



Draft Regulatory Support Document: Control of Emissions from Spark-Ignition Marine Vessels and Highway Motorcycles

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**Draft Regulatory Support Document:
Control of Emissions from Spark-Ignition
Marine Vessels and Highway Motorcycles**

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Table of Contents

Overview

CHAPTER 1: Health and Welfare Concerns

1.1 - Ozone	1-1
1.1.1 - General Background	1-1
1.1.2 - Health and Welfare Effects of Ozone and Its Precursors	1-2
1.1.3 - Additional Health and Welfare Effects of NO _x Emissions	1-3
1.1.4 - Ozone Nonattainment	1-4
1.1.5 - Public Health and Welfare Concerns from Prolonged and Repeated Exposures to Ozone	1-7
1.2 - Particulate Matter	1-8
1.2.1 - General Background	1-8
1.2.2 - Health and Welfare Effects of PM	1-10
1.2.3 - PM Nonattainment	1-11
1.3 - Gaseous Air Toxics	1-13
1.3.1 - Benzene	1-13
1.3.2 - 1,3-Butadiene	1-14
1.3.3 - Formaldehyde	1-15
1.3.4 - Acetaldehyde	1-16
1.3.5 - Acrolein	1-17
1.4 - Inventory Contributions	1-18
1.4.1 - Inventory Contribution	1-18
1.4.2 - Inventory Impacts on a Per Vehicle Basis	1-20
1.5 - Other Health and Environmental Effects	1-21
1.5.1 - Carbon Monoxide	1-21
1.5.2 - Acid Deposition	1-22
1.5.3 - Eutrophication and Nitrification	1-23

CHAPTER 2: Industry Characterization

2.1 - Highway Motorcycles	2-1
2.1.1 - Manufacturers	2-1
2.1.2 - Sales and Fleet Size	2-2
2.1.3 - Usage	2-3
2.1.4 - Current Trends	2-4
2.1.5 - Customer Concerns	2-5
2.1.5.1 - Performance	2-5
2.1.5.2 - Cost	2-5
2.1.5.3 - Consumer Modifications	2-6
2.1.5.4 - Safety	2-6
2.2 - Marine	2-7
2.2.1 - Gasoline Engine Manufacturers	2-7
2.2.1.1 - Identification of Gasoline Engine Manufacturers	2-7

2.2.1.2 - Use of Gasoline Engines	2-8
2.2.1.3 - Current Trends	2-8
2.2.2 - Recreational Boat Builders	2-9
2.2.2.1 - Identification of Boat Builders	2-9
2.2.2.2 - Current Trends	2-9
2.2.2.3 - Production Practices	2-9
2.2.3 - Fuel Tank Manufacturers	2-10
2.2.3.1 - Identification of Fuel Tank Manufacturers	2-10
2.2.3.2 - Current Trends	2-11
2.2.3.3 - Production Practices	2-11
2.2.4 - Hose Manufacturers	2-11
2.2.4.1 - Identification of Hose Manufacturers	2-11
2.2.4.2 - Current Trends	2-11
2.2.4.3 - Production Practices	2-12

CHAPTER 3: Technology

3.1 - Introduction to Spark-Ignition Engine Technology	3-1
3.1.1 - Basics of Spark-Ignition Four-Stroke Engines	3-1
3.1.2 - Engine Calibration	3-2
3.1.2.1 - Air-fuel ratio	3-2
3.1.2.2 - Spark-timing:	3-3
3.1.2.3 - Fuel Metering	3-3
3.1.3 - Gaseous Fuels	3-4
3.2 - Exhaust Emissions and Control Technologies	3-5
3.2.1 - Combustion chamber design	3-5
3.2.2 - Exhaust gas recirculation	3-5
3.2.3 - Secondary air	3-6
3.2.4 - Catalytic Aftertreatment	3-6
3.2.4.1 - System cost	3-7
3.2.4.2 - Packaging constraints	3-7
3.2.5 - Multiple valves and variable valve timing	3-7
3.2.6 - Advanced Emission Controls	3-8
3.3 - Evaporative Emissions	3-10
3.3.1 - Sources of Evaporative Emissions	3-10
3.3.1.1 - Diurnal and Running Loss Emissions	3-11
3.3.1.2 - Hot Soak Emissions	3-12
3.3.1.3 - Refueling Emissions	3-12
3.3.1.4 - Permeation	3-12
3.3.2 - Evaporative Emission Controls	3-13
3.3.2.1 - Sealed System with Pressure Relief	3-13
3.3.2.2 - Limited Flow Orifice	3-14
3.3.2.3 - Insulated Fuel Tank	3-14
3.3.2.4 - Volume Compensating Air Bag	3-15
3.3.2.5 - Collapsible Bladder Fuel Tank	3-15
3.3.2.6 - Charcoal Canister	3-16

3.3.2.7 - Floating Fuel and Vapor Separator	3-16
3.3.2.8 - Low-permeability Materials	3-16

CHAPTER 4: Technological Feasibility

4.1 - Highway Motorcycles	4-1
4.1.1 - Class I and II Motorcycles	4-3
4.1.1.1 - Class I Motorcycles Above 50cc and Class II Motorcycles ...	4-3
4.1.1.2 - Class I Motorcycles Under 50cc	4-3
4.1.2 - Class III Motorcycles	4-5
4.1.2.1 - Tier-1 Standards	4-5
4.1.2.2 - Analysis of EPA Certification Data	4-8
4.1.2.3 - Tier-2 Standards	4-9
4.1.3 - Impacts on Noise, Energy, and Safety	4-13
4.1.4 - Conclusion	4-14
4.1.4.1 - Tier-1 Standards	4-14
4.1.4.2 - Tier-2 Standards	4-14
4.2 - Evaporative Emission Control from Boats	4-15
4.2.1 - Diurnal Evaporative Emissions	4-15
4.2.1.1 - Baseline Emissions	4-16
4.2.1.2 - Diffusion Effect	4-18
4.2.1.3 - Sealed System with Pressure Relief	4-19
4.2.1.4 - Insulated Fuel Tank	4-21
4.2.1.5 - Volume Compensating Air Bag	4-24
4.2.1.6 - Bladder Fuel Tank	4-24
4.2.1.7 - Fuel and Vapor Separator	4-25
4.2.2 - Permeation Evaporative Emissions	4-25
4.2.2.1 - Fuel Tanks	4-25
4.2.2.2 - Hoses	4-30
4.2.3 - Evaporative Emission Test Procedures	4-31
4.2.3.1 - Diurnal Emission Testing	4-31
4.2.3.2 - Fuel Tank Permeation Testing	4-32
4.2.3.3 - Hose Permeation Testing	4-33
4.3 - Sterndrive/Inboard Marine	4-34
4.3.1 - Exhaust Emission Data from SD/I Engines	4-35
4.3.1.1 - Baseline Emission Data	4-35
4.3.1.2 - Emission Data For Catalyst Development Test Program ...	4-36
4.3.1.3 - Emission Data Using Exhaust Gas Recirculation	4-38
4.3.2 - Open Issues for Using Catalysts in Marine Applications	4-39
4.3.2.1 - Packaging	4-39
4.3.2.2 - Durability	4-40
4.3.2.3 - Water Reversion	4-40
4.3.2.4 - Safety	4-42

CHAPTER 5: Estimated Costs

5.1 - Methodology	5-1
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5.2 - Cost of Emission Controls by Engine/Vehicle Type	5-2
5.2.1 - Evaporative Emission Control from Boats	5-2
5.2.1.1 - Technologies and Estimated Costs	5-2
5.2.1.2 - Operating Cost Savings	5-3
5.2.1.3 - System Integration and Compliance Costs	5-4
5.2.1.4 - Total Costs	5-4
5.2.2 - Highway Motorcycles	5-5
5.2.2.1 - Technologies and Estimated Costs	5-6
5.2.2.2 - Compliance Costs	5-10
5.2.2.3 - Highway Motorcycle Total Costs	5-11
5.2.2.4 - Highway Motorcycles Under 50 cc	5-14
5.2.2.5 - Highway Motorcycle Aggregate Costs	5-15
5.3 - Aggregate Costs	5-16

CHAPTER 6: Emissions Inventory

6.1 - General Methodology	6-1
6.1.1 - Highway Motorcycle Emissions	6-1
6.1.2 - Marine Evaporative Emissions	6-1
6.1.2.1 - Diurnal Emissions	6-2
6.1.2.2 - Refueling Emissions	6-3
6.1.2.3 - Permeation Emissions	6-4
6.1.2.3 - Hot Soak Emissions	6-4
6.1.3 - SD/I Exhaust Emissions	6-4
6.2 - Effect of Emission Controls by Engine/Vehicle Type	6-6
6.2.1 - On-highway Motorcycles	6-6
6.2.1.1 - Inputs for the Inventory Calculations	6-6
6.2.1.2 - Reductions Due to the Proposed Standards	6-11
6.2.1.3 - Per Equipment Emissions from On-highway Motorcycles ..	6-13
6.2.2 - Evaporative Emission Control from Boats	6-14
6.2.2.1 - Inputs for the Inventory Calculations	6-15
6.2.2.2 - Reductions Due to the Proposed Standard	6-19
6.2.2.3 - Per Boat Evaporative Emissions	6-20
6.2.3 - Sterndrive and Inboard Marine	6-21
6.2.3.1 - Inputs for the Inventory Calculations	6-21
6.2.3.2 - Baseline Emissions from SD/I Marine Engines	6-22
6.2.3.3 - Analysis of Catalyst-based Approach	6-22
6.2.3.4 - Analysis of EGR-based Approach	6-24

CHAPTER 7 Cost Per Ton

7.1 - Cost Per Ton by Engine Type	7-1
7.1.1 - Introduction	7-1
7.1.2 - Evaporative Emission Control from Boats	7-1
7.1.3 - On-Highway Motorcycles	7-2
7.2 - Cost Per Ton for Other Mobile Source Control Programs	7-4
7.3 - 20-Year Cost and Benefit Analysis	7-5

CHAPTER 8: Initial Regulatory Flexibility Analysis

8.1 - Requirements of the Regulatory Flexibility Act	8-13
8.2 - Description of Affected Entities	8-14
8.2.1 - Recreational Vehicles (off-highway motorcycles, ATVs, and snowmobiles)	8-14
8.2.2 - Highway Motorcycles	8-15
8.2.3 - Marine Vessels	8-15
8.2.3.1 - Small Recreational Boat Builders	8-16
8.2.3.2 - Small Marine Fuel Tank Manufacturers	8-16
8.2.3.3 - Small Diesel Engine Marinizers	8-16
8.2.3.4 - Small Gasoline Engine Marinizers	8-17
8.2.4 - Large Spark Ignition Engines	8-17
8.3 - Projected Costs of the Proposed Program	8-17
8.4 - Projected Reporting, Recordkeeping, and Other Compliance Requirements of the Proposed Rule	8-17
8.5 - Other Related Federal Rules	8-17
8.6 - Regulatory Alternatives	8-18

Overview

EPA is proposing new standards for emissions of evaporative hydrocarbons from marine vessels and exhaust hydrocarbons and oxides of nitrogen from highway motorcycles. This proposal is the second part of an action for several sources. On October 5, 2001, we published proposed standards for large spark-ignition engines, recreational vehicles, and recreational marine diesel engines (66 FR 51098). That proposal had its own Draft Regulatory Support Document.

This Draft Regulatory Support Document provides economic, technical, cost, and environmental analyses of the proposed emission standards for marine vessels and highway motorcycles. 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.

This proposal also discusses potential future emission control of exhaust emission from sterndrive and inboard marine engines. This Draft Regulatory Support Document also provides technical and environmental analyses of potential control strategies for these engines.

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 and evaporative 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 sources 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.

Market Overview

This proposed regulation is designed to achieve emission reductions from marine vessels and highway motorcycles. Even though there are tangible and intangible benefits associated with reducing emissions from these sources, significant control has not been brought about by market forces. From an overall perspective these are a relatively small portion of the overall inventory for HC and NOx. This document will show that technology exists to achieve these significant reductions from these sources and demonstrates that this control would be inexpensive on a cost per ton basis. However, other externalities in the marketplace have deterred this shift to less

polluting technology. Presented below is a brief summary of the key factors pertaining to this analysis and reference to more substantive discussions in later chapters when available.

Emissions Overview

For marine vessels, there are three primary sources of evaporative emissions. The first source is diurnal emissions which are caused by fuel vapors escaping from the fuel tank. The marine industry currently designs their fuel systems with open vents through hoses that exit the vessel. The second source of evaporative emissions from marine vessels is permeation through the walls of the plastic fuel tank. Until the early 1970s, the vast majority of fuel tanks were made out of metal which does not permeate; now less than a quarter of new fuel tanks are made of metal. The third source of evaporative emissions from marine vessels is permeation through the fuel lines. In this case, there were some improvements to the permeation rate of hoses in the 1980s, but the industry standard for the permeation rate of hoses is still several orders of magnitude higher than typical automotive fuel lines.

