke engine.

Table 5.2.3-3. Air Assisted Direct Injection System Costs for Snowmobiles

	< 500 cc		> 500cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Fuel Metering Solenoid (each)		$15		$15
Number Required		2		3
Air Pump		$25		$25
Air Pump Gear		$5		$5
Air Pressure Regulator		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Electric Fuel Pump	$5	$5	$5	$5
Fuel Pressure Regulator		$3		$3
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$324	$185	$339
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$100	$55	$107
Royalty @ 3%		$10		$10
Warranty Mark-up @ 5%		$10		$8
Total Component Costs	**$164**	**$464**	**$243**	**$493**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$12**	**$0**	**$12**
Total Costs	**$164**	**$476**	**$243**	**$505**
Incremental Total Cost		**$312**		**$262**

Table 5.2.3-4. Pump-Assisted Direct Fuel Injection System Costs for Snowmobiles

	< 500cc		> 500cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Nozzle/Accumulator (each)		$33		$33
Number Required		2		3
High-Pressure Cam Fuel Pump		$20		$25
Cam Pump Gear		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Fuel Transfer Pump	$5	$5	$5	$5
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$347	$185	$385
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$106	$55	$120
Royalty @ 3%		$10		$12
Warranty Mark-up @ 5%		$11		$10
Total Component Costs	**$164**	**$494**	**$243**	**$556**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,600	4,600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$12**	**$0**	**$12**
Total Costs	**$164**	**$506**	**$243**	**$568**
Incremental Total Cost		**$342**		**$325**

Table 5.2.3-5. Two-Stroke to Four Stroke Conversion Costs for Snowmobiles

	< 500 cc		> 500 cc	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4-Stroke**
Engine	$400	$700	$650	$1,170
Clutch	$50	$75	$80	$120
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$136	$233	$217	$383
Warranty Mark up @ 5%		$16		$28
Total Component Costs	**$606**	**$1,053**	**$967**	**$1,730**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$20,000	$0	$20,000
Units/yr.	4,600	4,600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$7**	**$0**	**$7**
Total Costs	**$606**	**$1,060**	**$967**	**$1,737**
Incremental Total Cost		**$454**		**$770**

Table 5.2.3-6. Electronic Fuel Injection Costs for Snowmobiles

Fuel Injection Costs	400cc		700cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Injectors (each)		$12		$12
Number Required		2		3
Pressure Regulator		$10		$10
Intake Manifold		$30		$35
Throttle Body/Position Sensor		$35		$35
Fuel Pump	$5	$20	$5	$20
ECM		$100		$100
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$10		$10
Injection Timing Sensor		$5		$5
Wiring/Related Hardware		$10		$10
Hardware Cost to Manufacturer	**$125**	**$249**	**$185**	**$266**
Labor @ $28 per hour	$1	$4	$2	$6
Labor Overhead @ 40%	$1	$2	$1	$3
Manufacturer Mark-up @ 29%	$37	$72	$54	$77
Warranty Mark-up[a] @ 5%		$6		$4
Total Component Costs	**$164**	**$333**	**$242**	**$356**
Fixed Cost to Manufacturer				
R&D Costs	$0	$69,417	$0	$69,417
Tooling Costs	$0	$10,000	$0	$10,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$5**
Total Costs ($)	**$164**	**$338**	**$242**	**$361**
Incremental Total Cost ($)		**$174**		**$119**

We have estimated the incremental cost of going from carbureted 2-stroke to direct injection to range from $262 to $342 per engine and conversion to 4-stroke to be about $454 to $770. Electronic fuel injection for snowmobiles is estimated to incrementally cost $174 to $119. It should be noted that the overall consumer costs for these advanced technologies would be substantially lower after the fuel economy improvements are taken into account. Estimates of the fuel savings are provided below.

Manufacturers are likely to concentrate the use of the above technologies on the more expensive or performance oriented models. We are projecting that 50 percent of models will be equipped with either direct injection or 4-stroke engines. We anticipate that remaining models would consist of Phase 1 technologies with some further optimization. We are projecting the use of pulse air systems with recalibration on the portion of snowmobile engines that are not equipped with advanced technology systems. Pulse air would provide a small incremental emission reduction for these engines and help manufacturers meet the Phase 2 average HC and CO standards. As shown in Table 5.2.3.-7, we have estimated pulse air to cost about $16. Catalysts are also a potential option for snowmobiles. However, we believe manufacturers are more likely to focus on developing the advanced technologies noted above, which provide the consumer with substantial benefits in addition to lower emissions. Therefore, have we not included catalyst costs in our cost estimates.

Table 5.2.3.-7. Calibration/Pulse-Air Costs for Snowmobiles

	Baseline	**Modified**
Hardware Costs		
Pulse Air Valve		$8
Labor @ $28 per hour		$1
Labor overhead @ 40%		$0
Markup @ 29%		$3
Warranty Mark up @ 5%		$0
Total Component Costs	**$0**	**$12**
Fixed Cost to Manufacturer		
R&D Costs		$54,750
Tooling Costs		$10,000
Units/yr.		4,600
Years to recover		5
Fixed cost/unit		**$4**
Total Costs	**$0**	**$16**
Incremental Total Cost		**$16**

All-terrain Vehicles (ATVs)

ATVs are primarily equipped with carbureted 4-strokes, with 2-stroke engines used primarily in small displacement and sport models. For the first phase of standards, we expect manufacturers to phase out the use of 2-stroke engines. In addition, we are also projecting that recalibration and pulse air systems would be used on about 25 percent of the models for Phase 1 to ensure that the fleet meets the standards on average. Pulse air systems are currently used on a few ATV and off-highway motorcycles models to meet California standards. We do not believe that the level of the standards would require the use of pulse air beyond 25 percent, given that only a few models in California are currently equipped with the technology. Using these technologies may give the manufacturer more flexibility in calibrating for performance on some models.

We are basing our technology projection on what manufacturers have done to meet the California emissions standards. We believe this to be the most likely technology path for manufacturers because 4-strokes are accepted in the market and provide consumers with fuel economy and reliability benefits. Substantial new R&D and major changes in technology would be needed to allow 2-stroke engines to meet the proposed Phase 1 standards. Because manufacturers would be able to carry over certification from the California emissions control program, manufacturers would already have many models equipped with 4-strokes that would meet the proposed Phase 1 standards.

For Phase 2, we are projecting that manufacturers would significantly increase the use of pulse air systems, from 25 percent for Phase 1 to 75 percent for phase 2. We would expect that the remaining emissions reductions would be achieved through recalibration and the use of oxidation catalysts on a fraction of ATVs models.

Catalysts have not been used to date on ATVs, but we would expect that their use on some ATV models would be attractive for manufacturers in complying with Phase 2 standards. Using a catalyst to control emissions would allow manufacturers to calibrate more for performance. Catalysts are typically sized at about half the engine displacement and typically achieve at least about a 50 percent reduction in emissions.

For purposes of the cost analysis, we are projecting catalyst use for 50 percent of ATV models. We believe that this is conservatively high because manufacturers have substantial lead-time to optimize engine emissions performance and may be able to achieve Phase 2 standards using catalysts on fewer models.

Tables 5.2.3.-8 through 5.2.3-10 provide cost estimates for the ATV technologies discussed above. Table 5.2.3.-11 provides a breakdown of the estimated costs of the catalyst. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $220 to $350, depending on engine size. Costs for a mechanical pulse air system and recalibration is estimated to be about $13 to $16 per unit. The cost of a catalyst system is estimated to be about $60. As shown in the tables below, fixed costs for larger displacement models are spread over a significantly larger annual unit sales volume to account for the relatively high average number of unit sales per engine line for these products.

Table 5.2.3.-8 Two-Stroke to Four Stroke Conversion Costs for ATVs

	< 200 cc		**> 200 cc**	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4 Stroke**
Hardware Costs				
Engine	$400	$550	$500	$750
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$122	$168	$151	$226
Warranty Mark up @ 5%		$8		$13
Total Component Costs	**$542**	**$755**	**$671**	**$1,018**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$15,000	$0	$18,000
Units/yr.	4,200	4,200	15,000	15000
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$7**	**$0**	**$2**
Total Costs	**$542**	**$762**	**$671**	**$1,020**
Incremental Total Cost		**$220**		**$349**

Table 5.2.3.-9. Four-stroke Calibration/Pulse-Air Costs for Four-Stroke ATVs

	≤ 200 cc		> 200 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Pulse Air Valve		$8		$8
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$0		$0
Markup @ 29%		$3		$3
Warranty Mark up @ 5%		$0		$0
Total Component Costs	**$0**	**$12**	**$0**	**$12**
Fixed Cost to Manufacturer				
R&D Costs		$54,750		$54,750
Tooling Costs		$8,000		$10,000
Units/yr.		4,200		15000
Years to recover		5		5
Fixed cost/unit		**$4**		**$1**
Total Costs	**$0**	**$16**	**$0**	**$13**
Incremental Total Cost		**$16**		**$13**

Table 5.2.3.-10. Oxidation Catalyst Costs for 4-Stroke ATV

	≤ 200 cc		> 200 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Oxidation Catalyst		$39		$44
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$1		$1
OEM markup @ 29%		$12		$13
Warranty Mark up @ 5%		$2		$2
Total Component Costs	**$0**	**$55**	**$0**	**$61**
Fixed Cost to Manufacturer				
R&D Costs		$59,500		$59,500
Tooling Costs		$10,000		$12,000
Units/yr.		4,200		15,000
Years to recover		5		5
Fixed cost/unit		**$5**		**$1**
Total Costs	**$0**	**$60**	**$0**	**$62**
Incremental Total Cost		**$60**		**$62**

Table 5.2.3-11. Oxidation Catalyst Cost Breakdown

Catalyst Characteristic	Unit	Value
Washcoat Loading	g/L	160
% ceria	*by wt.*	*50*
% alumina	*by wt.*	*50*
Precious Metal Loading	g/L	1.8
% Platinum	*by wt.*	*83.3*
% Palladium	*by wt.*	*0.0*
% Rhodium	*by wt.*	*16.7*
Labor Cost	$/hr	$28.00

Material	**$/troy oz**	**$/lb**	**$/g**	**Density (g/cc)**
Alumina		$5.00	$0.011	3.9
Ceria		$5.28	$0.012	7.132
Platinum	$412		$13.25	
Palladium	$390		$12.54	
Rhodium	$868		$27.91	
Stainless Steel		$1.12	$0.002	7.817

Catalyst Volume (cc)	100	200	350
Substrate Diameter (cm)	4	6	8
Substrate	$6.93	$7.87	$9.27
Ceria/Alumina	$0.18	$0.36	$0.63
Pt/Pd/Rd	$2.83	$3.97	$6.95
Can (18 gauge 304 SS)	$0.43	$0.64	$0.93
Substrate Diameter (cm)	4.00	6.00	8.00
Substrate Length (cm)	8.0	7.1	7.0
Working Length (cm)	10.8	9.9	9.8
Thick. of Steel (cm)	0.121	0.121	0.121
Shell Volume (cc)	12	16	21
Steel End Cap Volume (cc)	4	8	14
Vol. of Steel (cc) w/ 20% scrap	19	29	42
Wt. of Steel (g)	150	227	328
TOTAL MATERIAL COST	**$10.37**	**$12.85**	**$17.78**
LABOR	**$14.00**	**$14.00**	**$14.00**
Labor Overhead @ 40%	$5.60	$5.60	$5.60
Supplier Markup @ 29%	$8.69	$9.90	$11.69
Manufacturer Price	**$38.66**	**$44.02**	**$52.01**

Off-highway Motorcycles

Currently, off-highway motorcycles are about 65 percent 2-stroke, with many of the 2-stroke engines used in competition and youth models. We are projecting essentially the same mix of technologies for off-highway motorcycle as for ATVs (Phase 1), discussed above. As with ATVs, we would expect that standards would be met primarily through the use of 4-stroke engines. Manufacturers may also use pulse air systems and recalibration on a fraction of their models to ensure their overall fleet meets the standards. We have estimated their use for off-highway motorcycles at about 25 percent. We do not believe that the level of the standards would require the use of pulse air beyond 25 percent, given the only a few models in California are currently equipped with the technology. As discussed in 5.2.3.4 below, vehicles used solely for competition are exempt from standards and we would expect some 2-stroke competition models to remain in the market.

Tables 5.2.3.-12 and 5.2.3.-13 provide cost estimates for off-highway motorcycles technologies for three engine displacement ranges. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $220 to $360, depending on engine size. Costs for a mechanical pulse air valve system and recalibration is estimated to be about $17 per unit.

5.2.3.2 Operating Cost Savings

Snowmobiles

Both direct injection and conversion from two-stroke to 4-stroke yield substantial fuel economy benefits. Typical 2-stroke engines have relatively poor fuel economy performance because a portion of the combustion mixture passes through the engines unburned. Because 4-stroke and direct injection 2-stroke engine designs essentially do not allow this to occur, they provide better fuel economy as well as substantially lower HC emissions. We have estimated fuel savings based on a 25 percent reduction in fuel consumption, based on typical performance of these technologies. Lifetime fuel costs are provided in Table 5.2.3.-14.[14, 15]

Table 5.2.3.-14. Fuel Cost for Snowmobiles

Engine	Baseline 2-Stroke		Advanced Technology Engines (25% savings)	
	small	large	small	large
Engine power	75	125	75	125
Load Factor	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	57	57	57	57
Lifetime, yr	9	9	9	9
BSFC, lb/bhp-hr	1.66	1.25	1.66	1.25
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	396	659	297	494
Yearly Fuel Cost ($/yr)	$435	$725	$326	$544
Lifetime Fuel Cost (NPV)	**$2,835**	**$4,725**	**$2,126**	**$3,543**

* Excluding taxes

ATVs and Off-highway Motorcycles

Conversion from 2-stroke to 4-stroke engines would yield a fuel economy improvement for ATVs and off-highway motorcycles. Tables 5.2.3.-15 and 5.2.3.-16 provide estimates of fuel consumption for both 2-stroke and 4-stroke engines. We have estimated that switching from a 2-stroke to a 4-stroke engine would reduce fuel consumption by about 25 percent. Lifetime fuel savings for ATVs resulting from switching from a 2-stroke to a 4-stroke engine is estimated to be $234 for a small displacement engine and $1,166 for a large displacement engine. For off-highway motorcycles, the projected lifetime fuel savings range from $63 to $311.

Table 5.2.3.-15. Fuel Cost for ATVs

Engine	2-Stroke		4-Stroke	
	small	large	small	large
Engine power	5	25	5	25
Load Factor	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	350	350	350	350
Lifetime, yr	13	13	13	13
BSFC, lb/bhp-hr	1.05	1.05	0.79	0.79
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	102	512	77	385
Yearly Fuel Cost ($/yr)	$113	$563	$85	$424
Lifetime Fuel Cost (NPV)	**$942**	**$4,708**	**$708**	**$3,542**

* Excluding taxes

Table 5.2.3.-16. Fuel Cost Savings for Off-highway Motorcycles

Engine	2-stroke			4-stroke		
	small	med.	large	small	med.	large
Engine power	5	12	25	5	12	25
Load Factor	0.34	0.34	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	120	120	120	120	120	120
Lifetime, yr	9	9	9	9	9	9
BSFC, lb/bhp-hr	1.05	1.05	1.05	0.79	0.79	0.79
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	35	84	176	26	63	132
Yearly Fuel Cost ($/yr)	$39	$93	$193	$29	$70	$145
Lifetime Fuel Cost (NPV)	**$252**	**$604**	**$1,258**	**$189**	**$454**	**$947**

* Excluding taxes

It should be noted that conversion to 4-stroke engines would also result in savings in oil consumption and improvements in durability. In a 2-stroke engine, oil is added to the gasoline in order to lubricate the engine, resulting in a faster oil use rate than in a 4-stroke engine. Also, 4-stroke engines have increased durability compared to 2-strokes, resulting in less frequent major engine repairs. We have not attempted to quantify the resulting cost savings, but the savings would provide a benefit for the consumer.

5.2.3.3 Compliance Costs

We estimate ATV and off-highway motorcycle chassis-based certification to cost about $25,000 per engine line, including $10,000 for engineering and clerical work and $15,000 for durability and certification testing. For snowmobile engine-based certification, we estimate costs to be about $30,000, recognizing that engine testing is somewhat more expensive than vehicle testing due to the time needed to set up the engine on the test stand. As with other fixed costs, we amortized the cost over 5 years of engine sales to calculate per unit certification costs shown in Table 5.2.3.-17. The actual certification costs for ATVs and off-highway motorcycles are likely to be lower than those shown in the table above because manufacturers are likely to use certification data generated for the California program.

Table 5.2.3.-17 Estimated Per Unit Certification Costs

	Snowmobiles	ATVs		Off-highway Motorcycles
units/year	4,600	4,200	15,000	3,500
certification costs	$1.70	$1.55	$0.42	$1.86

We have estimated that manufacturers would be required to test about 0.2% of production to meet production line testing requirements. Using per test costs of $2,500 for vehicle testing and $5,000 per test for engine testing, we estimate a per unit cost for production line testing of $5 for off-road motorcycles and ATVs and $10 for snowmobiles.

In general, we expect manufacturers would be able to use existing test facilities. For manufacturers that do not have sufficient chassis testing capabilities for ATVs, we would expect them to carry over engine-based certifications from the California program during Phase 1 of the ATV standards. Because the option of carrying over California engine test data would not be available for Phase 2 standards, manufacturer could be required to conduct chassis testing of ATVs. Therefore, we have estimated the cost of new chassis testing facilities to be included in the cost of the Phase 2 standards. The costs are based on an estimate provided by one manufacturer that a full test cell would cost $2 million to build. We have estimated that on average manufacturers would need two such facilities to conduct testing. The costs will vary somewhat among manufacturers depending on the state of their existing facilities and the number of vehicle families that must be certified. However, we believe that this is a generous estimate because some manufacturers would likely be able to upgrade existing test facilities instead of building new facilities.

By estimating $4 million per manufacturer, with 7 manufacturers, and amortizing the costs over 10 years (10 years x 546,000 units), we estimate an average per unit cost of $8.94. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used at least that long. It should be noted that these costs would be avoided if an adequate engine-based test procedure can eventually be developed and adopted for ATVs for Phase 2.

5.2.3.4 Recreational Vehicle Total Costs

The analysis below combines the costs estimated above into a total composite or average cost for each vehicle type. The composite analysis weights the costs by projecting the percentage of their use, both in the baseline and control scenario, to project industry-wide average per vehicle costs.

A summary of the estimated near-term and long-term per unit average incremental costs and fuel savings for recreational vehicles is provided in Table 5.2.3.-18. Long-term costs do not include fixed costs, which are retired, and include cost reductions due to the learning curve.