Exhaust emissions from motorcycle have been the subject of a Federal emission control program for almost twenty-five years. However, it has been over two decades since EPA last reviewed these requirements. Technology has progressed over these years and indeed the nature of the business and market forces are substantially different. The technology used and available for most highway motorcycles now is far advanced beyond that called for by the 1980 era Federal standards. Thus, there is a need for an update. Also, today, highway motorcycles are predominantly an international commodity and importing and exporting of product is the norm. Thus, harmonization of emission standards and control requirements is a key need for industry with the added benefit of lower consumer cost.

Alternatives

In developing the proposed marine regulation, we looked at several alternatives for potential emission control strategies and programs. In considering alternatives, we investigated a wide range of technologies and considered various test procedures and implementation dates. In addition, we are considering an emission credit program, including early banking, designed to give manufacturers flexibility in what technology they use to comply with the proposed standards.

For diurnal emission control, we are proposing that manufacturers be able to certify to the proposed standards by design, if they elect to do so, by implementing designs consistent with available data. In the preamble we specify several emission control designs and the certification levels we would assign to these designs. The technologies we specify include insulation with a limited flow orifice in the vent, several control levels of sealed systems with pressure relief valves, a sealed system with a volume compensating air bag and pressure relief, and a bladder fuel tank. We are also proposing an averaging, banking, and trading program in conjunction on this design-based certification for diurnal emission control.

For permeation emission control of fuel tanks, we identify a number of technologies that

could be used to meet the proposed standards. These technologies include surface treatments such as fluorination or sulfonation, low permeability barrier materials, and construction using low permeability materials. For permeation emission control through hoses, we identify a number of low permeability materials that could be used as either barriers or as construction materials for the fuel lines.

With regard to highway motorcycles, the alternatives focus primarily on meeting statutory requirements while at the same time tailoring the program to the way motorcycles are produced, sold, and used. The program alternatives evaluation focused heavily on identifying options that would lead to the largest emission reductions available at the lowest cost taking into account these factors. Consultations with industry made it clear that harmonization with the California program was critical and that international harmonization was also valuable when possible. From the engineering and users perspective, optimal design meant establishing a program which permitted manufacturers and users technology choices to be applied within the program. Thus, the alternatives considered by EPA looked at harmonization, lead time, and emission credit averaging programs. For under 50cc motorcycles international harmonization and adequate lead time were key as these drove cost and emission control technology considerations. For over 50 cc and larger motorcycles, California harmonization and emission credit averaging had a first order impact on cost and consumer choice. The actual program and control technology options are further in later chapters of this document.

Proposed Emission Standards

Marine vessels powered by spark-ignition engines

We proposing evaporative emission standards that would apply to any marine vessel powered by any spark-ignition marine engine. This includes yachts, sport boats, fishing boats, jet boats, and other types of pleasure craft. This specifically includes personal watercraft and boats with outboard engines as well as portable tanks used in any marine vessel. These evaporative emissions include diurnal breathing losses and permeation. The proposed standards are presented in Table 1. These standards represent more than a 80 percent reduction in total evaporative emissions from new boats.

Table III.C-1: Proposed Evaporative Standards

Evaporative Emission Component	Proposed Emission Standard	Test Temperature
Diurnal Venting	1.1 g/gallon/day	22.2-35.6°C (72-96°F)
Fuel Tank Permeation	0.08 g/gallon/day	40°C (104°F)
Hose Permeation	5 g/m ² /day (15 g/m ² /day with 15% methanol blend)	23°C (73°F)

Highway motorcycles

In addition, we are proposing new exhaust emission standards for highway motorcycles. Motorcycles come in a variety of two- and three-wheeled configurations and styles, but for the most part they are two-wheeled, self-powered vehicles. Federal regulations currently define a motorcycle as “any motor vehicle with a headlight, taillight, and stoplight and having: two wheels, or three wheels and a curb mass less than or equal to 793 kilograms (1749 pounds)” (see 40 CFR 86.402-98). Note that if any motorcycle or motorcycle-like vehicle that can’t be defined as a motor vehicle (for example, if its top speed is less than 25 miles per hour), it would fall under requirements that apply to nonroad recreational vehicles. Highway motorcycles include a category referred to as “dual use” or “dual-sport,” meaning that their designs incorporate features that allow riders to use them both for street and off-highway application. Highway motorcycles are operated on public roadways predominantly during warmer weather and often in or near urban areas where they can contribute to ozone formation and ambient CO and PM levels. Table 2 shows the proposed standards for highway motorcycles.

Table 2
Proposed Highway Motorcycle Exhaust Emission Standards

Class	Engine Size (cc)	Implementation Date	HC (g/km)	HC+NO _x (g/km)	CO (g/km)
Class I	0-169	2006	1.0	—	12.0
Class II	170-279	2006	1.0	—	12.0
Class III	280 and above	2006	—	1.4	12.0
		2010	—	0.8	12.0

We are also seeking comment on plastic tank and fuel hose permeation emission control requirements for highway motorcycles, similar to that mentioned above for marine vessels.

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 3 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 3
2020 Projected Emissions Inventories (thousand short tons)

Category	CO			NOx			HC*		
	base case	with proposed standards	percent reduction	base case	with proposed standards	percent reduction	base case	with proposed standards	percent reduction
Marine SI evap	0	0	0%	0	0	0%	114	50	56%
All Highway Motorcycles	569	569	0%	14	7	50%	58	29	50%
Total	569	569	0%	14	7	50%	172	80	53%

* Evaporative HC for marine SI; exhaust HC for highway motorcycles.

Table 4 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. All costs are presented in 2001 dollars.

Table 4
Estimated Average Cost Impacts of Proposed Emission Standards

Category	Standard Date	Increased Production Cost per Vehicle*	Lifetime Operating Costs per Engine (NPV)
Marine SI diurnal tank permeation	2008	\$9	(\$4)
hose permeation		\$12	(\$9)
<u>aggregate</u>		<u>\$14</u>	<u>(\$14)</u>
aggregate		\$36	(\$27)
Highway motorcycles <50cc	2006	\$44	(\$8)
Highway motorcycles >50cc	2006	\$26	—
Highway motorcycles >50cc	2010	\$35**	—

* The estimated long-term costs for highway motorcycles >50cc decrease by about 35 percent.

** Costs presented are incremental to the first-phase standards.

We also calculated the cost per ton of emission reductions for the proposed standards. For both of the proposed programs, we attributed the entire cost of the proposed program to the control of ozone precursor emissions (HC or NOx or both). Table 5 presents the discounted cost-per-ton estimates for the various engines factoring in the effect of reduced operating costs such as fuel savings.

Table 5
Estimated Cost-per-Ton of the Proposed Emission Standards

Engine Type	Date	Pollutant	Discounted Reductions per Vehicle (short tons)	Discounted Cost per Ton	
				Without Fuel Savings	With Fuel Savings
Marine SI diurnal tank permeation hose permeation aggregate	2008	HC	0.01	\$745	\$382
			0.02	\$523	\$160
			0.04	\$367	\$4
			0.07	\$478	\$115
Highway Motorcycles <50cc	2006	HC	0.02	\$2,130	\$1,750
Highway Motorcycles >50cc	2006	HC+NOx	0.03	\$970	\$970
Highway Motorcycles >50cc	2010	HC+NOx	0.03	\$1,230	\$1,230
Aggregate	—	—	—	\$754	\$515

Table 6 presents the sum of the costs and emission benefits over the twenty-two year period after all of the 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-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 2006 for on-highway motorcycles and concludes in 2008 for the proposed evaporative emission requirements for boats.)

Table 6
Annualized Cost and Emission Benefits for the Period 2006-2027
due to the Proposed Requirements for All Equipment Categories

	HC+NOx Benefits (tons)	Cost w/o Fuel Savings (Million \$)	Fuel Savings (Million \$)	Cost w/ Fuel Savings (Million \$)
Undiscounted 22-year Value	1,550,000	\$934	\$369	\$565
Discounted 22-year Value	616,000	\$464	\$147	\$317
Annualized Value	56,000	\$42	\$13	\$29

CHAPTER 1: Health and Welfare Concerns

The engines and vehicles that would be subject to the proposed standards generate emissions of HC, PM and air toxics that contribute to ozone nonattainment as well as adverse health effects associated with ambient concentrations of PM and air toxics. 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 NO_x 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 NO_x, VOC, heat, and sunlight.¹ As a result, differences in weather patterns, as well as NO_x 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 NO_x emissions.

On the chemical level, NO_x and VOC are the principal precursors to ozone formation. The highest levels of ozone are produced when both VOC and NO_x emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_x enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_x. Under these conditions, NO_x reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NO_x 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 (NO₂); as the air moves downwind and the cycle continues, the NO₂ 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 1.3, below.

1.1.3 - Additional Health and Welfare Effects of NO_x Emissions

In addition to their role as an ozone precursor, NO_x 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). NO_x 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 1.5.4 and 1.5.5, 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 greater 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, marine vessels, and highway motorcycles 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 NO_x 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 inflammation. 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 for 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 NO_x 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 - Particulate Matter

1.2.1 - General Background

Particulate pollution is a problem affecting urban and non-urban localities in all regions of the United States. Nonroad engines and vehicles and highway motorcycles 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 PM₁₀. 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.¹⁷ 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 1.2-1: 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.

1.2.2 - 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.¹⁸

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 most 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.

1.2.3 - PM Nonattainment

The NAAQS for PM₁₀ was established in 1987. According to these standards, the short term (24-hour) standard of 150 µg/m³ 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 µg/m³ over three years.

The most recent PM₁₀ monitoring data indicate that 14 designated PM₁₀ nonattainment areas with a projected population of 23 million violated the PM₁₀ NAAQS in the period 1997-1999. Table 1.2-2 lists the 14 areas, and also indicates the PM₁₀ nonattainment classification, and 1999 projected population for each PM₁₀ 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 1.2-2: PM₁₀ Nonattainment Areas Violating the PM₁₀ 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 PM₁₀ 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 PM₁₀ nonattainment areas that are currently violating the PM₁₀ NAAQS listed in Table 1.2-2, there are 25 unclassifiable areas that have recently recorded ambient concentrations of PM₁₀ above the PM₁₀ NAAQS. EPA adopted a policy in 1996 that allows areas with PM₁₀ 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 PM₁₀ 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 PM₁₀ 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 PM₁₀, may be responsible for the problem. Emission reductions from today's action will assist these currently unclassifiable areas to achieve ambient PM₁₀ concentrations below the current PM₁₀ 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 µg/m³ (37 percent of the population in the areas with monitors).¹⁹ This 16 µg/m³ 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.²⁰ To estimate the number of people who live in areas where long-term

ambient fine particulate matter levels are at or above $16 \mu\text{g}/\text{m}^3$ 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 $\text{PM}_{2.5}$ concentrations at or above $16 \mu\text{g}/\text{m}^3$ (29 percent of the population).²¹

To estimate future $\text{PM}_{2.5}$ 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).²² 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 $\text{PM}_{2.5}$ 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 $16 \mu\text{g}/\text{m}^3$ to increase to 49 percent in 2030.²³

1.3 - 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 for our final Mobile Source Air Toxics rule.²⁴

1.3.1 - 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.²⁵

EPA has recently reconfirmed that benzene is a known human carcinogen by all routes of exposure.²⁶ 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,²⁷ 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.^{28,29} 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 animals³⁰ and increased

proliferation of mouse bone marrow cells.³¹ 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.³²

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.³³ 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,³⁴ a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).^{35,36} Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,³⁷ whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.^{38 39} The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood.⁴⁰

1.3.2 - 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.⁴¹

1,3-Butadiene was classified by EPA as a Group B2 (probable human) carcinogen in 1985.⁴² 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.⁴³ 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.⁴⁴ 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.⁴⁵ 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.⁴⁶ 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/m³ to avoid appreciable risks of these reproductive and developmental effects.⁴⁷ 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.

1.3.3 - 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.⁴⁸ 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.⁴⁹ 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.⁵⁰ Research has demonstrated that formaldehyde produces mutagenic activity in cell cultures.⁵¹

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.⁵² In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm.⁵³ Formaldehyde exposure may also cause bronchial asthma-like symptoms in non-asthmatics.^{54 55}

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.

1.3.4 - 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.⁵⁶

The atmospheric chemistry of acetaldehyde is similar in many respects to that of formaldehyde.⁵⁷ 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).^{58 59}

Noncancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes.^{60 61 62} 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 µg/m³ to avoid appreciable risk of these noncancer health effects.⁶³

1.3.5 - 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.⁶⁴

1.4 - Inventory Contributions

1.4.1 - Inventory Contribution

The contribution of emissions from the nonroad engines and vehicles and highway motorcycles 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. Emission estimates for highway motorcycles were developed using information on the emission levels of current motorcycles and updated information on motorcycle use provided by the motorcycle industry. A more detailed description of the modeling and our estimation methodology can be found in the Chapter 6 of this document.

Baseline emission inventory estimates for the year 2000 for the marine vessels and highway motorcycles covered by this proposal are summarized in Table 1.4-1. This table shows the relative contributions of the different mobile-source categories to the overall national mobile-source inventory. Of the total emissions from mobile sources, evaporative emissions from spark-ignition marine vessels contribute about 1.3 percent of HC. Highway motorcycles contribute about 1.1 percent, 0.1 percent, 0.4 percent, and 0.1 percent of HC, NO_x, CO, and PM emissions, respectively, in the year 2000. When only nonroad emissions are considered, the marine evaporative and motorcycle emissions would account for a larger share.

Our draft emission projections for 2020 for the spark-ignition marine vessels and highway motorcycles that would be subject to the proposed standards show that emissions from these categories are expected to increase over time if left uncontrolled. The projections for 2020 are summarized in Table 1.4-2 and indicate that the evaporative emissions from marine vessel are expected to contribute 1.8 percent of mobile source HC, and motorcycles are expected to contribute 2.3 percent, 0.2 percent, 0.6 percent, and 0.1 percent of mobile source HC, NO_x, CO, and PM emissions in the year 2020. Population growth and the effects of other regulatory control programs are factored into these projections.

Table 1.4-1
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
Highway Motorcycles	8	0.1%	84	1.1%	331	0.4%	0.4	0.1%
Marine SI Evaporative	0	0.0%	108	1.3%	0	0.0%	0	0.0%
Marine SI Exhaust	32	0.2%	708	9.6%	2,144	2.8%	38	5.4%
Nonroad Industrial SI > 19 kW	306	2.3%	247	3.2%	2,294	3.0%	1.6	0.2%
Recreational SI	13	0.1%	737	9.6%	2,572	3.3%	5.7	0.8%
Recreation Marine CI	24	0.2%	1	0.0%	4	0.0%	1	0.1%
Nonroad SI < 19 kW	106	0.8%	1,460	19.1%	18,359	23.6%	50	7.2%
Nonroad CI	2,625	19.5%	316	4.1%	1,217	1.6%	253	36.2%
Commercial Marine CI	977	7.3%	30	0.4%	129	0.2%	41	5.9%
Locomotive	1,192	8.9%	47	0.6%	119	0.2%	30	4.3%
Total Nonroad	5,275	39%	3,646	48%	26,838	35%	420	60%
Total Highway	7,981	59%	3,811	50%	49,813	64%	240	34%
Aircraft	178	1%	183	2%	1,017	1%	39	6%
Total Mobile Sources	13,434	100%	7,640	100%	77,668	100%	699	100%
Total Man-Made Sources	24,538	--	18,586	--	99,747	--	3,095	--
Mobile Source percent of Total Man-Made Sources	55%	--	41%	--	78%	--	23%	--

Table 1.4-2
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
Highway Motorcycles	14	0.2%	142	2.3%	572	0.6%	0.8	0.1%
Marine SI Evaporative	0	0.0%	114	1.8%	0	0.0%	0	0.0%
Marine SI Exhaust	58	0.9%	284	4.6%	1,985	2.2%	28	4.4%
Nonroad Industrial SI > 19 kW	486	7.8%	348	5.6%	2,991	3.3%	2.4	0.4%
Recreational SI	27	0.4%	1,706	27.7%	5,407	3.3%	7.5	1.2%
Recreation Marine CI	39	0.6%	1	0.0%	6	0.0%	1.5	0.2%
Nonroad SI < 19 kW	106	1.7%	986	16.0%	27,352	30.5%	77	12.2%
Nonroad CI	1,791	28.8%	142	2.3%	1,462	1.6%	261	41.3%
Commercial Marine CI	819	13.2%	35	0.6%	160	0.2%	46	7.3%
Locomotive	611	9.8%	35	0.6%	119	0.1%	21	3.3%
Total Nonroad	3,937	63%	3,651	59%	39,482	44%	444	70%
Total Highway	2,050	33%	2,276	37%	48,906	54%	145	23%
Aircraft	232	4%	238	4%	1,387	2%	43	7%
Total Mobile Sources	6,219	100%	6,165	100%	89,775	100%	632	100%
Total Man-Made Sources	16,195	--	16,234	--	113,443	--	3,016	--
Mobile Source percent of Total Man-Made Sources	38%	--	38%	--	79%	--	21%	--

1.4.2 - 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. On a typical summer day, an average sized boat emits as many hydrocarbon emissions to a current passenger car driven 500 miles. A highway motorcycle driven 10 miles emits as many hydrocarbon emissions as a current passenger car driven for 210 miles.

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 described in more detail in the next section.

1.5 - Other Health and Environmental Effects

1.5.1 - Carbon Monoxide

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.

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/).

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.⁶⁵

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.⁶⁶ 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).⁶⁷ CO standards for passenger cars and other light-duty trucks and heavy-duty vehicles did not change as a result of other recent rulemakings.

1.5.2 - Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when SO₂ and NO_x 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.⁶⁸ 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.

1.5.3 - 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.⁶⁹ 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.⁷⁰ 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 NO_x 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.⁷¹ 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 NO_x 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 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 our 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 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>.

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. I-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. U.S. EPA (1998) National Air Quality and Emissions Trends Report, 1997. Office of Air Quality Planning and Standards. EPA 454/R-99-016.

18. 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>.

19. 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. Air Docket A-2000-01, Document No. II-B-12.

20. 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. Air Docket 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>.

21. 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. Air Docket A-2000-01, Document No. II-B-14.
22. 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/diesel.htm#documents>.
23. 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 A-2000-01, Document I-B-14.
24. 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.
25. 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>.
26. 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>.
27. 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 blood cells 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.

- 28.U.S. EPA (1985) Environmental Protection Agency, Interim quantitative cancer unit risk estimates due to inhalation of benzene, prepared by the Office of Health and Environmental Assessment, Carcinogen Assessment Group, Washington, DC. for the Office of Air Quality Planning and Standards, Washington, DC., 1985.
- 29.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.
- 30.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.
- 31.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.
- 32.Lumley, M., H. Barker, and J.A. Murray (1990) Benzene in petrol, *Lancet* 336:1318-1319.
- 33.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.
- 34.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.
- 35.Aksoy, M (1991) Hematotoxicity, leukemogenicity and carcinogenicity of chronic exposure to benzene. In: Arinc, E.; Schenkman, J.B.; Hodgson, E., Eds. *Molecular Aspects of Monooxygenases and Bioactivation of Toxic Compounds*. New York: Plenum Press, pp. 415-434.
- 36.Goldstein, B.D. (1988) Benzene toxicity. *Occupational medicine. State of the Art Reviews*. 3: 541-554.
- 37.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

leukemias known as preleukemia. The aplastic anemia can progress to AML (acute myelogenous leukemia).

38. Aksoy, M., S. Erdem, and G. Dincol. (1974) Leukemia in shoe-workers exposed chronically to benzene. *Blood* 44:837.

39. Aksoy, M. and K. Erdem. (1978) A follow-up study on the mortality and the development of leukemia in 44 pancytopenic patients associated with long-term exposure to benzene. *Blood* 52: 285-292.

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41. 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>.

42. U.S. EPA (1985) Mutagenicity and Carcinogenicity Assessment of 1,3-Butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC.

43. U.S. EPA (1998) Draft Health Risk Assessment of 1,3-Butadiene, National Center for Environmental Assessment, Office of Research and Development, U.S. EPA, EPA/600/P-98/001A, February 1998.

44. Scientific Advisory Board. 1998. An SAB Report: Review of the Health Risk Assessment of 1,3-Butadiene. EPA-SAB-EHC-98, August, 1998.

45. EPA 1996. Proposed guidelines for carcinogen risk assessment. *Federal Register* 61(79):17960-18011.

46. U.S. EPA (1985) Mutagenicity and carcinogenicity assessment of 1,3-butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC. <http://www.epa.gov/ngispgm3/iris/subst/0139.htm>.

47. U.S. EPA (1985) Mutagenicity and carcinogenicity assessment of 1,3-butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC. <http://www.epa.gov/ngispgm3/iris/subst/0139.htm>.

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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 highway motorcycles, vessels with spark-ignition (SI) marine engines, and sterndrive and inboard marine engines.

2.1 - Highway Motorcycles

Motorcycles come in a variety of two- and three-wheeled configurations and styles. For the most part, however, they are two-wheeled self-powered vehicles. Federal regulations currently define a motorcycle as “any motor vehicle with a headlight, taillight, and stoplight and having: two wheels, or three wheels and a curb mass less than or equal to 793 kilograms (1749 pounds).” (See 40 CFR 86.402-98). Highway motorcycles are those motorcycles that meet this definition and are not excluded by the provisions that define a “motor vehicle” as, in part, a vehicle that can exceed 25 mph.¹ By definition a highway motorcycle is “street-legal,” i.e., it can be registered for use on public roads under existing state laws. Both EPA and California regulations sub-divide highway motorcycles into classes based on engine displacement. Table 2.1-1 below shows how these classes are defined.

**Table 2.1-1
Motorcycle Classes**

Motorcycle Class	Engine Displacement (cubic centimeters)
Class I	50 ^a - 169
Class II	170 - 279
Class III	280 and greater

^a This proposal would extend Class I to include <50cc.

2.1.1 - Manufacturers

Six companies account for about 95 percent of all motorcycles sold (Honda, Harley-Davidson/Buell, Yamaha, Kawasaki, Suzuki, and BMW). All of these companies except Harley-Davidson and BMW also manufacture off-road motorcycles and ATVs for the U.S. market. From 1996 to 2000, Harley-Davidson produced more on-road motorcycles than any other manufacturer

¹ Vehicles that appear to be motorcycle-like (e.g., mopeds, motorized bicycles, etc.) yet can not exceed 25 mph are considered non-road recreational vehicles, and would be subject to the proposed provisions for that category of vehicles.

and accounted for nearly 30 percent of total production by the six largest firms. Honda accounted for 23.2 percent of total production by the six largest firms and Yamaha accounted for 18.4 percent. Kawasaki and Suzuki each accounted for approximately 13 percent of production by the six largest firms, while BMW accounted for 2.7 percent. As a whole, these firms increased production steadily in 1997, 1998, 1999, and 2000. In 2001, these firms are projected to continue producing over 90 percent of all highway motorcycles manufactured for the US market.

Dozens of other companies make up the remaining few percent of sales. Many of these are small U.S. companies manufacturing anywhere from a couple dozen to a couple thousand motorcycles, although importers and U.S. affiliates of larger international companies also contribute to the remaining few percent.

With the exception of Harley-Davidson/Buell, all the major manufacturers produce at least a portion of their on-road motorcycles for the U.S. market outside of the U.S. BMW, Suzuki, and Yamaha manufacture all on-road motorcycles destined for the U.S. market outside of the U.S. Sixty-five percent of Honda's on-road motorcycles produced for the U.S. market are manufactured outside the U.S., in either Italy or Japan. Sixty-one percent of Kawasaki's on-road motorcycles destined for the U.S. market are produced in Japan.

2.1.2 - Sales and Fleet Size

Motorcycle sales are sensitive to economic cycles due to the recreational nature of motorcycle ownership. While certainly some are used as basic transportation, in general they are purchased by consumers who already own one or more cars, and the motorcycle is used for recreation on summer evenings or weekends. In much of the nation the motorcycle is not a practical means of transportation for one third of the year or more. Sales were high in the late 1970's and early 1980's, but as the economy neared its downturn that started around 1987-1988 sales clearly began to drop. Sales bottomed out with that downturn in 1992, then as the economy boomed in the 1990's sales once again began to take off, with retail dollars in 1998 approaching triple the retail dollars of ten years before. Historical sales and retail dollars are shown in Table 2.1-2. Data for 2000 indicate that the trend continued, with the retail sales of highway motorcycles up by more than 20 percent relative to 1999. The unit sales of highway motorcycles in calendar year 2000 was approximately 437,000 (including dual-sport motorcycles).² The current fleet of highway motorcycles is approximately 4.3 million units.

² Dealernews. Vol. 37, No. 2, Feb. 2001, p. 158.

**Table 2.1-2
On-Highway Motorcycle Retail Sales: 1982-1998***

<i>Year</i>	<i>Units (thousands)</i>	<i>Dollars (millions)</i>
1999	387	3921
1998	311	3132
1997	260	2556
1996	242	2213
1995	230	1931
1994	228	1773
1993	217	1563
1992	203	1333
1991	206	1157
1990	226	1148
1989	245	1072
1988	335	1304
1987	465	1401
1986	470	1375
1985	565	1580
1984	605	1777
1983	605	1542
1982	605	1463

* Source: Motorcycle Industry Council, 2000 Motorcycle Statistical Annual.

2.1.3 - Usage

Highway motorcycles are primarily for use on public roads and typically fall into one of four categories: cruiser, touring, sport bike, or standard. A cruiser motorcycle is designed for relatively short distances and is the most commonly purchased on-road motorcycle in the U.S. A touring motorcycle is designed for long distance travel and extra load capacity. A sport bike is designed for performance and uses racing technology, and finally a standard motorcycle is a basic

model. Each of these categories of motorcycles also differs in appearance and styling. For instance, a cruiser motorcycle has a heavier appearance, a custom paint job, full-view engines, and swept-back handlebars. A touring bike is built for rider comfort and includes saddlebags. In contrast, a sportbike is more aerodynamic in appearance, and has low handle bars and high performance tires.