Table 5.2.3.-18 Total Average Per Unit Costs and Fuel Savings

	Snowmobile Phase 1	Snowmobile Phase 2	ATV Phase 1	ATV Phase 2	Off-highway Motorcycle
near-term costs	$55	$216	$60	$52	$151
long-term costs	$27	$125	$38	$28	$94
fuel savings (NPV)	$0	($509)	($102)	$0	($98)

Tables 5.2.3.-19 through 5.2.3.-23 provide the detailed average, or composite, per unit costs for snowmobiles (Phase 1 and Phase 2), ATVs (Phase 1 and Phase 2), and off-highway motorcycles. The composite costs are based on the estimated distribution of the different engine displacement ranges. We estimated an approximate distribution of sales among the displacement ranges using limited sales data provided by some manufacturers on a confidential basis and production data from Power Systems Research. Incremental costs are shown both for the near-term and long-term. Long term costs reflect the retirement of fixed costs and the affect of the learning curve, described in section 5.1.

Table 5.2.3.-19 Estimated Average Costs For Snowmobiles (Phase 1)

		Cost	Lifetime Fuel Savings	Baseline	Control	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	engine modifications	$17	$0	0%	100%	$17	$0
	modified carburetor	$18	$0	0%	95%	$17	$0
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$46	$0
> 500 cc (70%)	engine modifications	$24	$0	0%	100%	$24	$0
	modified carburetor	$24	$0	0%	95%	$23	$0
	compliance	$12	$0	0%	100%	$12	$0
	total	--	--	--	--	$59	$0
Near Term Composite Incremental Cost		--	--	--	--	**$55**	**$0**
Long Term Composite Incremental Cost		--	--	--	--	**$27**	**$0**

Table 5.2.3.-20 Estimated Average Costs For Snowmobiles (Phase 2)

		Cost	Lifetime Fuel Savings	Baseline	Control	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$16	$0	0%	50%	$8	$0
	direct injection*	$327	($709)	0%	40%	$131	($284)
	electronic fuel injection	$174	$0	5%	15%	$17	$0
	4-stroke engine	$455	($709)	1%	10%	$41	($64)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$209	($348)
< 500 cc (70%)	pulse air/recalibration	$16	$0	0%	50%	$8	$0
	direct injection*	$294	($1,181)	0%	40%	$118	($472)
	electronic fuel injection	$119	$0	5%	15%	$12	$0
	4-stroke engine	$770	($1,181)	1%	10%	$69	($106)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$219	($578)
Near Term Composite Incremental Cost		--	--	--	--	**$216**	**($509)**
Long Term Composite Incremental Cost		--	--	--	--	**$125**	**$0**

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 5.2.3.-21 Estimated Average Costs For ATVs (Phase 1)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$220	$234	8%	100%	$202	($215)
	pulse air/recalibration	$16	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$213	($215)
> 200 cc (85%)	4-stroke engine	$349	$1,166	93%	100%	$24	$82
	pulse air/recalibration	$13	$0	0%	25%	$3	$0
	compliance	$6	--	0%	100%	$6	--
	total	--	--	--	--	$33	($82)
Near Term Composite Incremental Cost		--	--	--	--	**$60**	**($102)**
Long Term Composite Incremental Cost		--	--	--	--	**$38**	**($102)**

Table 5.2.3.-22 Estimated Average Costs For ATVs (Phase 2)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$220	$234	100%	100%	$0	$0
	pulse air/recalibration	$16	$0	25%	75%	$8	$0
	oxidation catalyst	$60	$0	0%	50%	$30	$0
	compliance	$16	--	0%	100%	$16	--
	total	--	--	--	--	$54	$0
> 200 cc (85%)	4-stroke engine	$349	$1,166	100%	100%	$0	$0
	pulse air/recalibration	$13	$0	25%	75%	$7	$0
	oxidation catalyst	$62	$0	0%	50%	$31	$0
	compliance	$14	--	0%	100%	$14	--
	total	--	--	--	--	$52	$0
Near Term Composite Incremental Cost		--	--	--	--	**$52**	**$0**
Long Term Composite Incremental Cost		--	--	--	--	**$28**	**$0**

Table 5.2.3.-23 Estimated Average Costs For Off-highway Motorcycles (Non-competition models only)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 125 cc (37%)	4-stroke engine	$222	$63	82%	100%	$40	($11)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$51	($11)
125 < 250 cc (21%)	4-stroke engine	$289	$150	30%	100%	$202	($105)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$213	($105)
≥ 250 cc (42%)	4-stroke engine	$357	$311	45%	100%	$196	($171)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total					$207	($171)
Near Term Composite Incremental Cost		--	--	--	--	**$151**	**($98)**
Long Term Composite Incremental Cost		--	--	--	--	**$94**	**($98)**

Currently, off-highway motorcycles are about 63 percent 2-stroke with many of the 2-stroke engines used in competition and youth models. In recent years, more high performance and competition models have been successfully introduced with 4-stroke engines and there appears to be a trend toward increased use of 4-stroke engines. Models used solely for competition are exempt from CAA requirements and we expect some 2-stroke competition models would continue to be sold under this exemption. For purposes of the cost analysis, we have estimated that 29 percent of all off-highway motorcycles would be exempt as competition models and that these models would be equipped with 2-stroke engines. We have based the estimate of exempt models on the our estimate of the current use of 2-strokes in the motocross market. We believe the emissions standards would be reasonably achievable for 4-stroke engines, especially with averaging, and that manufacturers would elect to certify all 4-stroke models in order to market them to the widest possible consumer base.

To account for the competition model exemption in the calculation of average costs, we have adjusted the percentage of 2-stroke engines from the overall baseline percentage of off-highway motorcycle sales using the 29 percent estimate noted above. This adjustment is necessary in order to determine the average costs for only those off-highway motorcycles that would be covered by the program. Table 5.2.3.-24 provides our estimate of the baseline percentage of 2-strokes in overall sales and the percentage of the non-competition model sales.

Table 5.2.3.-24 Estimated Off-highway Motorcycle Percent 2-stroke Engine Usage

Displacement	Overall Baseline 2-stroke percentage	Baseline 2-stroke percentage Excluding Competition Models
< 125 cc	42%	18%
125 to 249 cc	79%	70%
> 250 cc	68%	55%

5.2.3.5 Recreational Vehicle Aggregate Costs

The above analyses developed incremental per vehicle cost estimates for snowmobiles, ATVs, and off-highway motorcycles. Using these per vehicle costs and projections of future annual sales, we have estimated total aggregate annual costs for the recreational vehicles standards. The aggregate costs are presented on a cash flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the vehicle is operated over its life. Table 5.2.3.-25 presents a summary o f the results of this analysis. As shown in the table, aggregate net costs increase from about $40 million in 2006 to about $70 million in 2010 when the program is fully phased in. Net costs are projected then to decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used. Fuel savings are projected to more than offset the costs of the program starting in 2013.

Table 5.2.3.-25 Summary of Annual Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
Snowmobiles	$8.49	$39.50	$25.00	$26.28	$27.62
ATVs	$27.16	$78.46	$56.81	$51.93	$51.93
Off-highway Motorcycles	$8.81	$13.12	$11.63	$12.22	$12.85
Total	$44.46	$131.08	$93.45	$90.43	$92.40
Fuel Savings	($4.98)	($60.55)	($153.06)	($211.20)	($227.22)
Net Costs	$39.47	$70.53	($59.62)	($120.77)	($134.83)

To project annual sales, we started with 1999 sales estimates provided by industry organizations. We then adjusted the numbers and applied sales growth estimates consistent with the modeling performed to estimate total emissions (see Section 6.2.4.1.1). For ATVs, we added 70,000 units to account for sales from companies not included in the industry organization estimates. Sales growth for snowmobiles and off-highway motorcycle sales is projected to be about one percent per year. The off-road motorcycle sales were reduced by 29 percent to account for the exemption of competition models. ATVs are modeled differently because recent sales growth rates have been significantly higher than one percent but are at rates not likely to be sustained indefinitely. We project that ATV sales will continue to grow at a higher rate over the next few years but will level off by 2006. Table 5.2.3.-26 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.3.-26 Estimated Annual Recreational Vehicle Sales

	1999	2006	2010	2020
Snowmobiles	148,000	158,676	166,235	182,394
ATVs	616,000	838,102	838,102	838,102
Off-highway motorcycles*	105,790	113,421	118,027	130,375

* Non-competition only

To calculated annual aggregate costs, the sales estimates have been multiplied by the per unit costs. Fuel savings have been calculated using the NONROAD model to calculate the shift in use from 2-stroke to 4-stroke vehicles, and also direct injection 2-strokes for snowmobiles, over time. The model takes into consideration vehicle sales and scrappage rates. The standards phase-in schedule for off-highway motorcycles (50/100% in 2006/2007) and ATVs (Phase 1: 50/100% in 2006/2007, Phase 2: 50/100% in 2009/2010) has also been taken into account. The detailed year-by-year analysis is provided in Chapter 7.

Chapter 5 References

1."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 (Docket A-2000-01, document II-A-54).

2.For further information on learning curves, see Chapter 5 of the Economic Impact, from Regulatory Impact Analysis - Control if Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, EPA420-R-99-023, December 1999. A copy of this document is included in Air Docket A-2000-01, at Document No. II-A-83. The interested reader should also refer to previous final rules for Tier 2 highway vehicles (65 FR 6698, February 10, 2000), marine diesel engines (64 FR 73300, December 29, 1999), nonroad diesel engines (63 FR 56968, October 23, 1998), and highway diesel engines (62 FR 54694, October 21, 1997).

3."Estimated Economic Impact of New Emission Standards for Heavy-Duty Highway Engines," Acurex Environmental Corporation Final Report (FR 97-103), March 31, 1997. The Acurex Environmental Corporation has since changed its name to Arcadis Geraghty & Miller (Docket A-2000-01, document II-A-51).

4."Incremental Costs for Nonroad Engines: Mechanical to Electronic," Memorandum from Lou Browning, Acurex Environmental, to Alan Stout, EPA, April 1, 1997 (Docket A-2000-01, document II-A-52).

5."Incremental Cost Estimates for Marine Diesel Engine Technology Improvements," Memorandum from Louis Browning and Kassandra Genovesi, Arcadis Geraghty & Miller, to Alan Stout, EPA, September 30, 1998 (Docket A-2000-01, document II-A-53).

6."Large SI Engine Technologies and Costs," Arthur D. Little - Acurex Environmental, Final Report, September 2000.

7. "Exhaust Controls Available to Reduce Emissions from Nonroad Heavy-Duty Engines," in Clean Air Technology News, Winter 1997, p. 1 (Docket A-98-01; item II-A-02).

8. "It's Not Easy Being Green," Modern Materials Handling, April 2000 (Docket A-2000-01; item II-A-06).

9. Letter from William Platz, Western Propane Gas Association, January 24, 2001 (Docket A-2000-01; item II-D-40).

10. "It's Not Easy Being Green," Modern Materials Handling, April 2000 (Docket A-2000-01; item II-A-06).

11. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31)..

12. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31).

13. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31).

14. Brake-specific fuel consumption (BSFC) based on 4-stroke BSFC estimates provided by Power Systems Research.

15. “Monthly Energy Review”, Calendar year 2000 average Refiner Prices of Pertroleum Products to End Users (Cents per gallon, excluding taxes), Energy Information Administration.

CHAPTER 6: Emissions Inventory

6.1 Methodology

The following chapter presents our analysis of the emission impact of the proposed standards for recreational marine, large spark-ignition equipment, snowmobiles, all-terrain vehicles, and off-highway motorcycles. We first present an overview of the methodology used to generate the emissions inventories, followed by a discussion of the specific information used in generating the inventories for each of the regulated categories of engines as well as the emission inventories. Emissions from a typical piece of equipment are also presented.

6.1.1 Off-highway Exhaust Emissions

We are in the process of developing an emission model that will calculate emissions inventories for most off-highway vehicle categories, including those in this rule. This draft model is called NONROAD. For this effort we use the most recent version of the draft NONROAD model publicly available with some updates that we anticipate will be included in the next draft release. This section gives a brief overview of the calculation methodology used in NONROAD for calculating exhaust emission inventories. Inputs and results specific to each of the off-highway categories in this rule are discussed in more detail later in this chapter. For more detailed information on the draft NONROAD model, see our website at www.epa.gov/otaq/nonrdmdl.htm.

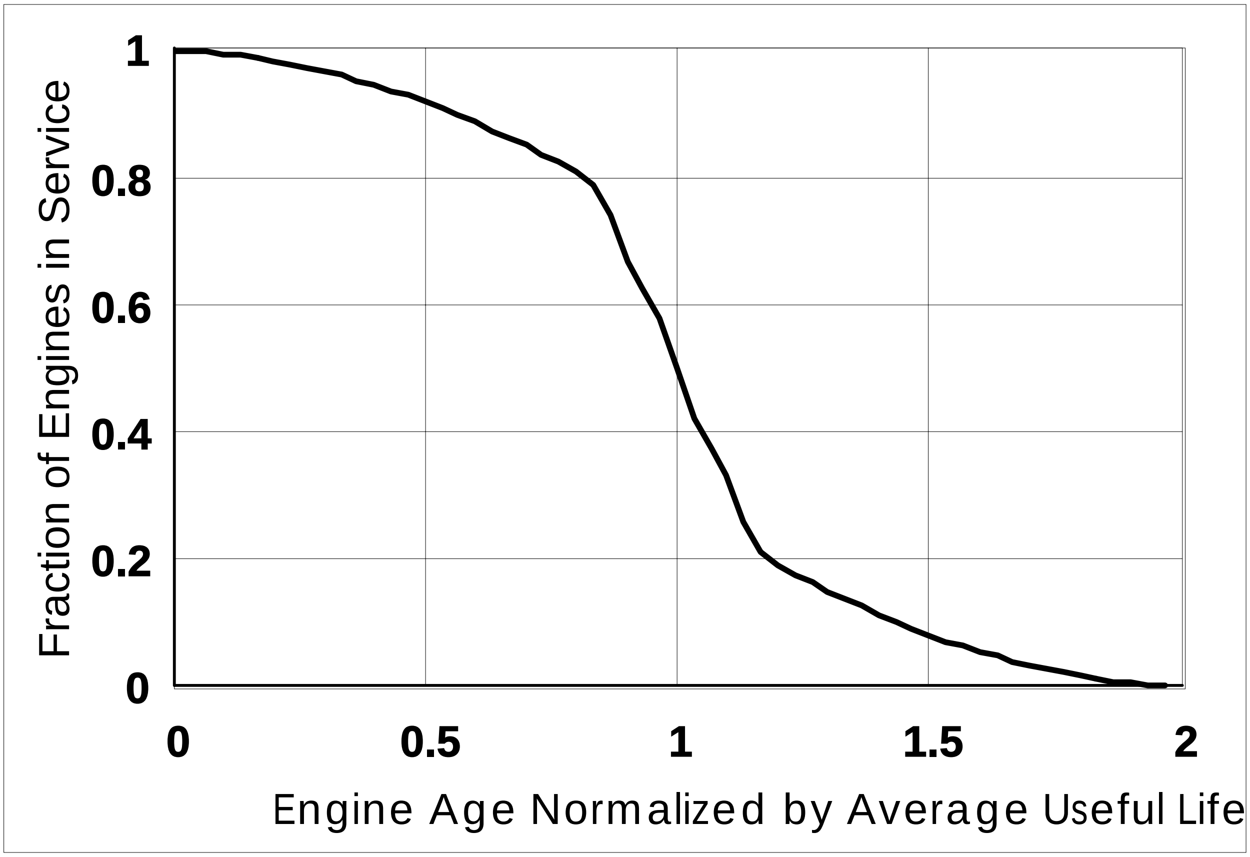
For the inventory calculations in this rule, each class of off-highway engines was divided into power ranges to distinguish between technology or usage differences in each category. Each of the engine applications and power ranges were modeled with distinct annual hours of operation, load factors, and average engine lives. The basic equation for determining the exhaust emissions inventory, for a single year, from off-highway engines is shown below:

$$Emissions = \sum_{ranges} \left(population \times power \times load \times annual\,use \times emission\,factor \right) \qquad (Eq. 6-1)$$

This equation sums the total emissions for each of the power ranges for a given calendar year. “Population” refers to the number of engines estimated to be in the U.S. in a given year. “Power” refers to the population-weighted average rated power for a given power range. Two usage factors are included; “load” is the ratio between the average operational power output and the rated power, and “annual use” is the average hours of operation per year. Emission factors are applied on a brake-specific basis (g/kW-hr) and represent the weighted value between levels from baseline and controlled engines operating in a given calendar year. Exhaust emission inventories were calculated for HC, CO, and NOx from all engines and additionally for PM from compression-ignition engines. Although some of the proposed emission standards combine HC and NOx, it is useful to consider the HC and NOx emission impacts separately. (As described throughout this document, the proposed standards for all-terrain vehicles (ATVs) and off-highway motorcycles are based on a chassis test, with the standards proposed in grams per kilometer. For these two categories of equipment, the equation used by the NONROAD model for calculating emissions is similar to Equation 6-1 except that the "load factor" and "power" terms are not included in the calculation, the "annual use" is input on a miles/year basis, and the "emission factors" are entered on a gram per mile basis.)

To be able to determine the mix between baseline and controlled engines, we need to determine the turnover of the fleet. Through the combination of historical population and scrappage rates, historical sales and retirement of engines can be estimated. We use a normalized scrappage rate and fit it to the data for each engine type on average operating life. Figure 6.1.1-1 presents the normalized scrappage curve used in the draft NONROAD model. For further discussion of this scrappage curve, see our report titled "Calculation of Age Distributions -- Growth and Scrappage," (NR-007).

Figure 6.1.1-1: Normalized Scrappage Curve



6.1.2 Off-highway Evaporative Emissions

Evaporative emissions refer to hydrocarbons released into the atmosphere when gasoline, or other volatile fuels, evaporate from a vehicle. For this analysis, we model three types of evaporative emissions:

- diurnal: These emissions are due to temperature changes throughout the day. As the day gets warmer, the fuel heats up and begins to evaporate.

- refueling: These emissions are the vapors displaced from the fuel tank when fuel is dispensed into the tank.

- permeation: These emissions are due to fuel that works its way through the material used in the fuel system. Permeation is most common through plastic fuel tanks and rubber hoses.