The highway motorcycle category also includes motorcycles termed “dual-use” or “dual-sport,” meaning that their designs incorporate features that enable them to be competent both on and off road. Dual-sport motorcycles generally can be described as street-legal dirt bikes, because they often bear a closer resemblance in terms of design features and engines to true off-road motorcycles than to highway cruisers, touring, or sport bikes.

2.1.4 - Current Trends

Analyzing production and sales numbers based on type of motorcycle and engine displacement reveals that heavyweight motorcycles have become particularly popular in recent years. In 2000, 72 percent of all on-road motorcycles produced for the U.S. market were heavyweight motorcycles (651 cc or greater displacement). Just five years prior, heavyweight motorcycles made up 67 percent of total production for the U.S. market. Until relatively recently, Harley-Davidson was the only significant manufacturer of American heavyweight cruiser and touring motorcycles. In 2000, Harley-Davidson/Buell was still the largest producer of heavyweight on-road motorcycles (it produced 34 percent of all heavyweight motorcycles). However, it has had insufficient production capacity to satisfy increased demand for heavyweight motorcycles. Estimated shortfall in 1999 is 40,000 motorcycles or 30 percent of total demand. Estimated annual growth in heavyweight motorcycle sales is 8 percent. Harley-Davidson is reported to have plans to increase production by only 9 percent, which allows it to just keep up with annual growth in the market.

Of the 175 engine families certified in 2002 by manufacturers for sale in the U.S., 151 fall in the Class III category (above 279cc), representing more than 90 percent of projected sales. More than three-quarters of projected 2001 highway motorcycle sales are above 700cc. The average displacement of all 2001 certified engine families is about 980cc, and the average displacement of certified Class III engine families is above 1100cc. The sales-weighted average displacement of 2002 highway motorcycles is about 1100cc. Class I and II motorcycles, which make up less than seven percent of projected 2002 sales and only 24 out of 175 certified 2002 engine families, consist mostly of dual-sport bikes, scooters, and entry-level sportbikes and cruisers.

According to the Motorcycle Industry Council (MIC), in 1998 there were about 5.4 million highway motorcycles in use in the United States (565,000 of these were dual-sport).¹ Total sales in 1998 of highway motorcycles was estimated to be about 411,000, or about 72 percent of motorcycle sales. About 13,000 of these were dual-sport motorcycles. Recent figures for the 2000 calendar year show that retail sales approached 438,000 highway motorcycles, about

19,000 of which were dual-sport bikes.²

In the second half of the 1990's, motorcycle production at Harley-Davidson fell short of meeting the rapidly growing demand for their motorcycles. The result has been the entry of at least ten new companies into the heavyweight motorcycle market in the last several years. These companies include two that ceased producing on-road motorcycles more than 50 years ago, Excelsior Henderson Motorcycles and Indian Motorcycles. Polaris began manufacturing Victory motorcycles in 1998. American Eagle Motorcycle Company began commercial production in 1996. Other competitors include companies that custom-build heavyweight motorcycles from mostly non-proprietary components, including Titan, Big Dog, Pure Steel, American Ironhorse, and Ultra.

A number of these companies have not been successful in the heavyweight motorcycle market. American Quantum, Excelsior-Henderson, and Titan have filed for bankruptcy. One possible explanation for the difficulty that smaller companies have had in profiting from insufficient production of heavyweight motorcycle is that Harley increased its production by more than expected. Harley-Davidson reports a 17.5 percent increase in production from 1998 to 1999. MIC projects that Harley-Davidson increased production by 15.4 percent between 1999 and 2000.

2.1.5 - Customer Concerns

2.1.5.1 - Performance

Adequate performance is clearly an important attribute for highway motorcycles. In particular, buyers of sport or super-sport motorcycles are generally seeking performance that is high or even extreme, sometimes rivaling the performance of exclusive racing motorcycles. In the touring and cruiser segments of the market this kind of outrageous performance is generally not sought after; these bikes have attributes (such as riding style and position) that make high performance a less important design factor. For example, touring motorcycles are designed for long-term riding comfort and luggage carrying capacity, and cruisers are often more focused on a retro look, sound, and feel that allows them to be noticed cruising down Main Street, not sprinting down the freeway.

2.1.5.2 - Cost

Motorcycles can range in price from around \$1500 - \$2000 for inexpensive entry-level or dual-sport machines and mopeds and scooters to over \$50,000 for elite custom machines. According to Motorcycle Industry Council data the average amount spent by consumers on new motorcycles in 1999 can be estimated at just over \$10,300.³ As with other recreational vehicles, highway motorcycles are generally discretionary purchases. Significant cost increases could therefore result in decreased sales of these motorcycles if the increased costs cause consumers to take their discretionary income elsewhere and into other recreational opportunities.

2.1.5.3 - Consumer Modifications

Many motorcycle owners personalize their motorcycles in a variety of ways. This is one of the aspects of motorcycle ownership that is appealing to a large number of motorcycle owners, and they take their freedom to customize their bikes very seriously. However, there are some forms of customization that are not legal under the provisions of Clean Air Act section 203(a), which states that it is illegal:

“for any person to remove or render inoperative any device or element of design installed on or in a motor vehicle or motor vehicle engine in compliance with regulations under this title ... after such sale and delivery to the ultimate purchaser...”

In other words, owners of motor vehicles cannot legally make modifications that cause the emissions to exceed the applicable emissions standards, and they cannot remove or disable emission-control devices installed by the manufacturer.

We use the term “tampering” to refer specifically to actions that are illegal under Clean Air Act section 203; the term, and the prohibition, do not apply generally to the wide range of actions that a motorcycle enthusiast can do to personalize their vehicle, but only to actions that remove or disable emission control devices or cause the emissions to exceed the standards. We know, from anecdotal reports and from some data collected from in-use motorcycles, that a portion of the motorcycle riding population has removed, replaced, or modified the original equipment on their motorcycles. This customization can include changes that can be detrimental (or, in some cases, possibly beneficial) to the motorcycle’s emission levels. The ANPRM sought comments and data that could better help us understand the nature of the issue, such that our proposal could be made with the best understanding possible of current consumer practices. We did not intend to suggest that we would be revising the existing tampering restrictions to prohibit many of the things that motorcycle owners are now doing legally.

The proposed emissions standards, if adopted by EPA, would not change this “tampering” prohibition, which has been in place for more than 20 years. Owners would still be free generally to customize their motorcycles in any way, as long as they do not disable emission controls or cause the motorcycle to exceed the emission standards. They would also be free, as they are now, to perform routine maintenance on their motorcycles to restore or maintain the motorcycle engine and related components in their original condition and configuration.

2.1.5.4 - Safety

The nature of motorcycling makes riders particularly aware of the many safety issues that confront them. Many riders that submitted comments to us following the publication of the ANPRM in December of 2000 questioned whether catalytic converters could be implemented on motorcycles without increasing the risk of harm to the rider and/or passenger. The primary concern is regarding the close proximity of the riders to hot exhaust pipes and the catalytic converter. Protecting the rider from the excessive heat is a concern for both riders and

manufacturers. The current use of catalytic converters on a number of motorcycles (accounting for tens of thousands in the current fleet) already indicates that these issues are not insurmountable on a variety of motorcycle styles and engine sizes. A number of approaches to shielding the rider from the heat of the catalytic converter are possible, such as exterior pipe covers, shielded foot rests, and similar components. Some manufacturers have found that placing the converter on the underside of the engine can keep it adequately distant from the rider. Others may use double-pipe systems that reduce overall heat loss while remaining cooler on the exterior. Based on the significant lead time that would be allowed for meeting these standards, as well as on the two years of prior experience in California before meeting the requirements federally, we believe that these issues can be satisfactorily resolved for the proportion of motorcycles for which catalytic converters will be required.

2.2 - 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 four segments: gasoline engine manufacturers, boat builders, fuel tank manufacturers, and hose manufacturers. This industry characterization was developed in part under contract with ICF Consulting⁴ as well as independent analyses conducted by EPA through interaction with the industry and other sources.^{5,6,7}

2.2.1 - Gasoline Engine Manufacturers

2.2.1.1 - Identification of Gasoline Engine Manufacturers

We have determined that there are at least 25 companies that manufacture sterndrive and inboard gasoline engines for recreational vessels (including airboats and jetboats). Nineteen of the identified companies are considered small businesses as defined by Small Business Administration SIC code 3519 (less than 1000 employees). These nineteen companies represent 10-20 percent of SD/I engine sales for 2000. Approximately 70-80 percent of gasoline SD/I engines manufactured in 2000 can be attributed to one company. The next largest company is responsible for about 10-20 percent of sales. Table 2.2-2 provides a list of gasoline engine manufacturers identified to date by EPA.

Table 2.2-1 List of SI SD/I Marine Engine Manufacturers Identified by EPA

<i>Greater than 1000 employees</i>	<i>Less than 1000 employees</i>
Bombardier Lamborghini Mercruiser Toyota Volvo Penta Yamaha	Alumitech Boostpower USA Cobra Power Diamondback Flagship Marine GTO Indmar Products KEM Kodiak Marine Power Marshland Panther PCM/Crusader Redline Marine Revenge Power Rotary Power Marine Stump Jumper Torque Engineering Windmark

There are currently eight companies that certify their engines to the U.S. standards for outboards and personal watercraft. None of these companies would qualify as a small business. These eight companies are Bombardier, Honda, Kawasaki, Mercury Marine, Polaris, Suzuki, Tohatsu, and Yamaha.

2.2.1.2 - Use of Gasoline Engines

Information gathered by ICF suggests that a vast majority of inboard runabouts most likely run on gasoline because of the small engines in these boats. Additionally, ICF estimates that approximately 75 to 85 percent of inboard cruisers run on gasoline. Runabouts are primarily designed for day-use where cruisers are generally designed with an enclosed cabin to used for extended cruising. Most cruisers that are less than 40 feet run on gasoline. Almost all outboards and personal watercraft in operation today run on gasoline.

2.2.1.3 - Current Trends

Sales of SD/I marine engines (including jet boats) have grown over the past ten years. Based on data provided by the National Marine Manufacturers Association (NMMA)⁸, sales of

gasoline these engines were 92,400 in 1991 and were 115,800 in 2000. However, these sales are down from peak sales years in the mid-to-late 1980's. Sales of outboards have grown steadily over the past ten years from 195,000 in 1991 to 241,600 in 2000. However, personal watercraft sales have seen a steady decline over the past five years from 200,000 in their peak year of 1995 to 92,000 in 2000.

2.2.2 - Recreational Boat Builders

2.2.2.1 - 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 than 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 boats using SI marine engines 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.

2.2.2.2 - 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.

2.2.2.3 - 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.

2.2.3 - Fuel Tank Manufacturers

2.2.3.1 - Identification of Fuel Tank Manufacturers

We estimate that total sales of tanks for marine applications is approximately 550,000 units per year. The market is broken into manufacturers that produce plastic tanks and manufacturers that produce aluminum tanks. We have determined that there are at least nine companies that make plastic fuel tanks with total sales of approximately 440,000 units per year. There are at least four companies that make aluminum fuel tanks with total sales of approximately 110,000 units per year. Most these fuel tank manufacturers are small businesses as defined under SBA SIC Code 3713. Table 2.2-3 provides a list of the diesel engine manufacturers identified to date by EPA.

Table 2.2-3 List of Marine Fuel Tank Manufacturers Identified by EPA

<i>Plastic</i>	<i>Aluminum</i>
Acrotech	Coastline
Attwood	Ezell
Chilton	Florida Marine
Inca	RTS
Kracor	
Moeller	
Skyline	

2.2.3.2 - Current Trends

Until about 20 years ago, the majority of fuel tanks were made of aluminum. Today, however, only about a quarter of installed fuel tanks are aluminum. This shift was likely due largely to the cost savings to boat builders by using plastic tanks.

2.2.3.3 - Production Practices

Plastic fuel tanks are either rotationally molded or blow molded. Generally, portable fuel tanks are blow molded. Blow molding involves forming polyethylene in large molds using air pressure to shape the tank. Because this has high fixed costs, blow molding is only used where production volumes are high. This works for portable fuel tanks where the volumes are high and a single shape can be used for most applications. For portable tanks, the fuel tank manufacturer will generally design the tank, then send it out to a blow molder for production.

Rotational molding is a lower cost alternative for smaller production volumes. In this method, a mold is filled with a powder form of polyethylene with a catalyst material. The mold is rotated in an oven; the heat melts the plastic and activates the catalyst which causes a strong cross-link material structure to form. This method is used for installed fuel tanks which generally need to meet specific size and shape requirements for each boat design.

Aluminum fuel tanks are also used primarily for installed fuel tanks. These tank manufacturers generally custom make each tank to meet the boat manufacturers needs. Generally, sheet aluminum is used and is cut, bent, and welded into the required configuration.

2.2.4 - Hose Manufacturers

2.2.4.1 - Identification of Hose Manufacturers

There are two primary U.S. manufacturers of extruded marine fuel hose (fuel supply and vent) used in marine applications. These manufacturers are Parker-Dayco and Goodyear. They generally sell their hose through distributors such as Lawrence Industries, MPI, Shields Marine Hoses, and Triton Rubber. Other hoses are imported from overseas, primarily from Asia; two such brand names are Thermoid and Flexacol. Lawrence Industries is the only U.S. manufacturer of marine fuel fill neck hose that we have identified. The majority of marine fuel fill neck hose is imported.

2.2.4.2 - Current Trends

Marine hose is designed to meet the Coast Guard performance requirements as defined by the Society of Automotive Engineer's recommended practice SAE J 1527. For fuel supply lines, this includes a permeation rate of 100 g/m²/day at 23°C (Class 1). For other fuel hose not

normally continuously in contact with fuel (vent and fuel fill neck), the permeation standard is 300 g/m²/day (Class 2). In general, boat builders will use Class 1 hose for both fuel supply and vent lines for simplicity. Some boat builders use low permeation barrier hose which is well below the permeation levels in SAE J 1527. For fuel fill necks, boat builders generally use Class 2 hose.

2.2.4.3 - Production Practices

Most fuel supply and vent marine hose is extruded nitrile rubber with a coating for better wear and flame resistance. Because nitrile rubber has a very high permeation rate, this cover also helps keep the permeation rate below the Coast Guard requirement. Under the SAE J 1527, hose is defined as being reinforced with fabric or wire. (In contrast, plastic automotive fuel lines are extruded without reinforcement and are generally referred to as “tubing.”) One hose manufacturer offers a barrier marine hose that has much better fuel resistance than standard nitrile hose. This hose uses a barrier layer of low permeability material, such as nylon or ethyl vinyl alcohol, either on the inside surface or sandwiched between layers of nitrile rubber.

Fuel fill hose is generally manufactured by hand wrapping layers of rubber and reinforcement materials around a steel mandril. This hose is then heated to cure the rubber. Fuel fill hose generally has a much larger diameter than fuel supply and vent hose and this process offers an effective method of producing this larger diameter hose. Although marine fuel fill necks are not produced today with low permeation barriers, multi-layer chemical hoses are produced using this method. Therefore, we believe that this method could be used to produce low permeation fill neck hoses.

Chapter 2 References

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CHAPTER 3: Technology

This chapter describes the current state of spark-ignition technology for engines and evaporative emission technology 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. SI engines may also be four-stroke or two-stroke which refers to the number of piston strokes per combustion cycle. Motorcycles and SD/I engines are primarily spark-ignition, four-stroke engines.

3.1.1 - Basics of Spark-Ignition Four-Stroke Engines

Four-stroke engines are used in many different applications. Virtually all highway motorcycles, automobiles, and many trucks are powered by four-stroke SI engines. Four-stroke engines are also common in off-road 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 its 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 - Engine Calibration

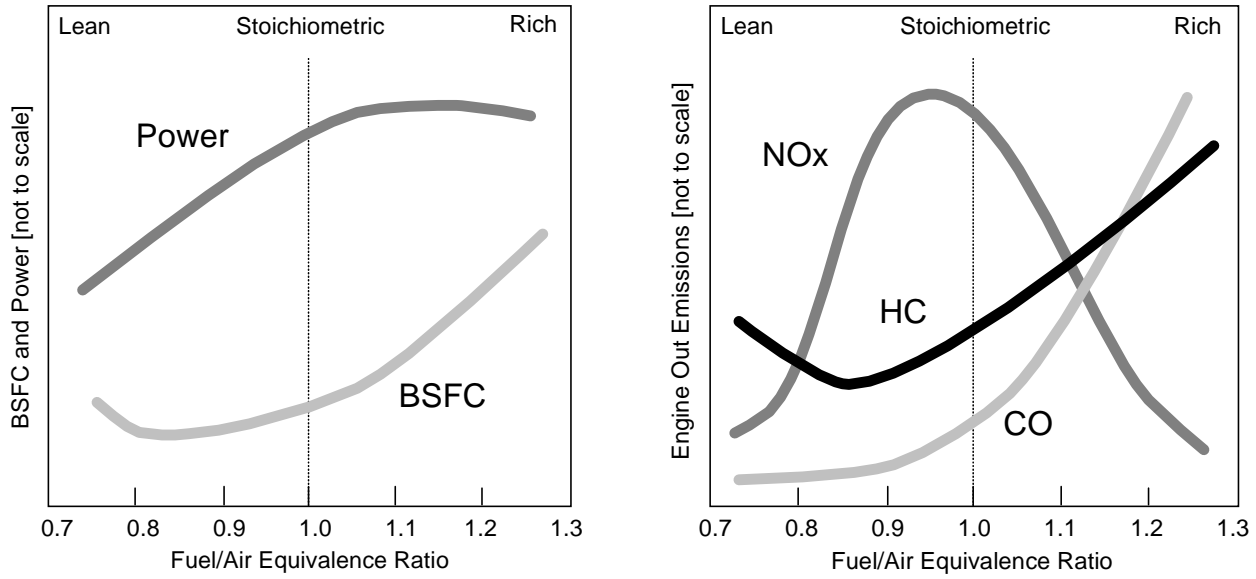
For most current SI engines, the two primary variables that manufacturers can control to reduce emissions are the air and fuel mixture (henceforth referred to as air-fuel ratio) and the spark timing. For highway motorcycles, these two variables are the most common methods for controlling exhaust emissions.

3.1.2.1 - 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 NO_x 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



3.1.2.2 - 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.

3.1.2.3 - 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

3.1.3 - Gaseous Fuels

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

HC and CO emissions from four-stroke engines are primarily the result of poor in-cylinder combustion. Higher levels of NO_x 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 3.1.2.1 and 3.1.2.2, 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 NO_x emissions, but is not necessarily needed for recreational vehicles and highway motorcycles, due to their relatively low NO_x 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.

3.2.1 - 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 NO_x 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.

3.2.2 - 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 NO_x 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.

3.2.3 - 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 - 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 palladium 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 required. The NOx efficiency drops rapidly as the air-fuel ratio becomes leaner than stoichiometric. If the air-fuel ratio can be maintained precisely at or just rich of stoichiometric, 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.

3.2.4.1 - 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 highway motorcycle engines. For this reason, we believe it is not appropriate to consider highly refined catalyst systems that are tailored specifically to nonroad applications. The cost of these systems will decrease substantially when catalysts become commonplace. Chapter 5 describes the estimated costs for a nonroad catalyst system.

3.2.4.2 - Packaging constraints

Many motorcycles have space constraints for adding a catalyst because they have been fine-tuned over many years with a very compact fit. Automotive catalyst designs typically have one or two catalyst units upstream of the muffler. This is a viable option for some motorcycles. 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 already operating on highway motorcycles clearly demonstrate this.

3.2.5 - 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.

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.

3.2.6 - 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. 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.³

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.⁴ 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.⁵ Since ordinary catalysts typically

³ <http://www.epa.gov/otaq/tr2home.htm#Documents>. EPA 420-R-99-023

⁴ McDonald, J., L. Jones, Demonstration of Tier 2 Emission Levels for Heavy Light-Duty Trucks, SAE 2000-01-1957.

⁵ Burch, S.D., and J.P. Biel, SULEV and "Off-Cycle" Emissions Benefits of a Vacuum-Insulated Catalytic Convert, SAE 1999-01-0461.

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 quickly.⁶ 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.

3.3 - Evaporative Emissions

3.3.1 - Sources of Evaporative Emissions

Evaporative emissions from vessels using spark-ignition marine engines can be very high. This is largely because they have fuel tanks that are vented to the atmosphere and because materials are used in the construction of the plastic fuel tanks and hoses which have high permeation rates. Evaporative emissions can be grouped into five categories:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day,

⁶ Laing, P.M., Development of an Alternator-Powered Electrically-Heated Catalyst System, SAE 941042.

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.

3.3.1.2 - Hot Soak Emissions

Hot soak emissions occur after the engine is turned off, especially during the resulting temperature rise. 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 emissions continue at a nearly constant rate, regardless of how much the vehicle or equipment is used. Because of these effects, permeation-related emissions can therefore add up to a large fraction of the total emissions from recreational boats.

3.3.2 - Evaporative Emission Controls

Several emission-control technologies can be used to reduce evaporative emissions. We expect manufacturers to use a wide variety of these potential technology approaches to meet the proposed emission standards for marine fuel tanks. 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 marine applications, U.S Coast Guard safety regulations require that fuel tanks be able to withstand at least 3 psi and must be able to pass a pressure impulse test which cycles the tank from 0 to 3 psi 25,000 times (33 CFR part 183) . The Coast Guard also requires that these fuel tanks must be vented such that the pressure in the tank in-use never exceeds 80 percent of the pressure that the tank is designed to withstand without leaking. The American Boat and Yacht Council makes the additional recommendation that the vent line should have a minimum inner diameter of 7/16 inch (H-24.13). However, these recommended practices also note that “there may be EPA or state regulations that limit the discharge of hydrocarbon emissions into the atmosphere from gasoline fuel systems. The latest version of these regulations should be consulted.”

To prevent pressure from building too high in marine tanks, we considered a 2 psi pressure relief valve. This is a typical automotive rating and is below the Coast Guard requirements. With this valve, vapors would be retained in the tank until 2 psi of pressure is built up in the tank due to heating of the fuel. Once the tank pressure reached 2 psi, just enough of the vapor would be vented to the atmosphere to maintain 2 psi of pressure. As the fuel cooled, the pressure would decrease. We estimate that this would achieve about a 55-percent reduction in evaporative emissions over the proposed test procedure. A 1 psi valve would achieve a reduction of about half of this over the proposed test procedure. In use, this reduction could be greater because the test procedure is designed to represent a hotter than average day. On a more mild day there could be less pressure buildup in the tank and the valve may not even need to open. With the use of a sealed system, a low pressure vacuum relief valve would also be necessary so that air could be drawn into the tank to replace fuel drawn from the tank when the engine is running.

Manufacturers of plastic fuel tanks have expressed concern that their tanks are not designed to operate under pressure. For instance, although they will not leak at 3 psi, rotationally

molded fuel tanks with large flat surfaces could begin deforming at pressures as low as 0.5 psi. At 2.0 psi, the deformation would be greater. This deformation would affect how the tank is mounted in the boat. Also, fuel tank manufacturers commented that some of the fittings or valves used today may not work properly under 2 psi of pressure. Finally, they commented that backup pressure-relief valves would be necessary for safety.

We believe that, with enough lead time, fuel tank manufacturers will be able to redesign their fuel tanks to be more resistant to deformation under pressure. We also believe that if certain fittings and valves cannot withstand pressure today, they can be designed to do so. In addition, designing to meet a pressure of 1 psi valve would require significantly less modification to current tanks than designing for 2 psi of pressure. Below, we discuss strategies that could be used in conjunction with a sealed system to minimize the build-up of pressure in the fuel tank. Such technologies are insulation, volume-compensating air bags, and bladder fuel tanks. With the use of these technologies, the same emission reductions could be achieved with a pressure-relief valve set to allow lower vent pressures. Finally the structure of the proposed standards gives manufacturers the flexibility to meet the emission limits without building up pressure in the fuel tank.

3.3.2.2 - Limited Flow Orifice

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. We tested a 17-gallon tank with a 75-micron diameter limited-flow orifice over the proposed diurnal test procedure and saw close to a 50 percent reduction in diurnal emissions. The peak pressure in this test was 1.6 psi.

3.3.2.3 - 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. It should be noted that today's fuel tanks, when installed in boats, have some amount of "inherent insulation." This is especially true for boats that remain in the water and is discussed in more detail in Chapter 4.

The method of insulation would have to be consistent with U.S. Coast Guard fuel system requirements specified in 33 CFR 183. These requirements regulate the resistance to fuels, oils

and other chemicals, water adsorption, compressive strength, and density of foam used to encase fuel tanks. To prevent water from trapping between the fuel tank and foam and causing corrosion in metal fuel tanks, the Coast Guard requires that the bond between the tank and the foam be stronger than the sheer strength of the foam. Corrosion between the tank and foam would be hidden from view and could be undetected until the tank fails. Also, water must be able to drain from the fuel tank when a boat is in its static floating position.

There are several methods that could be used to insulate the fuel tank while maintaining safe practices. For metal tanks, a honeycomb material could be used as an insulating barrier, but this may be expensive. The manufacturer could insulate the compartment that the tank is in rather than the tank itself. In this case it would be important that no ignition sources were in the compartment with the tank. In some cases, manufacturers will foam the tank in place by filling the entire compartment the tank is in. For boats, such as yachts, that are stored in the water, the tank can be cooled just by placing it below the waterline near the hull.

3.3.2.4 - 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 fluorosilicon 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 in the fuel tank.

3.3.2.5 - 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 would increase costs

by 30 to 100 percent depending on tank size. However, bladder fuel tanks have positive safety implications as well and are already sold by at least one manufacturer to meet market demand in niche applications.

3.3.2.6 - 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. This technology does not appear to be attractive for marine fuel tanks because boats may sit for weeks at a time without the engine running. Once the canister is saturated, it provides no emission control

3.3.2.7 - 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 marine fuel tanks. Because of the motion of the boat, 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. In addition, the unique geometry of many marine fuel tanks could cause the balls to collect in one area of the tank.