We are currently in the process of revising the inputs to the calculations for evaporative emissions in the draft NONROAD model. The analysis for this rule includes the inputs that we anticipate will be used in the draft NONROAD model. Because diurnal and refueling emissions are dependent on ambient temperatures and fuel properties which vary through the nation and through the year, we divided the nation into six regions and modeled each region individually for each day of the year. The daily temperatures by region are based on a report which summarizes a survey of dispensed fuel and ambient temperatures in the United States.[1]

For diurnal emission estimates, we used the Wade-Reddy equations[2,3,4] to calculate grams of hydrocarbons emitted per day per volume of fuel tank capacity. The Wade-Reddy equations are well established and are used in both the MOBILE and draft NONROAD models with an adjustment based on empirical data. These calculations are a function of vapor space, fuel vapor pressure, and daily temperature variation and are as follows:

$$\text{Vapor space } (\text{ft}^3) = ((1 - \text{tank fill}) \times \text{tank size} + 3) / 7.841 \qquad \textbf{(Eq. 6-2)}$$

where:

tank fill = fuel in tank/fuel tank capacity
tank size = fuel tank capacity in gallons

$$T_1\ (^\circ\text{F}) = (T_{max} - T_{min}) \times 0.922 + \text{Tmin} \qquad \textbf{(Eq. 6-3)}$$

where:

T_{max} = maximum diurnal temperature (°F)
T_{min} = minimum diurnal temperature (°F)

$$V_{100}\ (\text{psi}) = 1.0223 \times \text{RVP} + [(0.0357 \text{ X RVP})/(1-0.0368 \times \text{RVP})] \qquad \textbf{(Eq. 6-4)}$$

where:

V_{100} = vapor pressure at 100°F
RVP = Reid Vapor Pressure of the fuel

$$E_{100}\,(\%) = 66.401-12.718 \times V_{100} +1.3067 \times V_{100}^2 - 0.077934 \times V_{100}^3 + 0.0018407 \times V_{100}^4 \qquad \textbf{(Eq. 6-5)}$$

$$D_{min}\,(\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113] \times (100 - T_{min}) \qquad \textbf{(Eq. 6-6a)}$$

$$D_{max}\,(\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113] \times (100 - T_1) \qquad \textbf{(Eq. 6-6b)}$$

where:

$D_{min/max}$ = distillation percent at the max/min temperatures in the fuel tank
E_{100} = percent of fuel evaporated at 100°F from equation 6-5

$$P_I\,(psi) = 14.697 - 0.53089 \times D_{min} + 0.0077215 \times D_{min}^2 - 0.000055631 \times D_{min}^3 + 0.0000001769 \times D_{min}^4 \qquad \textbf{(Eq. 6-7a)}$$

$$P_F\,(psi) = 14.697 - 0.53089 \times D_{max} + 0.0077215 \times D_{max}^2 - 0.000055631 \times D_{max}^3 + 0.0000001769 \times D_{max}^4 \qquad \textbf{(Eq. 6-7a)}$$

$$\text{Density (lb/gal)} = 6.386 - 0.0186 \times RVP \qquad \textbf{(Eq. 6-8)}$$

$$\text{MW (lb/lb mole)} = (73.23 - 1.274 \times RVP) + [0.5 \times(T_{min} + T_1) - 60] \times 0.059 \qquad \textbf{(Eq. 6-9)}$$

$$\text{Diurnal emissions (grams)} = \text{vapor space} \times 454 \times \text{density} \times [520 / (690 - 4 \times MW)] \times 0.5 \times [P_I / (14.7 - P_I) + P_F / (14.7 - P_F)] \times [(14.7 - P_I) / (T_{min} + 460) - (14.7 - P_F) / (T_1 + 460)] \qquad \textbf{(Eq. 6-10)}$$

where:

MW = molecular weight of hydrocarbons from equation 6-9
$P_{I/F}$ = initial and final pressures from equation 6-7

Because these calculations were developed and verified using automotive sized fuel tanks, we ran the above equations for a 20 gallon fuel tank and then divided by 20 gallons to get emission factors on a gram per gallon basis. This ensures that the vapor space calculation gives a reasonable result.

We used the draft NONROAD model to determine the amount of fuel consumed by spark-ignition marine engines. To calculate refueling emissions, we used an empirical equation to calculate grams of vapor displaced during refueling events. This equation was developed based on testing of 22 highway vehicles under various refueling scenarios and in the benefits calculations for our onboard refueling vapor recovery rulemaking for cars and trucks.[5] These calculations are a function of fuel vapor pressure, ambient temperature, and dispensed fuel temperature. The refueling vapor generation equation is as follows:

$$\text{Refueling vapor (g/gal)} = \text{EXP}(-1.2798 - 0.0049 \times (Td - Ta) + 0.0203 \times Td + 0.1315 \times RVP) \quad \textbf{(Eq. 6-11)}$$

where:

Td = dispensed fuel temperature (°F)
Ta = ambient fuel temperature (°F)
RVP = Reid Vapor Pressure of the fuel

Title 40, Section 80.27 of the Code of Federal Regulations specifies the maximum allowable fuel vapor pressure allowed for each state in the U.S. for each month of the year. We used these limits as an estimate of fuel vapor pressure in our calculations.

We are not aware of a model that will allow us to calculate fuel permeation from nonroad equipment. However we have limited data on the permeability of plastic fuel tanks and rubber hoses. Based on this data, and a distribution of fuel tank sizes, materials, and assumed hose lengths, we were able to estimate evaporative emissions due to permeation.

6.2 Effect of Emission Controls by Engine/Vehicle Type

The remainder of this chapter discusses the inventory results for each of the classes of engines/vehicles included in this document. These inventory projections include both exhaust and evaporative emissions. Also, this section describes inputs and methodologies used for the inventory calculations that are specific to each engine/vehicle class.

6.2.1 Compression-Ignition Recreational Marine

We projected the annual tons of exhaust HC, CO, NOx, and PM from CI recreational marine engines using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to CI recreational marine engines then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.1.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for CI recreational marine exhaust emissions. These inputs are load factor, annual use, average operating life, and population. Based on data collected in developing the draft NONROAD model, we use a load factor of 35 percent and an annual usage factor of 200 hours. We use an average operating life of 20 years for engines below 225 kW and 30 years for larger engines. The draft NONROAD model includes current and projected engine populations. Table 6.2.1-1 presents these population estimates for selected years.

Table 6.2.1-1
Projected CI Recreational Marine Population by Year

Year	*2000*	*2005*	*2010*	*2020*	*2030*
population	167,000	193,000	219,000	272,000	326,000

We used the data presented in Chapter 4 to develop the baseline emission factors. For the control emission factors, we assumed that the manufacturers would design their engines to meet the proposed standard at regulatory useful life with a small compliance margin. (The regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards.) To determine the HC and NOx split for the proposed standards, we used the HC and NOx data presented in Chapter 4 from CI recreational marine engines near the proposed standards. Consistent with our modeling of heavy-duty highway emissions, we assumed a compliance margin of 8 percent. This compliance margin is based on historical practices for highway and nonroad engines with similar technology. Engine manufacturers give themselves some cushion below the certification level on average so that engine-to-engine variability will not cause a significant number of engines to exceed the standard. Also, we used the deterioration factors in the draft NONROAD model. Table 6.2.1-2 presents the emission factors used in this analysis for new engines and for engines deteriorated to the regulatory useful life (10 years).

Table 6.2.1-2
Emission Factors for CI Recreational Marine Engines

Engine Technology	*HC [g/kW-hr]*		*NOx [g/kW-hr]*		*CO [g/kW-hr]*		*PM [g/kW-hr]*	
	new	*10 yrs*	*new*	*10 yrs*	*new*	*10 yrs*	*new*	*10 yrs*
baseline	0.295	0.304	8.94	9.06	1.27	1.39	0.219	0.225
controlled:								
< 0.9 liters/cylinder	0.183	0.184	6.72	6.76	1.27	1.39	0.219	0.225
0.9-1.2 liters/cylinder	0.183	0.184	6.40	6.44	1.27	1.39	0.219	0.225
≥ 1.2 liters/cylinder	0.183	0.184	6.40	6.44	1.27	1.39	0.181	0.184

In our analysis of the CI recreational marine engine emissions inventory, we may underestimate emissions, especially PM, due to engine deterioration in-use. We believe that current modeling only represents properly maintained engines, but may not be representative of in-use tampering or malmaintenance. However, we have not fully evaluated the limited data currently available and we are in the process of collecting more data on in-use emission deterioration. Once this has been completed we will decide whether or not we need to update our deterioration rates both in this analysis and in the Draft NONROAD model.

6.2.1.2 Reductions Due to the Proposed Standard

We anticipate that the proposed standards will result in a 41 percent reduction in HC+NOx and a 22 percent reduction in PM from new engines. Because of the long lives of these engines, even in 2030 the only about half of the fleet will be turned over to the new engines. For this reason the reductions in 2030 are only about 26 percent HC+NOx and 9 percent PM. We are not claiming any benefits from the proposed cap on CO emissions. The following charts and tables present our projected exhaust emission inventories for CI recreational marine engines and the anticipated emission reductions.

Figure 6.2.1-1: Projected National HC from CI Recreational Marine Engines

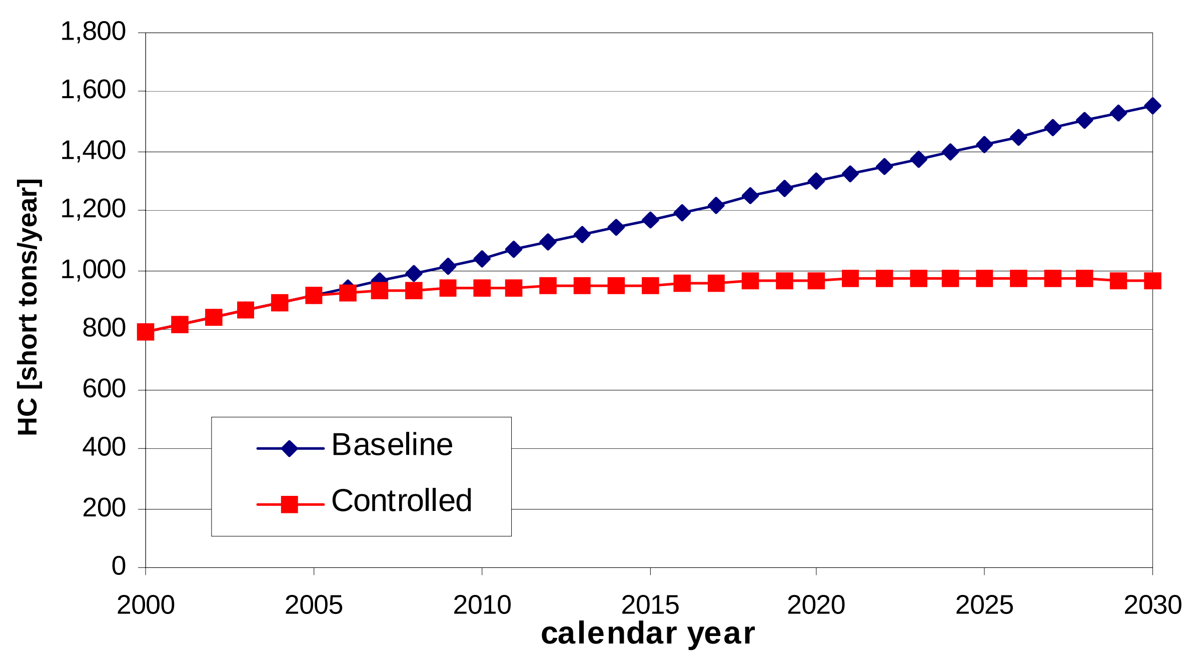


Table 6.2.1-3
Projected HC Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	*Baseline*	*Control*	*Reduction*	*% Reduction*
2000	800	800	0	0%
2005	920	920	0	0%
2010	1,040	940	100	10%
2020	1,300	970	330	25%
2030	1,550	970	580	38%

Figure 6.2.1-2: Projected National NOx from CI Recreational Marine Engines

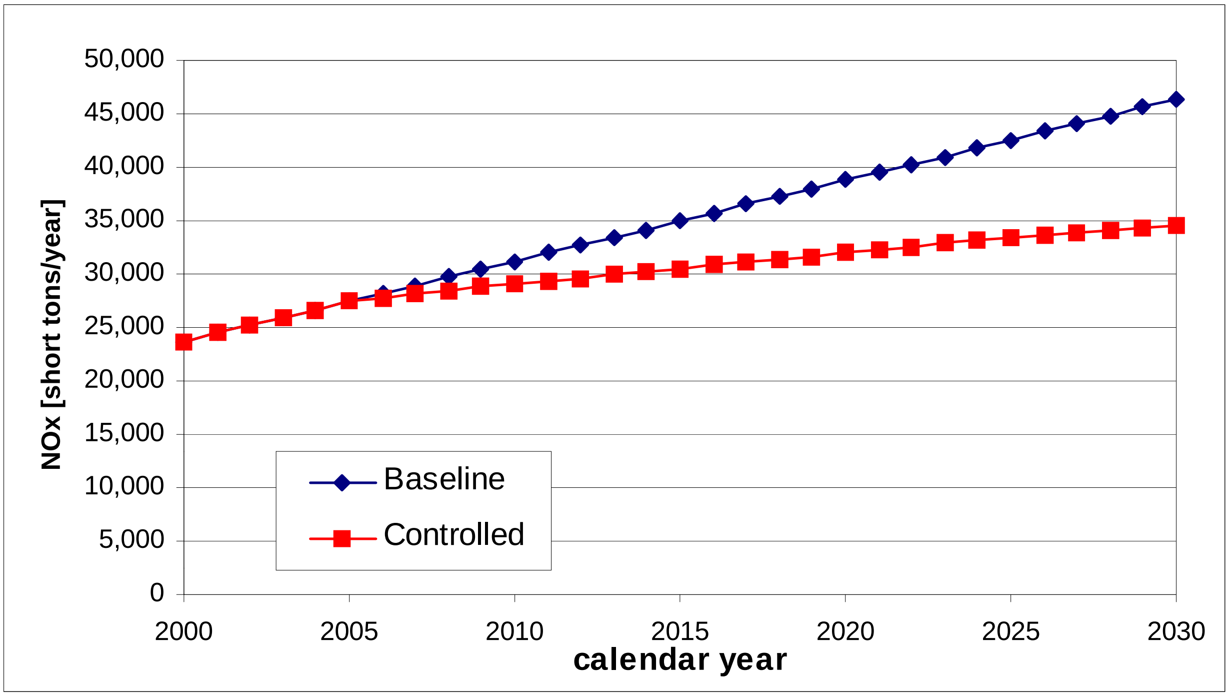


Table 6.2.1-4
Projected NOx Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	*Baseline*	*Control*	*Reduction*	*% Reduction*
2000	23,700	23,700	0	0%
2005	27,400	27,400	0	0%
2010	31,200	29,000	2,110	7%
2020	38,800	32,000	6,760	17%
2030	46,300	34,500	11,800	26%

Figure 6.2.1-4: Projected National PM from CI Recreational Marine Engines

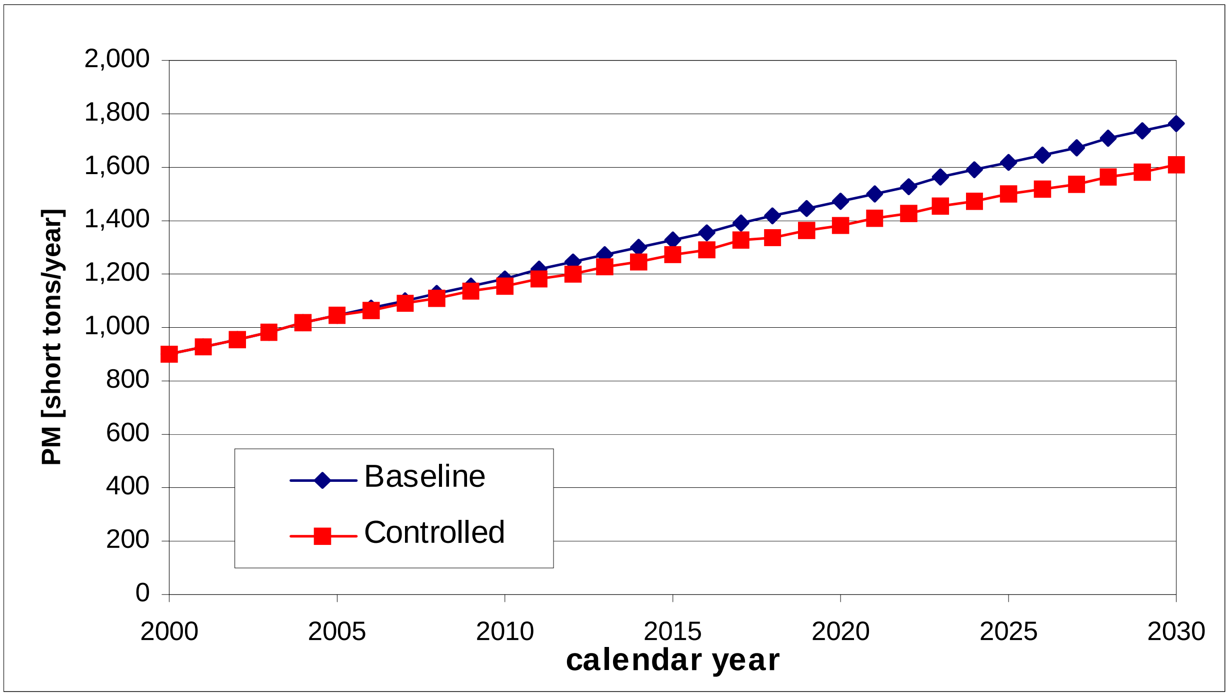


Table 6.2.1-6
Projected PM Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	*Baseline*	*Control*	*Reduction*	*% Reduction*
2000	900	900	0	0%
2005	1,040	1,040	0	0%
2010	1,180	1,160	20	2%
2020	1,470	1,390	80	6%
2030	1,760	1,600	160	9%

6.2.1.3 Per Vessel Emissions from CI Recreational Marine Engines

This section describes the development of the HC plus NOx emission estimates on a per engine basis over the average lifetime of typical CI recreational marine engines. As in the cost analysis in Chapter 5, we look at three engine sizes for this analysis (100, 400, and 750 kW) as well as a composite of all engine sizes. The emission estimates were developed to estimate the cost per ton of the proposed standards as presented in Chapter 7.

The new and deteriorated emission factors used to calculate the HC and NOx emissions from typical CI recreational marine engines were presented in Table 6.2.1-2. A brand new engine emits at the zero-mile level presented in the table. As the engine ages, the emission levels increase based on the pollutant-specific deterioration factor. The load factor for these engines is estimated to be 0.35, the annual usage rate is estimated to be 200 hours per year, and the average lifetime is estimated to be 20 years for engines less than 225 kW and 30 years for larger engines.