3.3.2.8 - Low-permeability Materials

Probably the largest source of evaporative emissions is permeation through the walls of plastic fuel tanks and rubber hoses. We estimate that about a third of the evaporative emissions from boats with plastic fuel tanks come from permeation through the walls of the fuel tanks and about a third through the walls of the fuel supply and fill-neck hoses.

3.3.2.8.1 - Fuel Tank Materials

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. For this reason, this manufacturing technique is generally only used for portable fuel tanks which are generally produced in higher volumes. For these tanks, however, multi-layer fuel tank construction may be an inexpensive and effective approach to controlling permeation emissions

Manufacturers of rotationally molded plastic fuel tanks generally have low production volumes and have commented that they could not produce their tanks with competitive pricing in

any other way. Currently, they use cross-link polyethylene which is a low density material that has relatively high rate of permeation. One material that could be used as a low permeation alternative in the rotational molding process is nylon. The use of nylon in the construction of these fuel tanks would reduce permeation by more than 95 percent when compared to cross-link polyethylene such as is used today.

Another type of barrier technology for fuel tanks would be to treat the surfaces of a plastic fuel tanks with fluorine. The fluorination process causes a chemical reaction where exposed hydrogen atoms are replaced by larger fluorine atoms which a barrier on surface of the fuel tank. In this process, fuel tanks are be stacked in a steel container. The container is then be voided of air and flooded with fluorine gas. By pulling a vacuum in the container, the fluorine gas is forced into every crevice in the fuel tanks. As a result of this process, both the inside and outside surfaces of the fuel tank would be treated. As an alternative, for tanks that are blow molded, the inside surface of the fuel tank can be exposed to fluorine during the blow molding process. A similar barrier strategy is called sulfonation where sulfur trioxide is used to create the barrier by reacting with the exposed polyethylene to form sulfonic acid groups on the surface. Either of these processes can be used to reduce gasoline permeation by more than 95 percent.⁷

About a third of fuel tanks installed in boats are made of metal, primarily aluminum. Hydrocarbons do not permeate through metal.

3.3.2.8.2 - Fuel Hose Materials

The majority of fuel hoses used in boats today are made of nitrile rubber (NBR), reinforced with fabric and/or wire, and finished with a heat-resistant cover. The Coast Guard requires that these hoses meet the specifications in SAE J1527 which include fire resistance, strength, flexibility durability, and permeation requirements.^{8,9} The permeation requirement for fuel hoses is 100 g/m²/day at 23°C. Because NBR has a high permeation rate (669 g-mm/m²/day¹⁰) current marine hoses just meet this standard. In contrast, materials used in current automotive fuel lines are two to three orders of magnitude less permeable.¹¹ By replacing rubber hoses with low permeability hoses, evaporative emissions through the fuel and vent hoses can be reduced by more than 95 percent.

Low permeability hoses produced today are generally constructed in two ways: of low permeability rubber blends or with a low permeability barrier layer. One hose design, already used in some marine applications, uses a thermoplastic layer between two rubber layers to control permeation. This thermoplastic barrier may either be nylon or ethyl vinyl alcohol. In automotive applications, other barrier materials are used such as fluoroelastomers and fluoroplastics such as Teflon[®]. An added benefit of low permeability lines is that some fluoropolymers can be made to conduct electricity and therefore can prevent the buildup of static charges.¹²

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CHAPTER 4: Technological Feasibility

Section 213(a)(3) of the Clean Air Act presents statutory criteria that EPA must evaluate in determining standards for nonroad engines and vehicles including marine vessels. 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."

We are proposing new motorcycle standards under the authority of section 202 of the Clean Air Act. Sections 202(a) and (b) of the Act provide EPA with the general authority to prescribe vehicle standards, subject to any specific limitations otherwise included in the Act. Section 202(a)(1) of the Act directs us to establish standards regulating the emission of any air pollutant from an class or classes of new motor vehicles or engines that, in the Administrator's judgement, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Section 202(a)(2) directs the Administrator to provide lead time sufficient to "permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period." Section 202(a)(3)(E) directs the Administrator, in establishing emission standards for highway motorcycles, to "consider the need to achieve equivalency of emission reductions between motorcycles and other motor vehicles to the maximum extent practicable."

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 - Highway Motorcycles

The proposed emission standards for highway motorcycles are summarized in the Executive Summary. As discussed in Chapter 3, we believe there are several technologies that can be used to reduce exhaust emissions from highway motorcycles. This section presents certification emissions data on a range of emissions levels achieved using different technology options. The following sections summarize the data and rationale supporting the proposed emission standards for highway motorcycles.

In the development of this proposal following the publication of the ANPRM we considered several regulatory alternatives. These included: no revision to the standards, harmonization with one of the "tiers" of California standards (current, 2004 Tier-1, 2008 Tier-2), more stringent standards than those in place in California, or possibly different implementation timing. We also considered various alternatives designed to reduce the burden on small manufacturers (these are presented in Chapter 8 on the Regulatory Flexibility Act).

After considering comments on the ANPRM, we believe that the standards should be revised. The existing federal standards were established more than twenty years ago, and it is clear that emission control technology has advanced a great deal in that time. California has continued to revise their standards to maintain some contact with current technology, and manufacturers have generally (but not uniformly) responded by producing motorcycles for sale nationwide that meet the more stringent California standards. Thus, in large part the existing federal standards has been superseded because of the preponderance of manufacturers that have responded in this way. Those arguing against new emission standards often cite the fact that motorcycles are typically far cleaner than the existing federal standards require. Although we agree, we see this fact as a reason for improving emission standards and as evidence that the current federal standards are out of touch with the reality of today's technology.

We believe it is most appropriate at this time to propose harmonizing with the California exhaust emission standards, as opposed to other options discussed in the ANPRM. For example, the dissimilarities between on- and off-highway motorcycles do not encourage a one-size-fits-all approach for all motorcycles (this opinion is supported by a significant number of those who commented on the ANPRM). Off-highway motorcycles are powered predominantly by two-stroke engines, whereas highway motorcycles are all powered by four-stroke engines as of the 2002 model year. On- and off-highway motorcycle engines also lie at vastly different ends of the size spectrum. The average highway motorcycle sold today has a displacement of nearly 1000cc, whereas almost 90 percent of off-highway motorcycle engines have an engine displacement of less than 350cc. In addition, on- and off-highway motorcycles are used in very different ways; finding a set of standards and a test procedure that adequately represents the typical range of operation for both types would therefore be extremely challenging. On-highway motorcycle manufacturers have commented that, to the extent the standards are revised, harmonization with California, rather than a distinctly different set of standards, is preferable because it eliminates the possibility of needing two distinct product lines for California and Federal regulations.⁷

Delaying implementation of the California standards on a nationwide basis by two years would provide an opportunity for manufacturers to gain some experience with the technology needed to meet the new standards. Two years provides time for technology optimization and cost reduction. Providing a longer delay could potentially provide the option of a further decrease in the level of the emission standards, given that the technological feasibility of the California standards has been adequately demonstrated (at least one manufacturer is already selling a motorcycle meeting the 2008 California standards). However, this would be a tradeoff against a more timely introduction of the new standards.

We also evaluated whether the federal motorcycle program should incorporate averaging provisions, as the California program does. Given the desire of most manufacturers to manufacture a motorcycle for nationwide sale, such a program without averaging would not be

⁷ See comments on the ANPRM from Harley-Davidson and the Motorcycle Industry Council, available in the public docket for review.

desirable because it would not provide the flexibility needed to meet the California and federal requirements together and could have at least potentially led to a somewhat less stringent Federal standard. Therefore, we are proposing to provide an averaging program comparable to California's.

4.1.1 - Class I and II Motorcycles

4.1.1.1 - Class I Motorcycles Above 50cc and Class II Motorcycles

As noted above, we are proposing to adopt the current California standards for Class I and Class II motorcycles. These standards have been in place in California since 1982. The question of whether or not these standards are technically feasible has been answered in the affirmative, since 21 of the 22 EPA-certified 2001 model year motorcycle engine families in these classes are already certified to these standards, and all 24 of the 2002 model year engine families meet these standards. These 24 engine families are all powered by four-stroke engines, with a variety of emission controls applied, including basic engine modifications on almost all engine families, secondary air injection on three engine families, and a two-way oxidation catalyst on one engine family.

In past model years, but not in the 2002 model year, an engine family that does not meet the California standards had certified to the existing federal standards and not sold in California. It was a 100cc dual-sport motorcycle powered by a two-stroke engine, with an HC certification level of 3.9 g/km. This motorcycle no longer appears to be available as of the 2002 model year. Adopting the California standards for these motorcycle classes could preclude this motorcycle or others like it from being certified and sold federally, unless the federal program includes additional flexibility relative to the California program. As discussed above, we are proposing that the HC standard for Class I and Class II motorcycles be an averaging standard, in a departure from California's treatment of these motorcycle classes. This in itself could be of limited use given the low number of Class I and Class II engine families, but, as discussed in Section V.C.2 above, we are also proposing to allow credits accumulated by certifying Class III engine families to a level lower than the standard to be used to offset Class I or Class II engine families certified to levels above the fleet-average standard.⁸

4.1.1.2 - Class I Motorcycles Under 50cc

As we have described earlier we are proposing to apply the current California standard for Class I motorcycles to motorcycles with displacements of less than 50cc (e.g., most motor scooters). These motorcycles are currently not subject to regulation by the U.S. EPA or by the

⁸ The manufacturer that had certified this two-stroke for highway use has typically certified 4-5 other Class I or II engine families; therefore, a basic averaging program could enable them to continue to market their two-stroke dual-sport. However, other manufacturers may not have adequate additional engine families in these classes, making a basic averaging standard less useful to them.

State of California. They are, however, subject to emission standards in Europe and much of the rest of the world. Historically these motorcycles have been powered by 2-stroke engines, but a trend appears to be developing that would result in most of these being replaced by 4-stroke engines or possibly by advanced technology 2-stroke engines, in some cases with catalysts.

The 4-stroke engine is capable of meeting our proposed standards. Class I motorcycles above 50cc are already meeting it, most of them employing nothing more than a 4-stroke engine. For example, the existing Class I scooters certify at levels ranging from 0.4 to 0.8 grams per kilometer HC. All of these achieve the standards with 4-stroke engine designs, and only one incorporates additional technology (a catalyst). These engines range from 80 to 151cc in displacement, indicating that a smaller engine should encounter few problems meeting the proposed standards.

In order to meet more stringent standards being implemented worldwide, manufacturers are developing and implementing a variety of options. Honda, perhaps the largest seller of scooters in the U.S., has entirely eliminated 2-stroke engines from their scooter product lines as of the 2002 model year. They continue to offer a 50cc model, but with a 4-stroke engine. Both of Aprilia's 49cc scooters available in the U.S. have incorporated electronic direct injection technology, which, in the case of one model, enables it to meet the "Euro-2" standards of 1.2 grams per kilometer HC and 0.3 grams per kilometer NOx, without use of a catalytic converter.⁹ Piaggio, while currently selling a 49cc basic 2-stroke scooter in the U.S., expects to begin production of a direct injection version in 2002, and a 4-stroke 50cc scooter is also in development. Numerous 49cc models marketed by Piaggio in Europe are available either as a 4-stroke or a 2-stroke with a catalyst. Piaggio, also an engine manufacturer and seller, is already offering a 50cc 4-stroke engine to its customers for incorporation into scooters.

The U.S. represents a very small portion of the market for small motorcycles and scooters. There are few, if any, manufacturers that develop a small-displacement motorcycle exclusively for the U.S. market; the domestic sales volumes do not appear large enough at this time to support an industry of this kind. The Italian company Piaggio (maker of the Vespa scooters), for example, sold about as many scooters worldwide in 2000 (about 480,000) as the entire volume of highway motorcycles of all sizes sold in the U.S. in that year. U.S. sales of Vespas in 2000 amounted to about 4800. The largest scooter markets today are in South Asia and Europe, where millions are sold annually. In Taiwan alone almost 800,000 motorcycles were sold domestically. More than one third of these were powered by 2-stroke engines. Two- and three-wheelers constitute a large portion of the transportation sector in Asia, and in some urban areas these vehicles - many of them powered by 2-stroke engines - can approach 75 percent of the vehicle population. According to a World Bank report, two-stroke gasoline engine vehicles

⁹ Aprilia website,
<http://www.apriliausa.com/ridezone/ing/models/scarabeo50dt/moto.htm>.

are estimated to account for about 60 percent of the total vehicle fleet in South Asia.¹⁰

Many nations are now realizing that the popularity of these vehicles and the high density of these vehicles in urban areas are contributing to severe air quality problems. As a consequence, some of the larger small motorcycle markets in Asia and India are now placing these vehicles under fairly strict regulation. It is clear that actions in these nations will move the emission control technology on small motorcycles, including those under 50cc, in a positive direction. For example, according to the World Bank report, beginning in 2000 catalytic converters will be installed in all new two-stroke engine motorcycles in India, and 2003 standards in Taiwan will effectively ban new two-strokes with emission standards so stringent that only a four-stroke engine is capable of meeting them.

Given the emerging international picture regarding emission standards for scooters, we believe that scooter manufacturers will be producing scooters of less than 50cc displacement that meet our proposed standards well in advance of the 2006 model year, the first year we propose to subject this category of motorcycle to U.S. emission standards. We request comment on this assessment.

There are other numerous factors in the international arena that may affect the product offerings in the less than 50cc market segment. For example, Europe recently changed the laws regarding insurance and helmet use for under 50cc scooters and mopeds. Previously, the insurance discounts and lack of helmet requirements in Europe provided two relatively strong incentives to purchasers to consider a 49cc scooter. Recently, however, the provisions were changed such that helmets are now required and the insurance costs are comparable to larger motorcycles. The result was a drop of about 30% in European sales of 49cc scooters in 2001 due to customers perceiving little benefit from a 49cc scooter relative to a larger displacement engine.

4.1.2 - Class III Motorcycles

4.1.2.1 - Tier-1 Standards

In the short term, the proposed Tier-1 HC+NO_x standard of 1.4 g/km HC+NO_x reflects the goal of achieving emission reductions that could be met with reasonably available control technologies, primarily involving technologies less costly and complex, and more easily adaptable to the vast majority of motorcycles, than catalytic converters. As noted earlier, we are proposing that this standard become effective starting with the 2006 model year. Based on current certification data, a number of existing engine families would already comply with this standard or would need relatively simple modifications to comply. In other cases, the

¹⁰ Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles. Masami Kojima, Carter Brandon, and Jitendra Shah. December 2000. Prepared for the World Bank. Available in the public docket for review, or on the internet at: <http://www.worldbank.org/html/fpd/esmap/publication/airquality.html>.

manufacturers will need to use control technologies that are available but are not yet used on their particular vehicles (e.g., electronic fuel injection to replace carburetors, changes to cam lobes/timing, etc.). For the most part, manufacturers will not need to use advanced technologies such as close-coupled, closed-loop three way catalysts.

While manufacturers will use various means to meet the Tier-1 standard, there are four basic types of existing, non-catalyst-based, emission control systems available to manufacturers. The most important of these is the use of secondary pulse-air injection. Other engine modifications and systems include more precise fuel control, better fuel atomization and delivery, and reduced engine-out emission levels from engine changes. These technologies are used in varying degrees today and are not expected to result in a loss of performance. The combinations of low-emission technologies ultimately chosen by motorcycle manufacturers are dependent on the engine-out emission levels of the vehicle, the effectiveness of the prior emission control system, and individual manufacturer preferences.

Secondary pulse-air injection, as demonstrated on current motorcycles, is applied using a passive system (i.e., no air pump involved) that takes advantage of the flow of gases (“pulse”) in the exhaust pipes to draw in fresh air that further combusts unburned hydrocarbons in the exhaust. Engine modifications include a variety of techniques designed to improve fuel delivery or atomization; promote “swirl” (horizontal currents) and “tumble” (vertical currents); maintain tight control on air-to-fuel (A/F) ratios; stabilize combustion (especially in lean A/F mixtures); optimize valve timing; and retard ignition timing.

4.1.2.1.1 - Secondary 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, 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. Sixty-five of the 151 2001 model year Class III engine families certified for sale in the U.S employ secondary pulse-air injection to help meet the current California standards. We anticipate that most of the remaining engine families will use this technique to help meet the Tier-1 and Tier-2 standards.

4.1.2.1.2 - Improving Fuel Delivery and Atomization

Improving fuel delivery and atomization primarily involves the replacement of carburetors, currently used on most motorcycles, with more precise fuel injection systems. There are several types of fuel injection systems and components manufacturers can choose. The most likely type of fuel injection manufacturers will choose to help meet the Tier-1 standard is

sequential multi-point fuel injection (SFI).

Unlike conventional multi-point fuel injection systems that deliver fuel continuously or to paired injectors at the same time, sequential fuel injection can deliver fuel precisely when needed by each cylinder. With less than optimum fuel injection timing, fuel puddling and intake-manifold wall wetting can occur, both of which hinder complete combustion. Use of sequential-fuel- injection systems help especially in reducing cold start emissions when fuel puddling and wall wetting are more likely to occur and emissions are highest.

Motorcycle manufacturers are already beginning to use sequential fuel injection (SFI). Improved emission levels are one benefit of a fuel injection system relative to carburetion, but other advantages include improved reliability and fuel economy. Of the 151 Class III motorcycle engine families certified for sale this year, 27 employ SFI systems. These 27 engine families account for about 30 percent of projected 2001 sales, indicating that these engine families represent some popular motorcycle models. Indeed, three models that are among the highest-selling - two from Harley-Davidson and one from Honda - are equipped with SFI. We anticipate increased applications of this or similar fuel injection systems to achieve the more precise fuel delivery needed to help meet the Tier-1 and Tier-2 standards.

4.1.2.1.3 - Engine Modifications

In addition to the techniques mentioned above, various engine modifications can be made to improve emission levels. Emission performance can be improved, for example, by reducing crevice volumes in the combustion chamber. Unburned fuel can be trapped momentarily in crevice volumes before being subsequently released. Since trapped and re-released fuel can increase engine-out emissions, the elimination of crevice volumes would be beneficial to emission performance. To reduce crevice volumes, manufacturers can evaluate the feasibility of designing engines with pistons that have reduced, top "land heights" (the distance between the top of the piston and the first ring).

Lubrication oil which leaks into the combustion chamber also has a detrimental effect on emission performance since the heavier hydrocarbons in oil do not oxidize as readily as those in gasoline and some components in lubricating oil may tend to foul the catalyst and reduce its effectiveness. Also, oil in the combustion chamber may trap HC and later release the HC unburned. To reduce oil consumption, manufacturers can tighten the tolerances and improve the surface finish on cylinders and pistons, piston ring design and materials, and exhaust valve stem seals to prevent excessive leakage of lubricating oil into the combustion chamber.

Increasing valve overlap is another engine modification that can help reduce emissions. This technique helps reduce NO_x generation in the combustion chamber by essentially providing passive exhaust gas recirculation (EGR). When the engine is undergoing its pumping cycle, small amounts of combusted gases flow past the intake valve at the start of the intake cycle. This creates what is essentially a passive EGR flow, which is then either drawn back into the cylinder

or into another cylinder through the intake manifold during the intake stroke. These combusted gases, when combined with the fresh air/fuel mixture in the cylinder, help reduce peak combustion temperatures and NO_x levels. This technique can be effected by making changes to cam timing and intake manifold design to optimize NO_x reduction while minimizing impacts to HC emissions.

4.1.2.2 - Analysis of EPA Certification Data

Secondary pulse-air injection and engine modifications already play important parts in reducing emission levels; we expect increased uses of these techniques to help meet the Tier-1 standard. Direct evidence of the extent these technologies can help manufacturers meet the Tier-1 standard can be found in the ARB on-road motorcycle certification database. This database is comprised of publicly-available certification emission levels and confidential data (e.g., projected sales of each certified engine family) reported by the manufacturers pursuant to existing requirements. If one thing is clear from the EPA certification data, it is that the vast majority of motorcycles are certifying at emission levels well below the existing federal HC standard. The average certification HC level for 2001 Class III motorcycles is 1.0 g/km (the existing EPA standard is 5.0 g/km). This is due in large part to the fact that manufacturers are designing one engine family to market in all 50 states; therefore, it is the California requirements that are driving the emission levels down nationwide. In addition, European nations and others around the world are pursuing lower motorcycle emission levels, contributing further to the trend of lower overall emissions from companies that want to market a worldwide product.

The California ARB reports that discussions with manufacturers revealed that typical NO_x levels range from about 0.5 to 0.7 g/km. Some in-use data collected by the California ARB indicates an average NO_x level for the 109 motorcycles tested of 0.53 g/km. Restricting the data to 44 1988 and later non-tampered Class III motorcycles results in an average NO_x level of 0.5 g/km. Only seven out of these 44 motorcycles had NO_x levels that exceeded 0.7 g/km. In addition, some recent data from 16 1997-1999 Class III motorcycles tested by Environment Canada found an average NO_x level of 0.3 g/km, with a maximum of 0.5 g/km. For the purposes of our analysis we will use the upper end of the range reported by the California ARB, or 0.7 g/km.

Of the 151 Class III motorcycle engine families certified for the 2001 model year, 78, or just over 50 percent, could be certified to HC+NO_x levels up to 1.6 g/km today. Although 1.6 g/km would be in excess of the standard, we believe that the reduction required to get below the standard of 1.4 g/km HC+NO_x is minimal enough such that advanced technologies like high-efficiency two- or three-way catalysts would not be required. Table 4.1-1 shows the breakdown of the emission control technologies used by these 78 engine families that could potentially certify to the Tier-1 standards today. Only seven of these, or less than ten percent, use 3-way catalysts. The remaining 74 could be able to certify near the proposed Tier-1 HC+NO_x level by using simpler and less costly engine modifications and secondary air injection. Only 16 of these 74 use a two-way catalyst.

**Table 4.1-1
Breakdown of HC+NOx Estimated Certification Levels by Technology Use**

Estimated HC+NOx Certification Level	No. of Engine Families	No. of Engine Families Using Specified Technology			
		Engine Modifications ^A	Pulse Air Injection	2-way Ox-Cat.	3-way Catalyst
0.9 - 1.2	26	18	17	7	2
1.3 - 1.4	31	32	10	6	2
1.5 - 1.6	21	17	7	3	0
Total	78	67	34	16	7

^A Includes all forms of fuel injection, electronic control modules, etc.

Source: 2001 U.S. EPA Certification Database

In addition, we are confident that the two years of experience gained by manufacturers in meeting the new standard in California prior to having to extend compliance nationwide will help ensure that the new emission control systems are fully developed and fully capable of meeting the new standards on a nationwide basis.

4.1.2.3 - Tier-2 Standards

In the long term, the proposed Tier-2 HC+NOx standard of 0.8 g/km will ensure that manufacturers will continue to advance the status of control technologies. We are proposing the Tier-2 standard to be effective by the 2010 model year. This standard will present some challenges for manufacturers; however, several manufacturers are already using some of the technologies that will be needed to meet this standard. In addition, our proposed implementation time frame gives manufacturers two years of experience in meeting this standard in California before having to meet it on a nationwide basis. At least one manufacturer already uses closed-loop, three-way catalysts on several of its product lines, and another is already marketing a large touring motorcycle that meets this standard. Depending upon assumptions regarding NOx levels, other manufacturers have products on the market today with emission levels that could meet or almost meet the Tier-2 standards using two-way catalysts, fuel injection, secondary pulse-air injection, and other engine modifications. We expect that the significant lead time prior to meeting these standards on a nationwide basis will allow manufacturers to optimize these and other technologies to meet the Tier-2 standard.

To meet the Tier-2 standard for HC+NOx, manufacturers will likely use more advanced engine modifications and secondary air injection. Specifically, we believe manufacturers will use computer-controlled secondary pulse-air injection (i.e., the injection valve would be connected to a computer-controlled solenoid). In addition to these systems, manufacturers will

probably need to use catalytic converters on some motorcycles to meet the Tier-2 standards. There are two types of catalytic converters currently in use: two-way catalysts (which control only HC and CO) and three-way catalysts (which control HC, CO, and NO_x). Under the Tier-2 standard, manufacturers will need to minimize levels of both HC and NO_x. Therefore, to the extent catalysts are used, manufacturers will likely use a three-way catalyst in addition to engine modifications and computer-controlled, secondary pulse-air injection. These types of technologies are used in varying degrees on current models and are not expected to result in a loss of performance.

4.1.2.4.1 - Improving Fuel Control and Delivery

As discussed previously, improving fuel control and delivery provides emission benefits by helping to reduce engine-out emissions and minimizing the exhaust variability which the catalytic converter experiences. One method for improving fuel control is to provide enhanced feedback to the computer-controlled fuel injection system through the use of heated oxygen sensors. Heated oxygen sensors (HO₂S) are located in the exhaust manifold to monitor the amount of oxygen in the exhaust stream and provide feedback to the electronic control module (ECM). These sensors allow the fuel control system to maintain a tighter band around the stoichiometric A/F ratio than conventional O₂ sensors. In this way, HO₂S assist vehicles in achieving precise control of the A/F ratio and thereby enhance the overall emissions performance of the engine. At least one manufacturer is currently using this technology on several 2001 engine families.

In order to further improve fuel control, some motorcycles with electronic controls may utilize software algorithms to perform individual cylinder fuel control. While dual oxygen sensor systems are capable of maintaining A/F ratios within a narrow range, some manufacturers may desire even more precise control to meet their performance needs. On typical applications, fuel control is modified whenever the O₂S determines that the combined A/F of all cylinders in the engine or engine bank is “too far” from stoichiometric. The needed fuel modifications (i.e., inject more or less fuel) are then applied to all cylinders simultaneously. Although this fuel control method will maintain the “bulk” A/F for the entire engine or engine bank around stoichiometric, it would not be capable of correcting for individual cylinder A/F deviations that can result from differences in manufacturing tolerances, wear of injectors, or other factors.