Using the information described above and the equation used for calculating emissions from nonroad engines (see Equation 6-1), we calculated the lifetime HC+NOx emissions from typical marine engines both baseline and controlled engines. Table 6.2.1-7 presents these results with and without the consideration of a 7 percent per year discount on the value of emission reductions.

Table 6.2.1-7
Lifetime HC+NOx Emissions from Typical CI Recreational Marine Engines (tons)

Engine Size	Baseline		Control		Reduction	
	Undiscounted	Discounted	Undiscounted	Discounted	Undiscounted	Discounted
100 kW	1.44	0.82	1.01	0.57	0.43	0.24
400 kW	8.65	3.82	6.08	2.69	2.57	1.13
750 kW	16.2	7.16	11.4	5.04	4.84	2.12
Composite	5.64	2.58	3.96	1.81	1.68	0.76

6.2.1.4 Crankcase Emissions from CI Recreational Marine Engines

We anticipate some benefits in HC, NOx, and PM from the closed crankcase requirements for CI recreational marine engines. Based on limited engine testing, we estimate that crankcase emissions of HC and PM diesel engines are each about 0.013 g/kW-hr.[6] NOx data varies, but crankcase NOx emissions may be as high as HC and PM. Therefore, we use the same crankcase emission factor of 0.01 g/bhp-hr for each of the three constituents.

For this analysis, we assume that manufacturers will use the low cost option of routing crankcase emissions to the exhaust and including them in the total exhaust emissions when the engine is designed to the standards. Because exhaust emissions would have to be reduced slightly to offset any crankcase emissions, the crankcase emission control is functionally equivalent to a 100 percent reduction in crankcase emissions.

The engine data we use to determine crankcase emission levels is based on new heavy-duty engines. We do not have data on the effect of in-use deterioration of crankcase emissions. However, we expect that these emissions would increase as the engine wears. Therefore, this analysis may underestimate the benefits that would result from our crankcase emission requirements. Table 6.2.1-8 presents our estimates of the reductions crankcase emissions from CI recreational marine engines.

Table 6.2.1-8
Crankcase Emissions Reductions from CI Recreational Marine Engines

Calendar Year	*HC+NOx*	*PM*
2000	0	0
2005	0	0
2010	17	8
2020	63	32
2030	113	56

6.2.2 Large Spark-Ignition Equipment

6.2.2.1 Exhaust Emissions from Large SI Equipment

We projected the annual tons of exhaust HC, CO, and NOx from large industrial spark-ignition (SI) engines using the draft NONROAD model described above. This section describes inputs to the calculations that are specific to these engines then presents the results of the modeling.

6.2.2.1.1 Inputs for Exhaust Inventory Calculations

Several usage inputs are specific to the calculations for Large SI engines. These inputs are load factor, annual use, average operating life, and population. Because the Large SI category is made up of many applications, the NONROAD model contains application-specific information for each of the applications making up the Large SI category. Table 6.2.2-1 presents the inputs used in the NONROAD model for each of the Large SI applications. (The average operating life for a given application can vary within an application by power category. In such cases, the average operating life value presented in Table 6.2.2-1 is based on the average operating life estimate for the engine with the average horsepower listed in the table.)

The NONROAD model generally uses population data based on information from Power Systems Research, which is based on historical sales information adjusted according to survival and scrappage rates. We are, however, using different population estimates for forklifts based on a recent market study.[7] That study identified a 1996 population of 491,321 for Class 4 through 6 forklifts, which includes all forklifts powered by internal combustion engines. Approximately 80 percent of those were estimated to be fueled by propane, with the rest running on either gasoline or diesel fuel. Assuming an even split between gasoline and diesel for these remaining forklifts leads to a total population of spark-ignition forklifts of 442,000. The NONROAD model therefore uses this estimate for the forklift population, which is significantly higher than that estimated by Power Systems Research. Table 6.2.2-1 shows the estimated population figures used in the NONROAD model for each application, adjusted for the year 2000.

The split between LPG and gasoline in various applications warrants further attention.

Engines are typically sold without fuel systems, which makes it difficult to assess the distribution of engines sales by fuel type. Also, engines are often retrofitted for a different fuel after a period of operation, making it still more difficult to estimate the prevalence of the different fuels. The high percentage of propane systems for forklifts, compared with about 60 percent estimated by Power Systems Research, can be largely attributed to expenses related to maintaining fuel supplies. LPG cylinders can be readily exchanged with minimal infrastructure cost as compared to gasoline storage. Natural gas systems typically offer the advantage of pipeline service, but the cost of installing high-pressure refueling equipment is an obstacle to increased use of natural gas systems.

Some applications of nonroad SI equipment face much different refueling situations. Lawn and garden equipment is usually not centrally fueled and therefore operates almost exclusively on gasoline, which is more readily available. Agriculture equipment is predominantly powered by diesel engines. Most of these operators likely have storage tanks for diesel fuel. For those who use spark-ignition engines in addition to, or instead of, the diesel models, we would expect them in many cases to be ready to invest in gasoline storage tanks as well, resulting in little or no use of LPG or natural gas for those applications. For construction, general industrial, and other equipment, there may be a mix of central and noncentral fueling, and motive and portable equipment. We therefore believe that estimating an even mix of LPG and gasoline for these engines is most appropriate. The approximate distribution of fuel types for the individual applications used in the NONROAD model are listed in Table 6.2.2-1.

Table 6.2.2-1
Operating Parameters and Population Estimates for Various Large SI Applications

Application	Avg. Rated HP	Load Factor	Hours per Year	Average Operating Life (yrs)	2000 Population	Percent LPG/CNG
Forklift	69	0.30	1800	8.3	504,696	95
Generator	59	0.68	115	25.0	146,246	100
Commercial turf	28	0.60	682	3.7	55,433	0
Aerial lift	52	0.46	361	18.1	38,901	50
Pump	45	0.69	221	9.8	35,981	50
Welder	67	0.58	408	12.7	19,246	50
Baler	44	0.62	68	25.0	18,659	0
Air compressor	65	0.56	484	11.1	17,472	50
Scrubber/sweeper	49	0.71	516	4.1	13,363	50
Chipper/grinder	66	0.78	488	7.9	13,015	50
Swathers	95	0.52	95	25.0	12,060	0
Leaf blower/vacuum	79	0.94	282	11.3	11,797	0

Application	Avg. Rated HP	Load Factor	Hours per Year	Average Operating Life (yrs)	2000 Population	Percent LPG/CNG
Sprayers	66	0.65	80	25.0	9,441	0
Specialty vehicle/cart	66	0.58	65	25.0	9,145	50
Oil field equipment	44	0.90	1104	1.5	7,855	100
Skid/steer loader	47	0.58	310	8.3	7,436	50
Other agriculture equipment	162	0.55	124	25.0	5,501	0
Irrigation set	97	0.60	716	7.0	5,367	50
Trencher	54	0.66	402	11.3	3,627	50
Rubber-tired loader	71	0.71	512	8.8	3,177	50
Other general industrial	82	0.54	713	7.8	2,942	50
Terminal tractor	93	0.78	827	4.7	2,716	50
Bore/drill rig	78	0.79	107	25.0	2,607	50
Concrete/industrial saw	46	0.78	610	3.2	2,266	50
Rough terrain forklift	66	0.63	413	11.5	1,925	50
Other material handling	67	0.53	386	7.3	1,605	50
Ag. tractor	82	0.62	550	8.8	1,599	0
Paver	48	0.66	392	5.8	1,367	50
Roller	55	0.62	621	7.8	1,362	50
Other construction	126	0.48	371	16.8	1,276	50
Crane	75	0.47	415	15.4	1,240	50
Pressure washer	39	0.85	115	15.3	1,227	50
Paving equipment	39	0.59	175	14.5	1,109	50
Aircraft support	99	0.56	681	7.9	910	50
Gas compressor	110	0.60	6000	0.8	788	100
Front mowers	32	0.65	86	25.0	658	0
Other lawn & garden	61	0.58	61	25.0	402	0
Tractor/loader/backhoe	58	0.48	870	7.2	360	50
Hydraulic power unit	50	0.56	450	6.0	330	50
Surfacing equipment	40	0.49	488	6.3	314	50
Crushing/processing equip	63	0.85	241	14.6	235	50

Application	Avg. Rated HP	Load Factor	Hours per Year	Average Operating Life (yrs)	2000 Population	Percent LPG/CNG
Refrigeration/AC	55	0.46	605	10.8	169	100

An additional issue related to population figures is the level of growth factored into emission estimates for the future. The NONROAD model incorporates application-specific growth figures based on projections from Power Systems Research. The model projects growth rates separately for the different fuels for each application. Table 6.2.2-2 presents the population estimates of Large SI engines (rounded to the nearest 1,000 units) by fuel type for selected years.

Table 6.2.2-2
Projected Large SI Population by Year

Category	2000	2005	2010	2020	2030
Gasoline LSI	225,000	234,000	244,000	269,000	298,000
LPG LSI	653,000	789,000	927,000	1,195,000	1,440,000
CNG LSI	89,000	99,000	110,000	134,000	158,000
Total LSI	967,000	1,122,000	1,281,000	1,598,000	1,896,000

Southwest Research Institute recently compiled a listing of test data from past and current testing projects.[8] These tests were all conducted on new or nearly new engines and are used in the NONROAD model as zero-mile levels (ZML). Table 6.2.2-3 summarizes this test data. All engines were operated on the steady-state ISO C2 duty cycle, except for two engines that were tested on the steady-state D2 cycle. The results from the different duty cycles were comparable. Lacking adequate test data for engines fueled by natural gas, we model those engines to have the same emission levels as those fueled by liquefied petroleum gas (LPG), based on the similarity between engines using the two fuels (in the case of hydrocarbon emissions, the equivalence is based on non-methane hydrocarbons).

Emission levels often change as an engine ages. In most cases, emission levels increase with time, especially for engines equipped with technologies for controlling emissions. We developed deterioration factors for uncontrolled Large SI engines based on measurements with comparable highway engines.[9] Table 6.2.2-3 also shows the deterioration factors that apply at the median lifetime estimated for each type of equipment. For example, a deterioration factor of 1.26 for hydrocarbons multiplied by the emission factor of 6.2 g/hp-hr for new gasoline engines indicates that modeled emission levels increase to 7.8 g/hp-hr when the engine reaches its median lifetime. The deterioration factors are linear multipliers, so the modeled deterioration at different points can be calculated by simple interpolation.

Emissions during transient operation can be significantly higher than during steady-state operation. Based on emission measurements from highway engines comparable to uncontrolled Large SI engines, we have measured transient emission levels that are 30 percent higher for HC and 45 percent higher for CO relative to steady-state measurements.[10] The NONROAD model therefore multiplies steady-state emission factors by a transient adjustment factor (TAF) of 1.3 for HC and 1.45 for CO to estimate emission levels during normal, transient operation. Test data do not support adjusting NOx emission levels for transient operation and so a TAF of 1.0 is used for NOx emissions. Also, the model applies no transient adjustment factor for generators, pumps, or compressors, since engines in these applications are less likely to experience transient operation.

Table 6.2.2-3
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Pre-Control Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	6.2	1.26	1.3	203.4	1.35	1.45	7.1	1.03	1.0
LPG	1.7	1.26	1.3	28.2	1.35	1.45	12.0	1.03	1.0
CNG	24.6	1.26	1.3	28.2	1.35	1.45	12.0	1.03	1.0

As manufacturers comply with the proposed Phase 1 emission standards for Large SI engines, we expect the emission factors, deterioration factors and transient adjustment factors will be affected. To estimate the Phase 1 deterioration factors, we relied upon deterioration information for current Class IIb heavy-duty gasoline engines developed for the MOBILE6 emission model. Class IIb engines are the smallest heavy-duty engines and are comparable in size to many Large SI engines. They also employ catalyst/fuel system technology similar to the technologies we expect to be used on Large SI engines. To estimate the Phase 1 emission factors at zero miles, we back-calculated the emission levels based on the proposed standards and the estimated deterioration factors, assuming manufacturers will design to meet a level 10 percent below the proposed standard to account for variability. Given that these engines will employ a catalyst to meet the proposed standards, we believe a 10 percent compliance margin is appropriate. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines would comply in the event of a compliance audit.) Because the proposed standards include an HC+NOx standard, we assumed the HC/NOx split would stay the same as pre-control engines (at the end of the regulated useful life). Table 6.2.2-4 presents the zero-mile levels, deterioration factors used in the analysis of today's proposed Phase 1 standards for Large SI engines. The Phase 1 standards are proposed to take effect in 2004 for all engines.

The transient adjustment factors for Phase 1 engines were based on testing performed at Southwest Research Institute on engines that are similar to those expected to be certified under the proposed Phase 1 standards. The testing was performed on one gasoline fueled engine and two LPG-fueled engines. A complete description of the testing performed and the results of the testing is summarized in the docket for the rulemaking.[11] Because we did not have any test results for CNG-fueled engines, the same transient adjustment factors for LPG-fueled engines were used.

Table 6.2.2-4
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Phase 1 Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	0.85	1.64	1.7	24.5	1.36	1.7	1.1	1.15	1.4
LPG	0.25	1.64	2.9	24.5	1.36	1.45	2.1	1.15	1.5
CNG	3.7	1.64	2.9	24.5	1.36	1.45	2.1	1.15	1.5

In a similar manner, as manufacturers comply with the proposed Phase 2 emission standards for Large SI engines, we expect the emission factors, deterioration factors and transient adjustment factors will be affected. To estimate the Phase 2 deterioration factors, we relied upon the same information noted above for Phase 1 engines. The technologies used to comply with the proposed Phase 2 standards are expected to be further refinements of the technologies we expect to be used on Phase 1 Large SI engines. For that reason, we are applying the Phase 1 deterioration factors to the Phase 2 engines. To estimate the Phase 2 emission factors at zero miles, we back-calculated the emission levels based on the proposed standards and the estimated deterioration factors, assuming manufacturers will design to meet a level 10 percent below the proposed standard to account for variability. Given that these engines will employ a catalyst to meet the proposed standards, we believe a 10 percent compliance margin is appropriate. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines would comply in the event of a compliance audit.) Again, because the proposed standards include an HC+NOx standard, we assumed the HC/NOx split would stay the same as pre-control engines (at the end of the regulated useful life). Table 6.2.2-5 present the zero-mile levels, deterioration factors used in the analysis of today's proposed Phase 2 standards for Large SI engines. The Phase 2 standards are proposed to take effect in 2004 for all engines.

Under the proposed Phase 2 program for Large SI engines, the test procedure will be switched from a steady-state test to a transient test. Therefore, the in-use emission performance of Phase 2 engines should be similar to the emissions performance over the test cycle. For this reason, the transient adjustment factors for Phase 2 engines is set at 1.0 for all pollutants.

Table 6.2.2-5
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Phase 2 Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	0.3	1.64	1.0	13.2	1.36	1.0	0.4	1.15	1.0
LPG	3.1	1.64	1.0	1.7	1.36	1.0	1.7	1.15	1.0
CNG	0.2	1.64	1.0	1.7	1.36	1.0	1.8	1.15	1.0

6.2.2.1.2 Exhaust Emission Reductions Due to the Proposed Standards

Tables 6.2.2-6 through 6.2.2-8 present the projected HC, CO, and NOx exhaust emissions inventories respectively, assuming engines remain uncontrolled and assuming we adopt the proposed Phase 1 and Phase 2 standards. The tables also contain estimated emission reductions for each of the pollutants. We anticipate that the proposed standards will result in a 87% reduction in exhaust HC, 84% reduction in NOx, and a 92% reduction in CO.

Table 6.2.2-6
Projected HC Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	177,000	177,000	0	0
2005	193,000	149,000	44,000	23
2010	212,000	77,000	135,000	64
2020	252,000	32,000	220,000	87
2030	291,000	32,000	259,000	89

Table 6.2.2-7
Projected CO Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	2,294,000	2,294,000	0	0
2005	2,454,000	2,155,000	299,000	12
2010	2,615,000	1,152,000	1,463,000	56
2020	2,991,000	231,000	2,760,000	92
2030	3,364,000	168,000	3,196,000	95

Table 6.2.2-8
Projected NOx Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	306,000	306,000	0	0
2005	351,000	282,000	69,000	20
2010	397,000	152,000	245,000	62
2020	486,000	77,000	409,000	84
2030	565,000	83,000	483,000	85

6.2.2.2 Evaporative and Crankcase Emission Control from Large SI Equipment

We projected the annual tons of hydrocarbons evaporated into the atmosphere from Large SI gasoline engines using the methodology discussed above in Section 6.1.2. These evaporative emissions include diurnal and refueling emissions. Although the proposed standards do not specifically require the control of refueling emissions, we have included them in the modeling for completeness. We have also calculated estimates of hot-soak and running losses for Large SI gasoline engines using separate information on those emissions. Finally, we present crankcase emissions for all Large SI engines based on the NONROAD model. This section describes inputs to the calculations that are specific to Large SI engines and presents our baseline and controlled national inventory projections for evaporative and crankcase emissions.

6.2.2.2.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the evaporative emission calculations for Large SI engines. These inputs are fuel tank sizes, population, and distribution throughout the nation. The draft NONROAD model includes current and projected engine populations for each state and we used this distribution as the national fuel tank distribution. Table 6.2.2-9 presents the population of Large SI gasoline engines for 1998.

Table 6.2.2-9
1998 Population of Large SI Engines by Region

Region	*Total*
Northeast	106,000
Southeast	46,600
Southwest	27,600
Midwest	42,500
West	34,700
Northwest	11,200
Total	269,000

The draft NONROAD model breaks this engine distribution further into ranges of engine sizes. For each of these power ranges we apply a fuel tank size for our evaporative emission calculations based on the fuel tank sizes used in the NONROAD model.

Table 6.2.2-10 presents the baseline diurnal emission factors for the certification test conditions and a typical summer day with low vapor pressure fuel and a half-full tank.

Table 6.2.2-10
Diurnal Emission Factors for Test Conditions and Typical Summer Day

Evaporative Control	*72-96 °F, 9 RVP* Fuel, 40% fill*	*60-84 °F, 8 RVP* Fuel, 50% fill*
baseline	2.3 g/gallon/day	0.84 g/gallon/day

* Reid Vapor Pressure

We used the draft NONROAD model to determine the amount of fuel consumed by Large SI gasoline engines. As detailed earlier in Table 6.2.2-1, the NONROAD model has annual usage rates for all Large SI applications. Table 6.2.2-11 presents the fuel consumption estimates we used in our modeling. For 1998, the draft NONROAD model estimated that Large SI gasoline engines consumed about 300 million gallons of gasoline.

Table 6.2.2-11
Fuel Consumption Estimates used in Refueling Calculations for Large SI Gasoline Engines

Technology	*BSFC, lb/hp-hr*
Pre-control	0.605
Tier 1/Tier 2	0.484

To estimate inventories of hot-soak and running loss emissions from Large SI gasoline engines, we applied a factor to the diurnal emissions inventory estimates based on evaporative emission inventories prepared for the South Coast Air Quality Management District.[12] The hot soak inventory was estimated to be 3.9 times as high as the diurnal inventory, and the running loss inventory was estimated to be two-thirds of the diurnal inventory. Finally, crankcase emissions (from all Large SI engines) were generated using the draft NONROAD model.

Table 6.2.2-12 contains the baseline evaporative emission and crankcase emission inventories for Large SI engines.

Table 6.2.2-12
Baseline Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	*Diurnal*	*Refueling*	*Hot-Soak*	*Running Loss*	*Crankcase*
2000	1,660	1,250	6,530	1,100	58,280
2005	1,730	1,300	6,790	1,150	63,620
2010	1,800	1,350	7,040	1,190	69,690
2020	1,920	1,450	7,560	1,280	82,760
2030	2,060	1,550	8,070	1,360	95,870

6.2.2.2.2 Evaporative and Crankcase Emission Reductions Due to the Proposed Requirements

We anticipate that the proposed evaporative emission requirements for Large SI engines will result in approximately a 50% reduction in diurnal and running loss emissions, and a 90% reduction in hot soak emissions. The proposed evaporative emission requirements are scheduled to take effect in 2008 with the Tier 2 requirements. In addition, because the fuel consumption of Large SI engines will be reduced by 20%, the refueling emissions will be reduced proportionally as well. The refueling benefits will be realized beginning in 2004 as the Tier 1 standards take effect. Finally, the proposed standards also require that engines have a closed crankcase. We expect the crankcase emissions will be routed to the engine and combusted, nearly eliminating crankcase emissions. For modeling purposes, we have assumed that the crankcase emissions are reduced by 90%. The proposed crankcase requirements are schedule to take effect in 2004 with the Tier 1 requirements.

Table 6.2.2-13 present the evaporative emission inventories and crankcase emissions inventories for Large SI engines based on the reductions in emissions noted above. The reductions are achieved over time as the fleet turns over to Phase 1 or Phase 2 engines. (The control inventories were projected using a separate spreadsheet analysis. A copy of spreadsheet calculating the control inventories has been placed in the docket for this rulemaking.[13]) Table 6.2.2-14 presents the corresponding reductions in evaporative and crankcase emissions for Large SI engines due to the proposed requirements.

Table 6.2.2-13
Control Case Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	*Diurnal*	*Refueling*	*Hot-Soak*	*Running Loss*	*Crankcase*
2000	1,660	1,250	6,530	1,100	58,280
2005	1,730	1,230	6,790	1,150	48,370
2010	1,370	1,160	4,040	910	27,010
2020	1,070	1,180	1,490	710	13,780
2030	1,060	1,240	1,020	700	9,580

Table 6.2.2-14
Reductions in Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	*Diurnal*	*Refueling*	*Hot-Soak*	*Running Loss*	*Crankcase*
2000	0	0	0	0	0
2005	0	70	0	0	15,240
2010	420	180	3,000	280	42,680
2020	860	270	6,070	570	68,970
2030	1,000	310	7,050	660	86,240

6.2.2.3 Per Equipment Emissions from Large SI Equipment

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or typical Large SI piece of equipment. The emission estimates were developed to estimate the cost per ton of the proposed standards as presented in Chapter 7. The estimates are made for an average piece of Large SI equipment for each of the three fuel groupings (gasoline, LPG, and CNG). Although the emissions vary from one nonroad application to another, we are presenting the average numbers for the purpose of determining the emission reductions associated with the proposed standards from a typical piece of Large SI equipment over its lifetime.

In order to estimate the emission from a piece of Large SI equipment, information on the emission level of the engine, the power of the engine, the load factor of the engine, the annual hours of use of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical piece of Large SI equipment were presented in Table

6.2.2-3 through Table 6.2.2-5. A brand new piece of equipment emits at the zero-mile level presented in the tables. As the equipment ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life of that equipment type. The deterioration factors presented in Table 6.2.2-3 through Table 6.2.2-5 when applied to the zero-mile levels presented in the same tables, represent the emission level of the engine at the end of its median life. The emissions at any point in time in between can be determined through interpolation. (For this analysis, the HC emissions from CNG engines is calculated on an NMHC+NOx basis, with NMHC emissions estimated to be 4.08% of THC emissions.)

To estimate the average power for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the average horsepower information presented in Table 6.2.2-1. To simplify the calculations, we used the most common applications within each category that represent 80% or more of the fuel grouping population. For gasoline engines, the top ten applications with the highest populations were used. For LPG and CNG, the top four applications with the highest populations were used. Table 6.2.2-15 lists the applications used in the analysis.

Table 6.2.2-15
Large SI Applications Used in Per Equipment Analysis

Gasoline	LPG	CNG
Commercial Turf Equipment Balers Forklifts Aerial Lifts Pumps Swathers Leafblowers/Vacuums Sprayers Welders Air Compressors	Forklifts Generator Sets Aerial Lifts Pumps	Forklifts Generator Sets Other Oil Field Equipment Irrigation Sets

Based on the applications noted above for each fuel, we calculated the population-weighted average horsepower for Large SI equipment to be 51.6 hp for gasoline equipment, 65.7 hp for LPG equipment, and 64.6 hp for CNG equipment.

To estimate the average load factor for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the load factors as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80% or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average load factor for Large SI equipment to be 0.58 for gasoline equipment, 0.39 for LPG equipment, and 0.49 for CNG equipment.

To estimate the average annual hours of use for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the hours per year levels as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80% or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average annual hours of use for Large SI equipment to be 536 hours for gasoline equipment, 1365 hours for LPG equipment, and 1161 hours for CNG equipment.

Finally, to estimate the average lifetime for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the average operating life information as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80% or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average lifetime for Large SI equipment to be 12.3 years for gasoline equipment, 12 years for LPG equipment, and 13 years for CNG equipment.

Using the information described above and the equation used for calculating emissions from nonroad equipment (see Equation 6-1), we calculated the lifetime HC+NOx emissions from typical Large SI equipment for both pre-control engines and engines meeting the proposed Phase 1 and Phase 2 standards. Table 6.2.2-16 presents the lifetime HC+NOx emissions for Large SI equipment on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.2-17 presents the corresponding lifetime HC+NOx emission reductions for the proposed Phase 1 and Phase 2 standards.

Table 6.2.2-16
Lifetime HC+NOx Emissions from Typical Large SI Equipment (tons)*

Control Level	Gasoline		LPG		CNG	
	Un-discounted	Discounted	Un-discounted	Discounted	Un-discounted	Discounted
Pre-control	3.51	2.44	6.80	4.79	7.06	4.85
Phase 1	0.75	0.51	1.86	1.30	1.83	1.24
Phase 2	0.17	0.12	0.97	0.68	1.07	0.73

* For CNG engines only, the emissions are calculated on the basis of NMHC+NOx.

Table 6.2.2-17
Lifetime HC+NOx Emission Reductions from Typical Large SI Equipment (tons)*

Control Increment	Gasoline		LPG		CNG	
	Un-discounted	Discounted	Un-discounted	Discounted	Un-discounted	Discounted
Pre-control to Phase 1	2.76	1.93	4.94	3.69	5.23	3.61
Phase 1 to Phase 2	0.58	0.39	0.89	0.62	0.76	0.51

* For CNG engines only, the reductions are calculated on the basis of NMHC+NOx.

6.2.3 Snowmobiles

We projected the annual tons of exhaust HC, and CO from snowmobiles using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to snowmobiles then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.3.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for snowmobile exhaust emissions. These inputs are load factor, annual use, average operating life, and population. Based on data developed for our Final Finding for recreational equipment and Large SI equipment, we use a load factor of 34 percent, an annual usage factor of 57 hours and an average operating life of 9 years for snowmobiles.[14] The draft NONROAD model includes current and projected engine populations. Table 6.2.3-1 presents these population estimates (rounded to the nearest 1,000 units) for selected years.

Table 6.2.3-1
Projected Snowmobile Populations by Year

Year	*2000*	*2005*	*2010*	*2020*	*2030*
population	1,571,000	1,619,000	1,677,000	1,803,000	1,931,000

The baseline emission factors and deterioration factors (for pre-control engines) were developed for the Final Finding as noted above. For the control emission factors (i.e., engines complying with the Phase 1 or Phase 2 standards), we assumed that the manufacturers would design their engines to meet the proposed standards at regulatory useful life with a small compliance margin. (Because we are not proposing a NOx standard for snowmobiles, we have assumed that NOx levels will remain at the pre-control levels for both Phase 1 and Phase 2 snowmobile engines.) For both set of proposed standards for snowmobiles, we assumed a compliance margin of 20 percent to account for variability. (The proposed standards for snowmobiles are not based on the use of catalysts. Engine out emissions tend to have more variability than the emissions coming from an engine equipped with a catalyst. For this reason, we are using a compliance margin of 20 percent. As noted earlier, including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines would comply in the event of a compliance audit.) Because the proposed standards for snowmobiles are expected to be met by mostly improved 2-stroke designs, we assumed that the deterioration rates would stay the same as the deterioration rates for pre-control engines. Table 6.2.3-2 presents the emission factors used in this analysis for new engines and the maximum deterioration factors applied to snowmobiles operated out to their median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 300 hours for snowmobiles. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.)

Table 6.2.3-2
Zero-Mile Level Emission Factors (g/hp-hr) and Deterioration Factors (at Median Lifetime) for Snowmobile Engines

Engine Category	*THC*		*CO*		*NOx*	
	ZML	*Max DF*	*ZML*	*Max DF*	*ZML*	*Max DF*
Baseline/Pre-control	111	1.2	296	1.2	0.9	1.0
Control/Phase 1	75	1.2	205	1.2	0.9	1.0
Control/Phase 2	56	1.2	148	1.2	0.9	1.0

The Phase 1 standards are proposed to take effect in 2006 for all engines. The Phase 2 standards are proposed to take effect in 2010 for all engines.

6.2.3.2 Reductions Due to the Proposed Standards

We anticipate that the proposed standards for snowmobiles will result in a 63 percent reduction in both HC and CO by the year 2020. We do not expect any reduction in NOx emissions from snowmobiles under the proposed program. Tables 6.2.3-3 and 6.2.3.-4 present our projected HC and CO exhaust emission inventories for snowmobiles and the anticipated emission reductions from the proposed Phase 1 and Phase 2 standards. Table 6.2.3-5 presents the projected NOx emission inventories from snowmobiles.

Table 6.2.3-3
Projected HC Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	200,000	200,000	0	0
2005	205,000	205,000	0	0
2010	213,000	155,000	58,000	27
2020	229,000	85,000	144,000	63
2030	245,000	88,000	157,000	64

Table 6.2.3-4
Projected CO Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	531,000	531,000	0	0
2005	547,000	547,000	0	0
2010	567,000	415,000	152,000	27
2020	609,000	227,000	382,000	63
2030	653,000	234,000	419,000	64

Table 6.2.3-5
Projected NOx Inventories for Snowmobiles (short tons)

Calendar Year	Baseline
2000	1,000
2005	1,000
2010	1,000
2020	2,000
2030	2,000

6.2.3.3 Per Equipment Emissions from Snowmobiles

The following section describes the development of the HC and CO emission estimates on a per piece of equipment basis over the average lifetime or a typical snowmobile. The emission estimates were developed to estimate the cost per ton of the proposed standards as presented in Chapter 7.

In order to estimate the emission from a snowmobile, information on the emission level of the engine, the power of the engine, the load factor of the engine, the annual hours of use of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and CO emission levels of a piece of equipment over the lifetime of a typical snowmobile were presented in Table 6.2.3-2. A brand new snowmobile emits at the zero-mile level presented in the table. As the snowmobile ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.3-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the snowmobile at the end of its median life. The emissions at any point in time in between can be determined through interpolation.

To estimate the average power for snowmobiles, we used the population and power distribution information contained in the NONROAD model and determined the population-weighted average horsepower for snowmobiles. The population-weighted horsepower for snowmobiles was calculated to be 48.3 hp.

As described earlier in this section, the load factor for snowmobiles is estimated to be 0.34, the annual usage rate is estimated to be 57 hours per year, and the average lifetime is estimated to be 9 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment (see Equation 6-1), we calculated the lifetime HC and CO emissions from a typical snowmobile for both pre-control engines and engines meeting the proposed Phase 1 and Phase 2 standards. Table 6.2.3-6 presents the lifetime HC and CO emissions for a typical snowmobile on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.3-7 presents the corresponding lifetime HC and CO emission reductions for the proposed Phase 1 and Phase 2 standards.

Table 6.2.3-6
Lifetime HC and CO Emissions from a Typical Snowmobile (tons)

Control Level	HC		CO	
	Undiscounted	Discounted	Undiscounted	Discounted
Pre-control	1.15	0.88	3.05	2.34
Phase 1	0.55	0.43	1.51	1.16
Phase 2	0.41	0.31	1.09	0.84

Table 6.2.3-7
Lifetime HC and CO Emission Reductions from a Typical Snowmobile (tons)

Control Increment	HC		CO	
	Undiscounted	Discounted	Undiscounted	Discounted
Pre-control to Phase 1	0.60	0.45	1.54	1.18
Phase 1 to Phase 2	0.14	0.12	0.42	0.32

6.2.4 All-Terrain Vehicles

6.2.4.1 Exhaust Emissions from All-Terrain Vehicles

We projected the annual tons of exhaust HC, CO, and NOx, from all-terrain vehicles (ATVs) using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to ATVs then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.4.1.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for ATV exhaust emissions. These inputs are annual use, average operating life, and population. Based on data developed for our Final Finding for recreational equipment and Large SI equipment, we use an annual usage factor of 7,000 miles and an average operating life of 13 years for ATVs.[15] (Because the ATV standards are chassis-based standard instead of engine-based, the NONROAD model has been revised to model ATVs on the basis of gram per mile emission factors and annual mileage accumulation rates. Load factor is not needed for such calculations.)

The draft NONROAD model includes current and projected engine populations. Table 6.2.4-1 presents these population estimates (rounded to the nearest 1,000 units) for selected years. The ATV population growth rates used in the NONROAD model have been updated to reflect the expected growth in ATV populations based on historic ATV sales information and sales growth projections supplied by the Motorcycle Industry Council (MIC), an industry trade organization. The growth rates were developed separately for 2-stroke and 4-stroke ATVs. Based on the sales information from MIC, sales of ATVs have been growing substantially throughout the 1990s, averaging 25% growth per year over the last 6 years. MIC estimates that growth in sales will continue for the next few years, although at lower levels of ten percent or less, with no growth in sales projected by 2005. Combining the sales history, growth projections, and information on equipment scrappage, we have estimated that the population of ATVs will grow significantly through 2010, and then grow as much lower levels. (The population of 2-stroke ATVs presented in Table 6.2.4-1 are for baseline population estimates. Under the proposed ATV standards, 2-stroke designs are expected to be phased-out as they are converted to 4-stroke designs.)

Table 6.2.4-1
Projected ATV Populations by Year

Category	*2000*	*2005*	*2010*	*2020*	*2030*
4-stroke ATVs	3,776,000	5,513,000	7,223,000	8,460,000	8,540,000
2-stroke ATVs*	673,000	1,457,000	2,057,000	2,424,000	2,445,000
All ATVs	4,449,000	6,970,000	9,280,000	10,884,000	10,985,000

* - The projected population estimates for 2-stroke ATVs are for baseline calculations only. Under the proposed Phase 1 standards, we expect all 2-stroke engines will be converted to 4-stroke designs.

The baseline emission factors used in the NONROAD model for ATVs have been updated based on recent testing of ATVs and Off-highway motorcycles as presented in Chapter 4 (sections 4.6 and 4.7). The baseline deterioration factors (for pre-control engines) were developed for the Final Finding as noted above. For the control emission factors (i.e., engines complying with the Phase 1 or Phase 2 standards), we assumed that the manufacturers would design their engines to meet the proposed standards at regulatory useful life with a small compliance margin. Because we are proposing a HC+NOx standard for ATVs, we have assumed that the HC/NOx split will remain the same as the pre-control HC/NOx split for Phase 1. For Phase 2 ATVs, we assumed the technologies expected to be used by the manufacturers would result in HC control, and so the Phase 2 NOx emission factor was kept at the Phase 1 level. For the Phase 1 standards for ATVs, we assumed a compliance margin of 20 percent to account for variability. For the Phase 2 standards for ATVs, we assumed a compliance margin of 20 percent to account for variability if a catalyst was not being used, and a compliance margin of 10 percent if a catalyst was being used. (Engine out emissions tend to have more variability than the emissions coming from an engine equipped with a catalyst. For this reason, we are using different compliance margins for catalyst and non-catalyst ATVs. As noted earlier, including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines would comply in the event of a compliance audit.) Because the proposed standards for ATVs are expected to be met by 4-stroke designs, we assumed that the deterioration rates would stay the same as the deterioration rates for pre-control 4-stroke ATVs. Table 6.2.4-2 presents the emission factors used in this analysis for new ATVs and the maximum deterioration factors for ATVs which applies at the median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 18,640 miles (30,000 kilometers) for ATVs. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.) For the Phase 2 standards, we have assumed that half of the ATVs will be engine recalibration and half of the engines will be recalibration plus a catalyst.

Table 6.2.4-2
Zero-Mile Level Emission Factors (g/mi) and Deterioration Factors (at Median Lifetime) for ATVs

Engine Category	*THC*		*CO*		*NOx*	
	ZML	*Max DF*	*ZML*	*Max DF*	*ZML*	*Max DF*
Baseline/Pre-control 2-stroke	55.7	1.2	52.7	1.2	0.15	1.0
Baseline/Pre-control 4-stroke	2.2	1.15	48.3	1.17	0.34	1.0
Control/Phase 1 4-stroke	2.2	1.15	31.1	1.17	0.31	1.0
Control/Phase 2 - 4-stroke plus Engine Recalibration	1.2	1.15	31.1	1.17	0.31	1.0
Control/Phase 2 - 4-stroke plus Engine Recalibration/Catalyst	0.8	1.15	31.1	1.17	0.31	1.0

The Phase 1 standards are proposed to be phased in at 50% in 2007 and 100% in 2008. The Phase 2 standards are proposed to be phased in at 50% in 2010 and 100% in 2011. However, because there are a significant number of small volume manufacturers that produce 2-stroke ATVs, and because we have proposed compliance flexibilities for such manufacturers, we have modeled the phase in of the proposed standards for the current 2-stroke ATVs based on the schedule contained in Table 6.2.4-3.

Table 6.2.4-3
Assumed Phase-In Schedule for Current 2-Stroke ATVs Used in the Modeling Runs

Model Year	Pre-control 2-stroke	Phase 1 4-stroke	Phase 2 4-stroke plus Recalibration	Phase 2 4-stroke plus Recalibration and Catalyst
2005	100%	0%	0%	0%
2006	65%	35%	0%	0%
2007	30%	70%	0%	0%
2008	15%	85%	0%	0%
2009	0%	65%	17.5%	17.5%
2010	0%	30%	35%	35%
2011	0%	15%	42.5%	42.5%
2012	0%	0%	50%	50%

6.2.4.1.2 Reductions Due to the Proposed Standards

We anticipate that the proposed standards for ATVs will result in a 84% reduction in HC and a 34% reduction in CO by the year 2020. As manufacturers convert their engines from 2-stroke to 4-stroke design, we expect there could be a minimal increase in NOx. (Because the amount of increase in the NOx inventory is so small, it is within the roundoff presented in the table below. Therefore, only the baseline NOx inventory is shown.) Tables 6.2.4-4 through 6.2.4.-6 present our projected HC, CO, and NOx, exhaust emission inventories for ATVs and the anticipated emission reductions from the proposed Phase 1 and Phase 2 standards.

Table 6.2.4-4
Projected HC Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	381,000	381,000	0	0
2005	771,000	771,000	0	0
2010	1,098,000	756,000	342,000	31
2020	1,301,000	205,000	1,096,000	84
2030	1,317,000	96,000	1,221,000	93

Table 6.2.4-5
Projected CO Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	1,860,000	1,860,000	0	0
2005	2,903,000	2,903,000	0	0
2010	3,901,000	3,380,000	521,000	13
2020	4,589,000	3,041,000	1,548,000	34
2030	4,641,000	2,939,000	1,702,000	37

Table 6.2.4-6
Projected NOx Inventories for ATVs (short tons)

Calendar Year	Baseline
2000	11,000
2005	16,000
2010	21,000
2020	25,000
2030	25,000

6.2.4.2 Evaporative Emissions from All-Terrain Vehicles

We projected the annual tons of hydrocarbons evaporated into the atmosphere from ATVs using the methodology discussed above in Section 6.1.2. These evaporative emissions include diurnal and refueling emissions. Although the proposed standards do not specifically require the control of refueling emissions, we have included them in the modeling for completeness. This section describes inputs to the calculations that are specific to ATVs and presents our baseline national inventory projections for evaporative emissions from ATVs.

6.2.4.2.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations of evaporative emissions from ATVs. These inputs are fuel tank sizes, population, and distribution throughout the nation. The draft NONROAD model includes current and projected engine populations for each state and we used this distribution as the national fuel tank distribution. Table 6.2.4-7 presents the population of ATVs for 1998.

Table 6.2.4-7
1998 Population of ATVs by Region

Region	*Total*
Northeast	1,420,000
Southeast	1,010,000
Southwest	363,000
Midwest	457,000
West	423,000
Northwest	249,000
Total	3,930,000

The draft NONROAD model breaks this engine distribution further into ranges of engine sizes. For each of these power ranges we apply a fuel tank size for our evaporative emission calculations based on the fuel tank sizes used in the NONROAD model.

Table 6.2.4-8 presents the baseline diurnal emission factors for the certification test conditions and a typical summer day with low vapor pressure fuel and a half-full tank.

Table 6.2.4-8
Diurnal Emission Factors for Test Conditions and Typical Summer Day

Evaporative Control	*72-96 °F, 9 RVP* Fuel, 40% fill*	*60-84 °F, 8 RVP* Fuel, 50% fill*
baseline	2.3 g/gallon/day	0.84 g/gallon/day

* Reid Vapor Pressure

We used the draft NONROAD model to determine the amount of fuel consumed by ATVs. As detailed earlier in this section, the NONROAD model has an annual usage rate for ATVs of 7,000 miles/year. Table 6.2.4-9 presents the fuel consumption estimates we used in our modeling. For 1998, the draft NONROAD model estimated that ATVs consumed about 1.4 billion gallons of gasoline.

Table 6.2.4-9
Fuel Consumption Estimates used in Refueling Calculations for ATVs

Technology	*BSFC, lb/mi*
Pre-control 2-stroke	0.197
Pre-control 4-stroke	0.332

Table 6.2.4-10 contains the diurnal and refueling emission inventories for ATVs.

Table 6.2.4-10
Projected Diurnal and Refueling Emissions from ATVs [short tons]

Calendar Year	*Diurnal*	*Refueling*
2000	2,910	6,100
2005	4,690	9,280
2010	6,280	12,200
2020	7,270	13,800
2030	7,440	14,000

6.2.4.3 Per Equipment Emissions from All-Terrain Vehicles

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or a typical ATV. The emission estimates were developed to estimate the cost per ton of the proposed standards as presented in Chapter 7.

In order to estimate the emissions from an ATV, information on the emission level of the vehicle, the annual usage rate of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical ATV were presented in Table 6.2.4-2. A brand new ATV emits at the zero-mile level presented in the table. As the ATV ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.4-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the ATV at the end of its median life. The emissions at any point in time in between can be determined through interpolation. (The emissions for Phase 2 ATVs are based on a 50/50 weighting of the “engine recalibration” and the “engine recalibration plus catalyst” technologies presented in Table 6.2.4-2.)

As described earlier in this section, the annual usage rate for an ATV is estimated to be 7,000 miles per year and the average lifetime is estimated to be 13 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment modified to remove the power and load variables (see Equation 6-1), we calculated the lifetime HC+NOx emissions from a typical ATV for both pre-control engines (shown separately for 2-stroke and 4-stroke engines and a composite weighted value) and engines meeting the proposed Phase 1 and Phase 2 standards. Table 6.2.4-10 presents the lifetime HC+NOx emissions for a typical ATV on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.4-11 presents the corresponding lifetime HC+NOx emission reductions for the proposed Phase 1 and Phase 2 standards.

Table 6.2.4-10
Lifetime HC+NOx Emissions from a Typical ATV (tons)

Control Level	HC+NOx	
	Undiscounted	Discounted
Pre-control (2-stroke)	6.16	4.19
Pre-control (4-stroke)	0.28	0.19
Pre-control (Composite)	1.58	1.07
Phase 1	0.28	0.19
Phase 2	0.14	0.10

Table 6.2.4-11
Lifetime HC+NOx Emission Reductions from a Typical ATV (tons)

Control Increment	HC+NOx	
	Undiscounted	Discounted
Pre-control (Composite) to Phase 1	1.30	0.88
Phase 1 to Phase 2	0.14	0.09

6.2.5 Off-highway Motorcycles

6.2.5.1 Exhaust Emissions from Off-highway Motorcycles

We projected the annual tons of exhaust HC, CO, and NOx, from off-highway motorcycles using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to off-highway motorcycles then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.5.1.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for off-highway motorcycles exhaust emissions. These inputs are annual use, average operating life, and population. Based on data developed for our Final Finding for recreational equipment and Large SI equipment, we use an annual usage factor of 2,400 miles and an average operating life of 9 years for off-highway motorcycles.[16] (Because the off-highway motorcycle standards are chassis-based standard instead of engine-based, the NONROAD model has been revised to model off-highway motorcycles on the basis of gram per mile emission factors and annual mileage accumulation rates. Load factor is not needed for such calculations.)

The draft NONROAD model includes current and projected engine populations. Table 6.2.5-1 presents these population estimates (rounded to the nearest 1,000 units) for selected years. (The population of 2-stroke off-highway motorcycles presented in Table 6.2.5-1 are for baseline population estimates. Under the proposed off-highway motorcycle standards, non-competition 2-stroke designs are expected to be phased-out as they are converted to 4-stroke designs. Competition models will remain 2-stroke designs.)

Table 6.2.5-1
Projected Off-Highway Motorcycle Populations by Year

Category	*2000*	*2005*	*2010*	*2020*	*2030*
4-stroke Off-highway Motorcycles	397,000	410,000	425,000	457,000	489,000
2-stroke Off-highway Motorcycles*	805,000	832,000	862,000	928,000	993,000
All Off-highway Motorcycles	1,202,000	1,242,000	1,287,000	1,385,000	1,482,000

* - The projected population estimates for 2-stroke off-highway motorcycles are for baseline calculations only. Under the proposed standards, we expect all non-competition 2-strokes will be converted to 4-stroke designs. All 2-stroke competition models are assumed to remain 2-strokes.

The baseline emission factors used in the NONROAD model for off-highway motorcycles have been updated based on recent testing of off-highway motorcycles and off-highway motorcycles as presented in Chapter 4 (sections 4.6 and 4.7). The baseline deterioration factors (for pre-control engines) were developed for the Final Finding as noted above. For the control emission factors (i.e., Phase 1 off-highway motorcycles), we assumed that the manufacturers would design their engines to meet the proposed standards at regulatory useful life with a small compliance margin. Because we are proposing a HC+NOx standard for off-highway motorcycles, we have assumed that the Phase 1 HC/NOx split will remain the same as the pre-control HC/NOx split. For the Phase 1 standards for off-highway motorcycles, we assumed a compliance margin of 20 percent to account for variability. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines would comply in the event of a compliance audit.) Because the proposed standards for off-highway motorcycles are expected to be met by 4-stroke designs, we assumed that the deterioration rates would stay the same as the deterioration rates for pre-control 4-stroke off-highway motorcycles. Table 6.2.5-2 presents the emission factors used in this analysis for new off-highway motorcycles and the maximum deterioration factors applied to off-highway motorcycles operated out to their median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 6,210 miles (10,000 kilometers) for off-highway motorcycles. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.)

Table 6.2.5-2
Zero-Mile Level Emission Factors (g/mi) and Deterioration Factors (at Median Lifetime) for Off-Highway Motorcycles

Engine Category	*THC*		*CO*		*NOx*	
	ZML	*Max DF*	*ZML*	*Max DF*	*ZML*	*Max DF*
Baseline/Pre-control 2-stroke*	55.7	1.2	52.7	1.2	0.15	1.0
Baseline/Pre-control 4-stroke	2.2	1.15	48.3	1.17	0.34	1.0
Control/Phase 1 4-stroke	2.2	1.15	30.7	1.17	0.31	1.0

* - Competition models are assumed to remain at pre-control levels under the proposed program for off-highway motorcycles.

The Phase 1 standards are proposed to be phased in at 50% in 2007 and 100% in 2008. However, because there are a significant number of small volume manufacturers that produce off-highway motorcycles (who can take advantage of proposed compliance flexibilities), and because competition off-highway motorcycles are exempt from the proposed standards, we have modeled the phase in of the proposed standards for off-highway motorcycles based on the schedule contained in Table 6.2.5-3.

Table 6.2.5-3
Assumed Phase-In Schedule for Current Off-Highway Motorcycles Used in the Modeling Runs

Model Year	Current 4-stroke Off-highway Motorcycles		Current 2-stroke Off-highway Motorcycles	
	Pre-control	Phase 1	Pre-control	Phase 1
2005	100%	0%	100%	0%
2006	56%	44%	76%	24%
2007	12%	88%	53%	47%

Model Year	Current 4-stroke Off-highway Motorcycles		Current 2-stroke Off-highway Motorcycles	
	Pre-control	Phase 1	Pre-control	Phase 1
2008	6%	94%	49%	51%
2009+	0%	100%	46%	54%

6.2.5.1.2 Reductions Due to the Proposed Standards

We anticipate that the proposed standards for off-highway motorcycles will result in a 22% reduction in HC and a 26% reduction in CO by the year 2020. As manufacturers convert their engines from 2-stroke to 4-stroke design, we project there could be a small increase in NOx inventories. (Because the amount of increase in the NOx inventory is so small, it is within the roundoff presented in the table below. Therefore, only the baseline NOx inventory is shown.) Tables 6.2.5-4 through 6.2.5.-6 present our projected HC, CO, and NOx, exhaust emission inventories for off-highway motorcycles and the anticipated emission reductions from the proposed Phase 1 standards. (The emission inventories presented below for off-highway motorcycles include the competition motorcycles that would be exempt from the proposed standards.)

Table 6.2.5-4
Projected HC Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	134,000	134,000	0	0
2005	138,000	138,000	0	0
2010	143,000	112,000	31,000	22
2020	154,000	77,000	77,000	50
2030	165,000	81,000	84,000	51

Table 6.2.5-5
Projected CO Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	181,000	181,000	0	0
2005	187,000	187,000	0	0
2010	194,000	172,000	22,000	11
2020	208,000	154,000	54,000	26
2030	223,000	164,000	59,000	27

Table 6.2.5-6
Projected NOx Inventories for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline
2000	1,000
2005	1,000
2010	1,000
2020	1,000
2030	1,000

6.2.5.2 Evaporative Emissions from Off-highway Motorcycles

We projected the annual tons of hydrocarbons evaporated into the atmosphere from off-highway motorcycles using the methodology discussed above in Section 6.1.2. These evaporative emissions include diurnal and refueling emissions. Although the proposed standards do not specifically require the control of refueling emissions, we have included them in the modeling for completeness. This section describes inputs to the calculations that are specific to off-highway motorcycles and presents our baseline national inventory projections for evaporative emissions from off-highway motorcycles.

6.2.5.2.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations of evaporative emissions from off-highway motorcycles. These inputs are fuel tank sizes, population, and distribution throughout the nation. The draft NONROAD model includes current and projected engine populations for each state and we used this distribution as the national fuel tank distribution. Table 6.2.5-7 presents the population of off-highway motorcycles for 1998.

Table 6.2.5-7
1998 Population of Off-Highway Motorcycles by Region

Region	*Total*
Northeast	427,000
Southeast	304,000
Southwest	109,000
Midwest	137,000
West	127,000
Northwest	75,000
Total	1,180,000

The draft NONROAD model breaks this engine distribution further into ranges of engine sizes. For each of these power ranges we apply a fuel tank size for our evaporative emission calculations based on the fuel tank sizes used in the NONROAD model.

Table 6.2.5-8 presents the baseline diurnal emission factors for the certification test conditions and a typical summer day with low vapor pressure fuel and a half-full tank.

Table 6.2.5-8
Diurnal Emission Factors for Test Conditions and Typical Summer Day

Evaporative Control	*72-96 °F, 9 RVP* Fuel, 40% fill*	*60-84 °F, 8 RVP* Fuel, 50% fill*
baseline	2.3 g/gallon/day	0.84 g/gallon/day

* Reid Vapor Pressure

We used the draft NONROAD model to determine the amount of fuel consumed by off-highway motorcycles. As detailed earlier in this section, the NONROAD model has an annual usage rate for off-highway motorcycles of 2,400 miles/year. Table 6.2.5-9 presents the fuel consumption estimates we used in our modeling. For 1998, the draft NONROAD model estimated that off-highway motorcycles consumed about 120 million gallons of gasoline.

Table 6.2.5-9
Fuel Consumption Estimates used in Refueling Calculations for Off-Highway Motorcycles

Technology	*BSFC, lb/mi*
Pre-control 2-stroke	0.291
Pre-control 4-stroke	0.170

Table 6.2.5-10 contains the diurnal and refueling emission inventories for off-highway motorcycles.

Table 6.2.5-10
Projected Diurnal and Refueling Emissions from Off-Highway Motorcycles [short tons]

Calendar Year	*Diurnal*	*Refueling*
2000	800	490
2005	830	510
2010	860	520
2020	920	530
2030	980	560

6.2.5.3 Per Equipment Emissions from Off-highway Motorcycles

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or a typical off-highway motorcycle. The emission estimates were developed to estimate the cost per ton of the proposed standards as presented in Chapter 7.

In order to estimate the emissions from an off-highway motorcycle, information on the emission level of the vehicle, the annual usage rate of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical off-highway motorcycle were presented in Table 6.2.5-2. A brand new off-highway motorcycle emits at the zero-mile level presented in the table. As the off-highway motorcycle ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.5-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the off-highway motorcycle at the end of its median life. The emissions at any point in time in between can be determined through interpolation.

As described earlier in this section, the annual usage rate for an off-highway motorcycle is estimated to be 2,400 miles per year and the average lifetime is estimated to be 9 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment modified to remove the power and load variables (see Equation 6-1), we calculated the lifetime HC+NOx emissions from a typical off-highway motorcycle for both pre-control engines (shown separately for 2-stroke and 4-stroke engines and a composite weighted value) and engines under the proposed Phase 1 standards. (Competition bikes, which are exempt from the proposed standards, are not included in the calculations.) Table 6.2.5-11 presents the lifetime HC+NOx emissions for a typical off-highway motorcycle on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.5-12 presents the corresponding lifetime HC+NOx emission reductions for the proposed Phase 1 standards.

Table 6.2.5-11
Lifetime HC+NOx Emissions from a Typical Off-highway Motorcycle (tons)*

Control Level	HC+NOx	
	Undiscounted	Discounted
Pre-control (2-stroke)	1.47	1.13
Pre-control (4-stroke)	0.07	0.05
Pre-control (Composite)	0.70	0.53
Phase 1	0.07	0.05

* The emission estimates do not include competition off-highway motorcycles that remain at pre-control emission levels.

Table 6.2.5-12
Lifetime HC+NOx Emission Reductions from a Typical Off-highway Motorcycle (tons)*

Control Increment	HC+NOx	
	Undiscounted	Discounted
Pre-control (Composite) to Phase 1	0.63	0.48

* The reduction estimates do not include competition off-highway motorcycles that remain uncontrolled, and therefore do not realize any emission reductions under the proposal.

Chapter 6 References

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13. “Spreadsheet for Predicting Evaporative and Crankcase Emission Inventories from Large SI Engines Under the September 2001 Proposed Rule,” EPA memorandum from Phil Carlson to Docket A-2000-01, September 12, 2001.

14. Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Docket A-2000-01, Document II-B-19.

15. Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Docket A-2000-01, Document II-B-19.

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CHAPTER 7 Cost Per Ton

7.1 Cost Per Ton by Engine Type

7.1.1 Introduction

This chapter presents our estimate of the cost per ton of the various standards contained in this proposal. The analysis relies on the costs estimates presented in Chapter 5 and the estimated lifetime emissions reductions using the information presented in Chapter 6. The chapter also presents a summary of the cost per ton of other recent EPA mobile source rulemakings for comparison purposes. Finally, this chapter presents the estimated costs and emission reductions as incurred over the first twenty years after the proposed standards are implemented.

In calculating net present values that were used in our cost-per-ton estimates, we used a discount rate of 7 percent, consistent with the 7 percent rate reflected in the cost-per-ton analyses for other recent mobile source programs. OMB Circular A-94 requires us to generate benefit and cost estimates reflecting a 7 percent rate. Using the 7 percent rate allows us to make direct comparisons of cost-per-ton estimates with estimates for other, recently adopted, mobile source programs.

However, we anticipate that the primary cost and cost-per-ton estimates for future proposed mobile source programs will reflect a 3 percent rate. The 3 percent rate is in the 2 to 3 percent range recommended by the Science Advisory Board’s Environmental Economics Advisory Committee for use in EPA social benefit-cost analyses, a recommendation incorporated in EPA's new *Guidelines for Preparing Economic Analyses (November 2000).* Therefore, we have also calculated the overall cost-effectiveness of today's rule based on a 3 percent rate to facilitate comparison of the cost-per-ton of this rule with future proposed rules which use the 3 percent rate. The results using both a 3 percent and 7 percent discount rate are provided in this Chapter.

7.1.2 Compression-Ignition Recreational Marine

As described in Chapter 5, several of the anticipated engine technologies will result in improvements in engine performance that go beyond emission control. While the cost estimates described in Chapter 5 do not take into account the observed value of performance improvements, these non-emission benefits should be taken into account in the calculation of cost-effectiveness. We believe that an equal weighting of emission and non-emission benefits is justified for those technologies which clearly have substantial non-emission benefits, namely electronic controls, fuel injection changes, turbocharging, and aftercooling for diesel engines and upgrading to electronic fuel injection for gasoline engines. For some or all of these technologies, a greater value for the non-emission benefits could likely be justified. This has the effect of halving the cost for those technologies in the cost-per-ton calculation. The cost-per-ton values in this chapter are based on this calculation methodology.

Although the proposed rule will also result in PM reductions, we apply the total cost to the ozone forming gases (HC and NOx) presented in Chapter 6 for these calculations. The estimated per vessel costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton as presented in Table 7.1.2.-1 assuming a 7 percent discount rate. Table 7.1.2.-2 presents the cost per tons results assuming a 3 percent discount rate..

Table 7.1.2.-1
Estimated CI Recreational Marine Cost Per Ton of HC + NOx Reduced
(7 percent discount rate)

	Total Cost per Vessel (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vessel Cost ($/ton)
100 kW near-term	$475	0.24	$1,963
100 kW long-term	$197		$814
400 kW near-term	$384	1.13	$339
400 kW long-term	$210		$185
750 kW near-term	$707	2.12	$334
750 kW long-term	$368		$174
Composite near-term	$443	0.76	$560
Composite long-term	$212		$277

Table 7.1.2.-2
Estimated CI Recreational Marine Cost Per Ton of HC + NOx Reduced
(3 percent discount rate)

	Total Cost per Vessel (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vessel Cost ($/ton)
100 kW near-term	$475	0.33	$1,450
100 kW long-term	$197		$600
400 kW near-term	$384	1.73	$222
400 kW long-term	$210		$122
750 kW near-term	$707	3.24	$218
750 kW long-term	$368		$114
Composite near-term	$443	1.15	$387
Composite long-term	$212		$185

7.1.3 Large Industrial SI Equipment

This section provides our estimate of the cost per ton of emissions reduced for large SI engines >19 kW. We have calculated cost per ton on the basis of HC plus NOx for gasoline, LPG and CNG engines. The analysis relies on the costs estimates in presented in Chapter 5 and the estimated net present value of the per vehicle lifetime emissions reductions (tons) presented in Chapter 6.

The estimated per vehicle costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton. In addition, we have estimated cost per ton both with and without estimated fuel/maintenance savings. We have estimated the cost per ton for both the Phase 1 and Phase 2 standards, with the Phase 2 estimates incremental to Phase 1. The results of the analysis are presented in Tables 7.1.3.-1 through 7.1.3-3 for gasoline, LPG and CNG engines assuming a 7 percent discount rate. The cost-per-ton results using a 3 percent discount rate follow in Tables 7.1.3.-4 through 7.1.3.-6.

Table 7.1.3.-1
Estimated Large SI Gasoline Engine >19 kW Cost Per Ton of HC+NOx Reduced
(7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$787	($3,257)	1.9	$409	($1,283)
Phase 1 long-term	$507			$264	($1,428)
Phase 2 near-term	$51	-	0.4	$129	$129
Phase 2 long-term	$20			$51	$51

Table 7.1.3.-2
Estimated Large SI LPG Engine >19 kW Cost Per Ton of HC+NOx Reduced
(7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$546	($4,554)	3.5	$156	($1,147)
Phase 1 long-term	$354			$101	($1,202)
Phase 2 near-term	$38	-	0.6	$61	$61
Phase 2 long-term	$14			$23	$23

Table 7.1.3.-3
Estimated Large SI CNG Engine >19 kW Cost Per Ton of HC+NOx Reduced (7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions* (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$546	($1,648)	3.6	$151	($306)
Phase 1 long-term	$354			$98	($359)
Phase 2 near-term	$38	-	0.5	$74	$74
Phase 2 long-term	$14			$27	$27

* The reductions are calculated on the basis of NMHC+NOx for CNG engines only.

Table 7.1.3.-4
Estimated Large SI Gasoline Engine >19 kW Cost Per Ton of HC+NOx Reduced (3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$787	($3,940)	2.3	$336	($1,346)
Phase 1 long-term	$507			$217	($1,465)
Phase 2 near-term	$51	-	0.5	$105	$105
Phase 2 long-term	$20			$41	$41

Table 7.1.3.-5
Estimated Large SI LPG Engine >19 kW Cost Per Ton of HC+NOx Reduced
(3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$546	($5,489)	4.2	$129	($1,171)
Phase 1 long-term	$354			$84	($1,217)
Phase 2 near-term	$38	-	0.8	$50	$50
Phase 2 long-term	$14			$19	$19

Table 7.1.3.-6
Estimated Large SI CNG Engine >19 kW Cost Per Ton of HC+NOx Reduced
(3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions* (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$546	($2,005)	4.4	$124	($331)
Phase 1 long-term	$354			$80	($374)
Phase 2 near-term	$38	-	0.6	$60	$60
Phase 2 long-term	$14			$22	$22

* The reductions are calculated on the basis of NMHC+NOx for CNG engines only.

7.1.4 Recreational Vehicles

This section provides our estimate of the cost per ton of emissions reduced for recreational vehicles. We have calculated cost per ton on the basis of HC plus NOx for off-road motorcycles and ATVs, and CO for snowmobiles. If reductions in other pollutants were included, the cost per ton estimates would be lower. The analysis relies on the per vehicle costs estimated in Chapter 5.2 and the estimated net present value of the per vehicle lifetime emissions reductions (tons) presented in Chapter 6.

The estimated per vehicle costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton. In addition, we have estimated cost per ton both with and without estimated fuel savings. For ATVs and snowmobiles, we have estimated the cost per ton for both the Phase 1 and Phase 2 standards, with the Phase 2 estimates incremental to Phase 1. The results of the analysis using the 7 percent discount rate are presented in Tables 7.1.4.-1 through Table 7.1.4.-3. The results using the 3 percent discount rate follow in Tables 7.1.4.-4 through 7.1.4.-6.

Table 7.1.4.-1
Estimated Snowmobile Average Cost Per Ton of CO Reduced
(7 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Phase 1 near-term	$55	-	1.18	$50	$50
Phase 1 long-term	$27			$20	$20
Phase 2 near-term	$216	($509)	0.32	$670	($910)
Phase 2 long-term	$125			$390	($1,200)

Table 7.1.4.-2
Estimated ATV Average Cost Per Ton of HC + NOx Reduced
(7 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Phase 1 near-term	$60	($102)	0.88	$70	($50)
Phase 1 long-term	$38			$40	($70)
Phase 2 near-term	$52	-	0.09*	$550	$550
Phase 2 long-term	$28			$300	$300

* HC reductions only. We are not projecting a change in NOx emissions from the Phase 2 standard.

Table 7.1.4.-3
Estimated Off-highway Motorcycle Average Cost Per Ton of HC + NOx Reduced*
(7 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
near-term	$151	($98)	0.48	$310	$110
long-term	$94			$190	($10)

* non-competition models only

Table 7.1.4.-4
Estimated Snowmobile Average Cost Per Ton of CO Reduced
(3 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Phase 1 near-term	$55	-	1.36	$40	$40
Phase 1 long-term	$27			$20	$20
Phase 2 near-term	$216	($621)	0.37	$580	($1,080)
Phase 2 long-term	$125			$330	($1,330)

Table 7.1.4.-5
Estimated ATV Average Cost Per Ton of HC + NOx Reduced
(3 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Phase 1 near-term	$60	($131)	1.08	$60	($70)
Phase 1 long-term	$38			$40	($90)
Phase 2 near-term	$52	-	0.12*	$450	$450
Phase 2 long-term	$28			$240	$240

* HC reductions only. We are not projecting a change in NOx emissions from the Phase 2 standard.

Table 7.1.4.-6
Estimated Off-highway Motorcycle Average Cost Per Ton of HC + NOx Reduced*
(3 percent discount rate)

	Total Cost per Vehicle	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
near-term	$151	($124)	0.56	$270	$50
long-term	$94			$170	($50)

* Non-competition models only

7.2 Cost Per Ton for Other Mobile Source Control Programs

Because the primary purpose of cost-effectiveness is to compare our program to alternative programs, we made a comparison between the cost per ton values presented in this chapter and the cost-effectiveness of other programs. Table 7.2-1 summarizes the cost effectiveness of several recent EPA actions for controlled emissions from mobile sources.

Table 7.2-1
Cost-effectiveness of Previously Implemented
Mobile Source Programs (Costs Adjusted to 1997 Dollars)

Program	*$/ton*
Tier 2 vehicle/gasoline sulfur	1,340 - 2,260
2007 Highway HD diesel	1,458-1,867
2004 Highway HD diesel	212 - 414
Off-highway diesel engine	425 - 675
Tier 1 vehicle	2,054 - 2,792
NLEV	1,930
Marine SI engines	1,171 - 1,846
On-board diagnostics	2,313
Marine CI engines	24 - 176

By comparing the cost per ton values presented in presented earlier in this chapter to those in Table 7.2-1, we can see that the cost effectiveness of the proposed standards for this rulemaking fall within the range of these other programs. It is true that some previous programs have been more cost efficient than the program we are proposing today. However, it should be expected that the next generation of standards will be more expensive than the last, since the least costly means for reducing emissions is generally pursued first.

The primary advantage of making comparisons to previously implemented programs is that their cost-effectiveness values were based on a rigorous analysis and are generally accepted as representative of the efficiency with which those programs reduce emissions. Unfortunately, previously implemented programs can be poor comparisons because they may not be representative of the cost-effectiveness of potential future programs. Therefore, in evaluating the cost-effectiveness of our engine/diesel sulfur program, we also considered whether our proposal is cost-effective in comparison with potential future means of controlling emissions. In the context of the Agency's rulemaking which would have revised the ozone and PM NAAQS[n], the Agency compiled a list of additional known technologies that could be considered in devising new emission reductions strategies.[1] Through this broad review, over 50 technologies were identified that could reduce NOx, VOC, or PM. The cost-effectiveness of these technologies averaged approximately $5,000/ton for VOC, $13,000/ton for NOx, and $40,000/ton for PM. Although a $10,000/ton limit was actually used in the air quality analysis presented in the NAAQS revisions rule, these values clearly indicate that, not only are future emission control strategies likely to be more expensive (less cost-effective) than past strategies, but the cost-effectiveness of our engine/diesel sulfur program falls within the range of potential future strategies.

In summary, given the array of controls that will have to be implemented to make progress toward attaining and maintaining the NAAQS, we believe that the weight of the evidence from alternative means of providing substantial NOx + NMHC emission reductions indicates that our proposed program is cost-effective. This is true from the perspective of other mobile source control programs or from the perspective of other stationary source technologies that might be considered.

7.3 20-Year Cost and Benefit Analysis

The following section presents the year-by-year cost and emission benefits associated with the proposed standards for the 20-year period after implementation of the proposed standards. For the categories where we expect a reduction in fuel consumption due to the proposed standards, the fuel savings are presented separately. The overall cost, incorporating the impact of the fuel savings is also presented.

Table 7.3.-1 presents the year-by-year cost and emission benefits for the proposed compression-ignition (CI) recreational marine requirements. (The numbers presented in Table 7.3.-1 are <u>not</u> discounted.)

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[n] This rulemaking was remanded by the D.C. Circuit Court on May 14, 1999. However, the analyses completed in support of that rulemaking are still relevant, since they were designed to investigate the cost-effectiveness of a wide variety of potential future emission control strategies.

Table 7.3.-1
Cost and Emission Benefits of the Proposed CI Recreational Marine Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	408	0	$2,951,157	$0	$2,951,157
2007	827	0	$3,312,159	$0	$3,312,159
2008	1,245	0	$3,396,992	$0	$3,396,992
2009	1,729	0	$3,646,513	$0	$3,646,513
2010	2,216	0	$3,735,360	$0	$3,735,360
2011	2,710	0	$2,314,047	$0	$2,314,047
2012	3,194	0	$2,367,961	$0	$2,367,961
2013	3,683	0	$2,230,244	$0	$2,230,244
2014	4,171	0	$2,191,180	$0	$2,191,180
2015	4,661	0	$2,238,896	$0	$2,238,896
2016	5,157	0	$2,290,857	$0	$2,290,857
2017	5,639	0	$2,338,809	$0	$2,338,809
2018	6,124	0	$2,386,760	$0	$2,386,760
2019	6,611	0	$2,434,712	$0	$2,434,712
2020	7,093	0	$2,482,664	$0	$2,482,664
2021	7,576	0	$2,530,616	$0	$2,530,616
2022	8,054	0	$2,578,568	$0	$2,578,568
2023	8,547	0	$2,626,520	$0	$2,626,520
2024	9,068	0	$2,674,472	$0	$2,674,472
2025	9,629	0	$2,722,423	$0	$2,722,423

Table 7.3.-2 presents the sum of the costs and emission benefits over the twenty year period after the CI recreational marine requirements are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3.-2
Annualized Cost and Emission Benefits for the Period 2006-2025
due to the Proposed CI Recreational Marine Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	98,342	0	$53.5	$0.0	$53.5
Discounted 20-year Value	43,726	0	$31.4	$0.0	$31.4
Annualized Value	4,127	0	$3.0	$0.0	$3.0

Table 7.3.-3 presents the year-by-year cost and emission benefits for the proposed large spark-ignition (SI) engine requirements. (The numbers presented in Table 7.3.-3 are not discounted.)

Table 7.3.-3
Cost and Emission Benefits of the Proposed Large SI Engine Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2004	73,472	150,685	$87,523,186	$49,094,701	$38,428,485
2005	129,407	298,527	$89,867,557	$96,402,876	($6,535,319)
2006	180,933	446,241	$74,189,576	$143,763,720	($69,574,144)
2007	254,759	753,861	$82,525,699	$189,779,490	($107,253,791)
2008	314,734	1,000,634	$84,571,791	$232,669,584	($148,097,793)
2009	371,693	1,235,609	$71,024,385	$273,576,196	($202,551,811)
2010	426,750	1,462,320	$72,702,127	$313,109,504	($240,407,377)
2011	478,793	1,675,145	$74,379,868	$349,996,101	($275,616,233)
2012	521,239	1,870,456	$71,570,190	$378,383,901	($306,813,711)
2013	554,784	2,052,958	$73,148,944	$398,274,918	($325,125,974)
2014	585,848	2,229,799	$74,727,698	$415,984,138	($341,256,440)
2015	612,293	2,362,438	$76,306,452	$431,606,591	($355,300,139)
2016	633,425	2,485,928	$77,885,207	$445,193,587	($367,308,380)
2017	653,387	2,566,367	$79,463,961	$457,797,866	($378,333,905)
2018	671,650	2,637,314	$81,042,715	$469,420,021	($388,377,306)
2019	688,861	2,702,977	$82,621,469	$480,293,483	($397,672,014)
2020	704,769	2,760,198	$84,200,223	$490,460,595	($406,260,372)
2021	719,823	2,811,641	$85,778,977	$500,194,473	($414,415,496)
2022	734,471	2,858,724	$87,357,732	$509,783,068	($422,425,336)
2023	748,711	2,901,826	$88,936,486	$519,236,885	($430,300,399)

Table 7.3.-4 presents the sum of the costs and emission benefits over the twenty year period after the large SI engine requirements are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3.-4
Annualized Cost and Emission Benefits for the Period 2004-2023 due to the Proposed Large SI Engine Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	10,059,802	37,263,648	$1,599.8	$7,145.0	($5,545.2)
Discounted 20-year Value	4,795,369	17,202,416	$904.3	$3,434.8	($2,530.5)
Annualized Value	452,649	1,623,789	$85.4	$324.2	($239.8)

Table 7.3.-5 presents the year-by-year cost and emission benefits for the proposed snowmobile requirements. (The numbers presented in Table 7.3.-5 are not discounted.)

Table 7.3.-5
Cost and Emission Benefits of the Proposed Snowmobile Requirements

Year	HC Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	10,949	28,488	$8,490,613	$0	$8,490,613
2007	21,937	57,072	$8,549,323	$0	$8,549,323
2008	32,848	85,448	$7,734,547	$0	$7,734,547
2009	44,140	114,808	$7,785,697	$0	$7,785,697
2010	57,886	151,436	$39,496,324	$6,636,300	$32,860,024
2011	71,954	188,906	$37,231,135	$13,258,300	$23,972,835
2012	85,448	224,873	$30,986,329	$19,660,300	$11,326,029
2013	98,859	260,626	$31,281,836	$26,031,500	$5,250,336
2014	111,904	295,402	$26,191,916	$32,094,700	($5,902,784)
2015	119,312	315,519	$25,003,879	$37,988,500	($12,984,621)
2016	126,527	335,157	$25,253,918	$43,918,600	($18,664,682)
2017	132,390	351,235	$25,506,457	$49,436,200	($23,929,743)
2018	137,680	365,808	$25,761,522	$54,772,300	($29,010,778)
2019	141,024	374,871	$26,019,137	$57,184,600	($31,165,463)
2020	143,752	382,265	$26,279,329	$59,141,500	($32,862,171)
2021	145,933	388,154	$26,542,122	$60,773,900	($34,231,778)
2022	147,725	393,054	$26,807,543	$62,147,800	($35,340,257)
2023	149,129	396,874	$27,075,618	$63,261,000	($36,185,382)
2024	150,308	400,077	$27,346,375	$64,179,500	($36,833,125)
2025	151,392	403,005	$27,619,838	$64,902,200	($37,282,362)

Table 7.3.-6 presents the sum of the costs and emission benefits over the twenty year period after the requirements for snowmobiles are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3.-6
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the Proposed Snowmobile Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	2,081,097	5,513,078	$487.0	$715.4	($228.4)
Discounted 20-year Value	979,258	2,588,835	$255.6	$300.0	($44.4)
Annualized Value	92,435	244,368	$24.1	$28.3	($4.2)

Table 7.3.-7 presents the year-by-year cost and emission benefits for the proposed requirements for ATVs. (The numbers presented in Table 7.3.-7 are <u>not</u> discounted.)

Table 7.3.-7
Cost and Emission Benefits of the Proposed ATV Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	29,157	52,512	$27,160,891	$4,292,200	$22,868,691
2007	100,482	165,812	$50,131,272	$14,731,200	$35,400,072
2008	171,247	281,480	$45,689,331	$24,938,100	$20,751,231
2009	255,542	401,518	$63,725,033	$36,446,300	$27,278,733
2010	341,496	520,318	$78,458,613	$47,393,500	$31,065,113
2011	426,374	639,187	$71,127,217	$58,026,100	$13,101,117
2012	515,980	762,621	$67,349,374	$69,170,200	($1,820,826)
2013	612,610	892,416	$60,745,130	$81,152,500	($20,407,370)
2014	701,796	1,013,664	$57,190,382	$91,989,700	($34,799,318)
2015	786,092	1,129,162	$56,810,044	$102,064,600	($45,254,556)
2016	863,212	1,235,362	$56,810,044	$111,098,900	($54,288,856)
2017	934,816	1,334,947	$56,810,044	$119,334,600	($62,524,556)
2018	999,821	1,425,240	$56,810,044	$126,656,200	($69,846,156)
2019	1,054,946	1,499,879	$54,369,424	$132,697,400	($78,327,976)
2020	1,095,016	1,548,389	$51,928,804	$136,876,300	($84,947,496)
2021	1,124,352	1,581,524	$51,928,804	$139,763,800	($87,834,996)
2022	1,148,062	1,608,835	$51,928,804	$142,059,500	($90,130,696)
2023	1,165,443	1,631,560	$51,928,804	$143,763,400	($91,834,596)
2024	1,179,935	1,651,047	$51,928,804	$145,032,800	($93,103,996)
2025	1,191,565	1,666,387	$51,928,804	$146,411,100	($94,482,296)

Table 7.3.-8 presents the sum of the costs and emission benefits over the twenty year period after the requirements for ATVs are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3.-8
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the Proposed ATV Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	14,697,944	21,041,860	$1,114.8	$1,873.9	($759.1)
Discounted 20-year Value	6,640,351	9,603,721	$629.8	$858.0	($228.3)
Annualized Value	626,803	906,525	$59.5	$81.0	($21.5)

Table 7.3.-9 presents the year-by-year cost and emission benefits for the proposed off-highway motocycles requirements. (The numbers presented in Table 7.3.-9 are not discounted.)

Table 7.3.-9
Cost and Emission Benefits of the Proposed Off-Highway Motorcycle Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	3,202	2,250	$8,806,305	$691,900	$8,114,405
2007	9,491	6,704	$17,208,490	$2,036,100	$15,172,390
2008	16,459	11,600	$15,768,334	$3,495,800	$12,272,534
2009	23,879	16,832	$14,297,728	$5,024,800	$9,272,928
2010	31,288	22,063	$13,123,614	$6,519,700	$6,603,914
2011	38,820	27,392	$11,551,224	$8,010,200	$3,541,024
2012	46,025	32,505	$11,289,563	$9,406,100	$1,883,463
2013	53,114	37,549	$11,402,459	$10,753,600	$648,859
2014	60,067	42,510	$11,516,483	$12,050,500	($534,017)
2015	65,156	46,242	$11,631,648	$13,010,800	($1,379,152)
2016	69,060	48,936	$11,747,964	$13,713,700	($1,965,736)
2017	71,707	50,833	$11,865,444	$14,203,200	($2,337,756)
2018	73,763	52,303	$11,984,099	$14,582,700	($2,598,601)
2019	75,530	53,567	$12,103,940	$14,911,600	($2,807,660)
2020	76,986	54,608	$12,224,979	$15,184,400	($2,959,421)
2021	78,115	55,411	$12,347,229	$15,395,600	($3,048,371)
2022	79,014	56,053	$12,470,701	$15,566,100	($3,095,399)
2023	79,721	56,555	$12,595,408	$15,701,400	($3,105,992)
2024	80,289	56,961	$12,721,362	$15,812,500	($3,091,138)
2025	80,802	57,323	$12,848,576	$15,910,400	($3,061,824)

Table 7.3.-10 presents the sum of the costs and emission benefits over the twenty year period after the requirements for off-highway motorcycles are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3.-10
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the Proposed Off-Highway Motorcycle Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	1,112,488	788,197	$249.5	$222.0	$27.5
Discounted 20-year Value	521,170	369,020	$142.9	$104.7	$38.2
Annualized Value	49,195	34,833	$13.5	$9.9	$3.6

Table 7.3.-11 presents the year-by-year cost and emission benefits for all of the proposed requirements, excluding snowmobiles. (The numbers presented in Table 7.3.-11 are not discounted.) Snowmobiles have been excluded from this aggregate analysis because the focus of the proposed snowmobile controls is CO emissions, unlike the other categories where the focus of the proposed controls is HC and/or NOx emissions.

Table 7.3.-11
Cost and Emission Benefits of the Proposed Requirements for All Equipment Categories covered by the Proposal (Excluding Snowmobiles)

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2004	73,472	150,685	$87,523,186	$49,094,701	$38,428,485
2005	129,407	298,527	$89,867,557	$96,402,876	($6,535,319)
2006	213,700	501,003	$113,107,928	$148,747,820	($35,639,892)
2007	365,559	926,377	$153,177,619	$206,546,790	($53,369,171)
2008	503,685	1,293,714	$149,426,447	$261,103,484	($111,677,037
2009	652,843	1,653,959	$152,693,660	$315,047,296	($162,353,636
2010	801,750	2,004,701	$168,019,714	$367,022,704	($199,002,990
2011	946,697	2,341,724	$159,372,356	$416,032,401	($256,660,045
2012	1,086,438	2,665,582	$152,577,088	$456,960,201	($304,383,113
2013	1,224,191	2,982,923	$147,526,776	$490,181,018	($342,654,242
2014	1,351,882	3,285,973	$145,625,743	$520,024,338	($374,398,595
2015	1,468,202	3,537,842	$146,987,040	$546,681,991	($399,694,951
2016	1,570,854	3,770,226	$148,734,072	$570,006,187	($421,272,115
2017	1,665,549	3,952,147	$150,478,257	$591,335,666	($440,857,409
2018	1,751,358	4,114,857	$152,223,617	$610,658,921	($458,435,304
2019	1,825,948	4,256,423	$151,529,544	$627,902,483	($476,372,939
2020	1,883,864	4,363,195	$150,836,670	$642,521,295	($491,684,625
2021	1,929,866	4,448,576	$152,585,626	$655,353,873	($502,768,247
2022	1,969,601	4,523,612	$154,335,804	$667,408,668	($513,072,864
2023	2,002,422	4,589,941	$156,087,217	$678,701,685	($522,614,468
2024	2,032,037	4,650,783	$157,839,878	$689,465,750	($531,625,872
2025	2,058,727	4,706,660	$159,593,797	$700,292,336	($540,698,539

Table 7.3.-12 presents the sum of the costs and emission benefits over the twenty-two year period after all of the requirements (excluding snowmobiles) are proposed to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-two year period (assuming the seven percent discount rate) are also presented. (A twenty-two period is used in this aggregate analysis to cover the first twenty years of each of the proposed standards which begins in 2004 for large SI engines and concludes in 2006 for the other categories of equipment.)

Table 7.3.-12
Annualized Cost and Emission Benefits for the Period 2004-2025
due to the Proposed Requirements for All Equipment (Excluding Snowmobiles)

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 22-year Value	29,579,850	69,744,333	$3,361.5	$11,006.2	($7,644.7)
Discounted 22-year Value	11,941,041	28,460,357	$1,688.7	$4,700.0	($3,011.2)
Annualized Value	1,037,257	2,476,552	$149.4	$410.6	($261.3)

Chapter 7 References

1.“Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Regional Haze Rule,” Appendix B, “Summary of control measures in the PM, regional haze, and ozone partial attainment analyses,” Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 17, 1997.

CHAPTER 8: Initial Regulatory Flexibility Analysis

This section presents our Initial Regulatory Flexibility Analysis (IRFA) which evaluates the impacts of our proposed program on small businesses. Prior to issuing our proposal, we analyzed the potential impacts of our program on small businesses. As a part of this analysis, we convened a Small Business Advocacy Review Panel, as required under the Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA). Through the Panel process, we gathered advice and recommendations from small entity representatives (SERs) who would be affected by our proposed vehicle and fuel standards. The report of the Panel has been placed in the rulemaking record.

8.1 Requirements of the Regulatory Flexibility Act

When proposing and promulgating rules subject to notice and comment under the Clean Air Act, we are generally required under the Regulatory Flexibility Act (RFA) to conduct a regulatory flexibility analysis unless we certify that the requirements of a regulation will not cause a significant impact on a substantial number of small entities. The key elements of the FRFA include:

- the number of affected small entities;
- the projected reporting, record keeping, and other compliance requirements of the proposed rule, including the classes of small entities that would be affected and the type of professional skills necessary for preparation of the report or record;
- other federal rules that may duplicate, overlap, or conflict with the proposed rule; and,
- any significant alternatives to the proposed rule that accomplish the stated objectives of applicable statutes and which minimize significant economic impacts of the proposed rule on small entities.

The RFA was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect them. Although we are not required by the CAA to provide special treatment to small businesses, the RFA requires us to carefully consider the economic impacts that our rules will have on small entities. Specifically, the RFA requires us to determine, to the extent feasible, our rule’s economic impact on small entities, explore regulatory options for reducing any significant economic impact on a substantial number of such entities, and explain our ultimate choice of regulatory approach.

In developing the NPRM, we concluded that the program under consideration for recreational vehicles would likely have a significant impact on a substantial number of small entities.

8.2 Description of Affected Entities

The following table (Table 1) provides an overview of the primary SBA small business categories potentially affected by this regulation. EPA is in the process of developing a more detailed industry characterization of the entities potentially subject to this regulation.

Table 8.2-1
Primary SBA Small Business Categories Potentially Affected by this Proposed Regulation

Industry	NAICS[a] Codes	Defined by SBA as a Small Business If:[b]
Motorcycles and motorcycle parts manufacturers	336991	<500 employees
Snowmobile and ATV manufacturers	336999	<500 employees
Independent Commercial Importers of Vehicles and parts	421110	<100 employees
Nonroad SI engines	333618	<1,000 employees
Internal Combustion Engines	333618	<1000 employees
Boat Building and Repairing	336612	<500 employees

NOTES:
a. North American Industry Classification System
b. According to SBA's regulations (13 CFR 121), businesses with no more than the listed number of employees or dollars in annual receipts are considered "small entities" for purposes of a regulatory flexibility analysis.

8.2.1 Recreational Vehicles (off-highway motorcycles, ATVs, and snowmobiles)

The ATV sector has the broadest assortment of manufacturers. There are seven companies representing over 95 percent of total domestic ATV sales. The remaining 5 percent come from importers who tend to import inexpensive, youth-oriented ATVs from China and other Asian nations. EPA has identified 21 small companies (as defined in Table 4.1, above) that offer off-road motorcycles, ATVs, or both products. Annual unit sales for these companies can range from a few hundred to several thousand units per year.

Based on available industry information, four major manufacturers, Arctic Cat, Bombardier (also known as Ski-Doo), Polaris, and Yamaha, account for over 99 percent of all domestic snowmobile sales. The remaining one percent comes from very small manufacturers who tend to specialize in unique and high performance designs .

We have identified three small manufacturers of snowmobiles and one potential small manufacturer who hopes to produce snowmobiles within the next year. Two of these manufacturers (Crazy Mountain and Fast), plus the potential newcomer (Redline) specialize in high performance versions of standard recreational snowmobile types (i.e., travel and mountain sleds). The other manufacturer (Fast Trax) produces a unique design, which is a scooter-like snowmobile designed to be ridden standing up. Most of these manufacturers build less than 50 units per year.

8.2.2 Marine Vessels

Marine vessels include the boat, engine, and fuel system. Exhaust emission controls including NTE requirements, as addressed in the August 29, 1999 SBREFA Panel Report, would affect the engine manufacturers and may affect boat builders.

8.2.2.1 Small Diesel Engine Marinizers

EPA has determined that there are at least 16 companies that manufacture CI diesel engines for recreational vessels. Nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to three large companies. Six of the 16 identified companies are considered small businesses as defined by SBA SIC code 3519. Based on sales estimates for 2000, these six companies represent approximately 4 percent of recreational marine diesel engine sales. The remaining companies each comprise between two and seven percent of sales for 2000.

8.2.2.2 Small Recreational Boat Builders

EPA has less precise information about recreational boat builders than is available about engine manufacturers. EPA has utilized several sources, including trade associations and Internet sites when identifying entities that build and/or sell recreational boats. EPA has also worked with an independent contractor to assist in the characterization of this segment of the industry. Finally, EPA has obtained a list of nearly 1,700 boat builders known to the U.S. Coast Guard to produce boats using engines for propulsion. More than 90% of the companies identified so far would be considered small businesses as defined by SBA SIC code 3732. EPA continues to develop a more complete picture of this segment of the industry and will provide additional information as it becomes available.

8.2.3 Large Spark Ignition Engines

The Panel is aware of one engine manufacturer of Large SI engines that qualifies as a small business. This company plans to produce engines that meet the standards adopted by CARB in 2004, with the possible exception of one engine family. If EPA adopts long-term standards, this would require manufacturers to do additional calibration and testing work. If EPA adopts new test procedures (including transient operation), there may also be a cost associated with upgrading test facilities.

8.3 Projected Costs of the Proposed Program

The costs associated with the proposed program can be found in Chapter 5 of the Draft Regulatory Support Document. Chapter 5 includes a description of our approach to estimating the cost of complying with emission standards. We start with a general description of the approach to estimating costs, then describe the technology changes we expect and assign costs to them. We also present an analysis of the estimated aggregate cost to society.

8.4 Projected Reporting, Recordkeeping, and Other Compliance Requirements of the Proposed Rule

For any emission control program, EPA must have assurances that the regulated engines will meet the standards. Historically, EPA programs have included provisions placing manufacturers responsible for providing these assurances. The program that EPA is considering for manufacturers subject to this proposal may include testing, reporting, and record keeping requirements. Testing requirements for some manufacturers may include certification (including deterioration testing), and production line testing. Reporting requirements would likely include test data and technical data on the engines including defect reporting. Manufacturers would likely have to keep records of this information.

8.5 Other Related Federal Rules

We are aware of several other current Federal rules that relate to the proposed rule under development. During the Panel's outreach meeting, SERs specifically pointed to Consumer Product Safety Commission (CPSC) regulations covering ATVs, and noted that they may be relevant to crafting an appropriate definition for a competition exclusion in this category. The Panel recommends that EPA continue to consult with the CPSC in developing a proposed and final rule in order to better understand the scope of the Commission's regulations as they may relate to the competition exclusion.

The Panel is also aware of other Federal rules that relate to the categories that EPA would address with the proposed rule, but are not likely to affect policy considerations in the rule development process. For example, there are now EPA noise standards covering off-road motorcycles; however, EPA expects that most emission control devices are likely to reduce, rather than increase, noise, and that therefore the noise standards are not likely to be important in developing a proposed rule.

8.6 Regulatory Alternatives

The Panel considered a wide range of options and regulatory alternatives for providing small businesses with flexibility in complying with the proposed emissions standards and related requirements. As part of the process, the Panel requested and received comment on several ideas for flexibility that were suggested by SERs and Panel members. The major options recommended by the Panel can be found in Section 9 of the Panel's full Report.

Many of the flexible approaches recommended by the Panel can be applied to several of the equipment categories that would potentially be affected by the proposed rule EPA is developing. These approaches are identified in Table 1. First Tier Flexibilities: Based on consultations with SERs, the Panel believes that the first four provisions in Table 1 are likely to provide the greatest flexibility for many small entities. These provisions are likely to be most valuable because they either provide more time for compliance (e.g., additional leadtime and hardship provisions) or allow for certification of engines based on particular engine designs or certification to other EPA programs. Second Tier Flexibilities: The remaining four approaches have the potential to reduce near-term and even long-term costs once a small entity has a product it is preparing to certify. These are important in that the costs of testing multiple engine families, testing a fraction of the production line, and/or developing deterioration factors can be significant. Small businesses could also meet an emission standard on average or generate credits for producing engines which emit at levels below the standard; these credits could then be sold to other manufacturers for compliance or banked for use in future model years.

During the consultation process, it became evident that, in a few situations, it could be helpful to small entities if unique provisions were available. Three such provisions are described below.

(a) Snowmobiles: The Panel recommends EPA seek comment on a provision which would allow small snowmobile manufacturers to petition EPA for a relaxed standard for one or more engine families, up to 300 engines per year, until the family is retired or modified, if such a standard is justifiable based on the criteria described in the Panel report.

(b) ATVs and Off-road Motorcycles: The Panel recommends that the hardship provision for ATVs and off-road motorcycles allow hardship relief to be reviewed annually for a period that EPA anticipates will likely be no more than two years in order for importers to obtain complying products.

(c) Large SI: The Panel recommends that small entities be granted the flexibility initially to reclassify a small number of their small displacement engines into EPA's small spark-ignition engine program (40 CFR part 90). Small entities would be allowed to use those requirements in lieu of the requirements EPA intends to propose for large entities.

Table 1 describes the flexibilities that the Panel is generally recommending for each of the sectors where appropriate as indicated in the table.

The Panel also crafted recommendations to address SERs' concerns that ATV and off-road motorcycle standards that essentially required manufacturers to switch to four-stroke engines might increase costs to the point that many small importers and manufacturers could experience significant adverse effects. The Panel recommends that EPA request comment in its proposed rule on the effect of the proposed standard on these small entities, with the specific intent of developing information—including the extent to which sales of their products would likely to be reduced in response to changes in product price attributable to the proposed standards—that could be used to inform a decision in the final rule as to whether EPA should provide additional flexibility beyond that considered by the Panel.