With individual cylinder fuel control, A/F variation among cylinders will be diminished, thereby further improving the effectiveness of the emission controls. By modeling the behavior of the exhaust gases in the exhaust manifold and using software algorithms to predict individual cylinder A/F, a feedback fuel control system for individual cylinders can be developed. Except for the replacement of the conventional front O₂S with an HO₂S sensor and a more powerful engine control computer, no additional hardware is needed in order to achieve individual cylinder fuel control. Software changes and the use of mathematical models of exhaust gas mixing behavior are required to perform this operation.

In order to maintain good driveability, responsive performance, and optimum emission control, fluctuations of the A/F must remain small under all driving conditions including transient operation. Virtually all current fuel systems in automobiles incorporate an adaptive fuel control system that automatically adjusts the system for component wear, varying environmental conditions, varying fuel composition, etc., to more closely maintain proper fuel control under various operating conditions. For some fuel control systems today, this adaptation process affects only steady-state operating conditions (i.e., constant or slowly changing throttle conditions). However, most vehicles are now being introduced with adaptation during "transient" conditions (e.g., rapidly changing throttle, purging of the evaporative system).

Accurate fuel control during transient driving conditions has traditionally been difficult because of the inaccuracies in predicting the air and fuel flow under rapidly changing throttle conditions. Because of air and fuel dynamics (fuel evaporation in the intake manifold and air flow behavior) and the time delay between the air flow measurement and the injection of the calculated fuel mass, temporarily lean A/F ratios can occur during transient driving conditions that can cause engine hesitation, poor driveability and primarily an increase in NO_x emissions. However, by utilizing fuel and air mass modeling, vehicles with adaptive transient fuel control are more capable of maintaining accurate, precise fuel control under all operating conditions. Virtually all cars sold in California will incorporate adaptive transient fuel control software; motorcycles with computer controlled fuel injection can also benefit from this technique at a relatively low cost.

4.1.2.4.2 - Three-way Catalytic Converters

Three-way catalytic converters traditionally utilize rhodium and platinum as the catalytic material to control the emissions of all three major pollutants (hydrocarbons (HC), CO, NO_x). Although this type of catalyst is very effective at converting exhaust pollutants, rhodium, which is primarily used to convert NO_x, 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 (light-off is defined as the catalyst bed temperature where pollutant conversion reaches 50% efficiency) 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 the Tier-2 standard, we expect manufacturers to use catalysts with cell densities of 300 to 400 cpsi. If catalyst volume is maintained at the same level (we assume volumes of up to 60% 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.

In addition to increasing catalyst volume and cell density, we believe that increased catalyst loading and improved catalyst washcoats will help manufacturers meet the Tier-2 standard. In general, 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 NO_x, and catalyst suppliers have been investigating methods to increase the amount of rhodium in catalysts for improved NO_x 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 Tier-2 standard at reduced cost relative to older three-way catalysts.

New washcoat formulations are now thermally stable up to 1050 °C. This is a significant improvement from conventional washcoats, which are stable only up to about 900 °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.

In addition to using computer-controlled secondary air injection and retarded spark timing to increase the heat provided to the catalyst, some vehicles may employ warm-up, pre-catalysts to reduce the size of their main catalytic converters. Palladium-only warm-up catalysts (also known as “pipe catalysts” or “Hot Tubes”) using ceramic or metallic substrates may be added to further decrease warm-up times and improve emission performance. Although metallic substrates are usually more expensive than ceramic substrates, some manufacturers and suppliers believe

metallic substrates may require less precious metal loading than ceramic substrates due to the reduced light-off times they provide.

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.

4.1.2.4.3 - Automotive Technologies

Besides the hardware modifications described above, motorcycle manufacturers may borrow from other current automobile techniques. These include using engine calibration changes such as a brief period of substantial ignition retard, increased cold idling speed, and leaner air-fuel mixtures to quickly provide heat to a catalyst after cold-starts. Only software modifications are required for an engine which already uses a computer to control the fuel delivery and other engine systems. For these engines, calibration modifications provide manufacturers with an inexpensive method to quickly achieve light-off of catalytic converters. When combined with pre-catalysts, computer-controlled secondary air injection, and the other heat conservation techniques described above, engine calibration techniques may be very effective at providing the required heat to the catalyst for achieving the Tier-2 standard. These techniques are currently in use on most low emission vehicle (LEV) automobiles and may have applications in on-road motorcycles.

4.1.3 - 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. Virtually all highway motorcycles are equipped with sound suppression systems or mufflers. The four-stroke engines used in highway motorcycles are considerably more quiet than the two-stroke engines used by many of their off-road counterparts. In addition, highway motorcycles are required to meet existing noise emission standards.

Adopting new technologies for controlling fuel metering and air-fuel mixing, particularly the conversion of some carbureted highway motorcycles to advanced fuel injection technologies, will lead to improvements in fuel consumption.

Many riders have expressed some concerns regarding the close proximity of the riders to hot exhaust pipes and the catalytic converter. Protecting the rider from the excessive heat is a concern for both riders and manufacturers. The current use of catalytic converters on a number of motorcycles (accounting for tens of thousands in the current fleet) already indicates that these issues are not insurmountable on a variety of motorcycle styles and engine sizes. A number of approaches to shielding the rider from the heat of the catalytic converter are possible, such as exterior pipe covers, shielded foot rests, and similar components. Some manufacturers have found that placing the converter on the underside of the engine can keep it adequately distant from the rider. Others may use double-pipe systems that reduce overall heat loss while remaining cooler on the exterior. Based on the significant lead time that would be allowed for meeting these standards, as well as on the two years of prior experience in California before meeting the requirements federally, we believe that these issues can be satisfactorily resolved for the proportion of motorcycles for which catalytic converters will be required.

We believe the technology discussed here would have no negative impacts on safety. Highway motorcycles have been predominantly powered by four-stroke engines for more than twenty years. Catalytic converters, secondary air injection, and fuel injection technologies have been increasingly used on highway motorcycles for a number of years, without any known adverse safety impacts.

4.1.4 - Conclusion

4.1.4.1 - Tier-1 Standards

We expect that the Tier-1 standard will be met with reasonably available control technologies. A number of existing engine families would already comply with this standard or would need relatively simple modifications to comply. In other cases, the manufacturers will need to use control technologies that are available but are not yet used on their particular vehicles (e.g., electronic fuel injection to replace carburetors, secondary pulse air injection, changes to cam lobes/timing, etc.). For the most part, manufacturers will not need to use advanced technologies such as close-coupled, closed-loop three way catalysts. The ultimate combinations of low-emission technologies ultimately chosen by motorcycle manufacturers are dependent on the engine-out emission levels of the vehicle, the effectiveness of the prior emission control system, and individual manufacturer preferences.

4.1.4.2 - Tier-2 Standards

We expect that the Tier-2 standard will likely require the use of more advanced engine modifications and secondary air injection. Depending upon assumptions regarding NO_x levels, some manufacturers have products on the market today with emission levels that could meet or almost meet the Tier-2 standard using two-way catalysts, fuel injection, secondary pulse-air injection, and other engine modifications. We believe that manufacturers will use computer-controlled secondary pulse-air injection, in addition to using catalytic converters on some

motorcycles to meet the Tier-2 standards. To the extent catalysts are used, manufacturers will likely use a three-way catalyst in addition to engine modifications and computer-controlled, secondary pulse-air injection. We expect that the significant lead time prior to meeting these standards on a nationwide basis will allow manufacturers to optimize these and other technologies to meet the Tier-2 standard.

4.2 - Evaporative Emission Control from Boats

The proposed emission standards for evaporative controls from marine vessels are summarized in the Executive Summary. As discussed in Chapter 3, we believe there are several technologies that can be used to reduce evaporative emissions from marine vessels as needed to meet the proposed standards. This section presents available emissions data on baseline emissions and on emission reductions achieved through the application of emission control technology. In addition, this section provides a description of the proposed test procedures for evaporative emission determination.

4.2.1 - Diurnal Evaporative Emissions

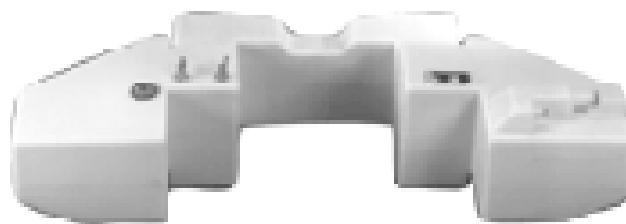
We are engaged in a test program to characterize baseline emissions from marine fuel tanks and to evaluate several emission reduction strategies. Although this test program is not complete, we present the initial results below. As we continue to collect test data, we will refine our proposed standard bins and our designs for the proposed design-based certification approach. This section first presents baseline emissions, then discusses several emission control strategies.

Figure 4.2-1 presents the fuel tanks that have been used for EPA testing of diurnal and permeation emissions. The plastic fuel tanks and one of the aluminum fuel tanks were produced for sale, while the other aluminum fuel tank was build by a tank manufacturer for this testing. However, this aluminum tank is in a configuration that is representative of fuel tanks used on marine vessels. One of the plastic tanks was a portable fuel tank while the other two were intended to be permanently installed into vessels. In addition, a bladder fuel tank was assembled for this testing.

Figure 4.2-1: Fuel Tanks Used In EPA Testing



Portable Plastic



Installed Plastic #1



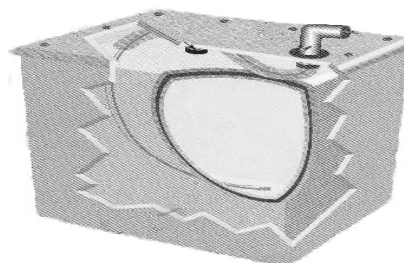
Aluminum #1



Installed Plastic #2



Aluminum #2



Bladder Tank

4.2.1.1 - Baseline Emissions

We tested three marine fuel tanks in their baseline configurations over the proposed certification test procedure for evaporative emissions in our laboratory. These fuel tanks included a portable plastic fuel tank and two aluminum fuel tanks. Aluminum tank #1 was constructed for this testing, but is representative of a typical fuel tank; aluminum tank # 2 was removed from an 18 foot runabout. The portable fuel tank was tested with its vent cracked open and the aluminum fuel tanks were tested with the venting through a length of $\frac{5}{8}$ inch hose. The advantage of using the aluminum fuel tanks for this testing was to exclude permeation emissions from the measured results.

As described later in Section 4.2.2, the test procedure involves a 24 hour diurnal from 72-

96°F (22.2-35.6°C) with a fuel tank filled to 40% of capacity with 9RVP^k test fuel. Under these conditions, the theoretical Wade equations (See Chapter 6) predict an emission level of about 2.3 g/gallon/day. However, this equation is known to over predict diurnal vapor generation and is generally corrected. Although the portable fuel tank was consistent with the Wade equations, we believe it was due to diffusion of vapor through the vent. This diffusion effect is discussed in more detail below. Because the plastic fuel tank was new at the time of testing, the material was not likely saturated with fuel; therefore the permeation component of the measured emissions should have been small.

Table 4.2-1: Baseline Diurnal Evaporative Emission Results (72-96°F)

<i>Tank Type</i>	<i>Manu- facturer</i>	<i>Vent Hose Length [cm]</i>	<i>Fuel Capacity [gallons]</i>	<i>Evaporative HC [g/gallon/day]</i>
Portable, polyethylene	Moeller	none	6	2.00*
Aluminum #1	Ezell	68	17	1.39
Aluminum #2	AFP	137	30	1.50

* tested with 50% fill (if adjusted to 40% fill using the Wade equations, would be about 2.3 g/gal/day)

We also tested aluminum tank #2 over three diurnal temperature swings that differ from the proposed test procedure. The temperature profiles used in this testing were based fuel temperatures measured with the whole boat in the SHED over the proposed test procedure. These profiles are discussed further below in the section on insulated fuel tanks. This tank was tested at 40% fill with 9RVP fuel. Table 4.2-2 presents the results compared to the Wade model. Although the Wade model over predicts the vapor generation, it does show a similar trend with respect to temperature.

Table 4.2-2: Baseline Diurnal Evaporative Emission Results (varied temperature)

<i>Temperatures</i>	<i>Evaporative HC [g/gallon/day]</i>	<i>Wade HC [g/gallon/day]</i>
24 - 33°C (74 - 91°F)	1.13	1.33
22 - 30°C (71 - 86°F)	0.88	1.02
25 - 31°C (77 - 88°F)	0.66	0.88

^k Reid Vapor Pressure (psi). This is a measure of the volatility of the fuel. 9 RVP represents a typical summertime fuel in northern states.

4.2.1.2 - Diffusion Effect

In testing diurnal emissions from fuel tanks with open vents, the configuration of the vent can have a significant effect on the measured emissions. This is due to diffusion of vapor out of the vent line. Depending on the size and configuration of the vent, diffusion can actually occur when the fuel temperature is cooling. To quantify this diffusion component for a typical fuel tank we ran the proposed diurnal test procedure for aluminum tank #1 using four configurations for venting. The first was with the fuel cap cracked open and the vent sealed, the second was with a 68 cm length of vent hose, and the third was with a 1000 micron limiting flow orifice in the vent opening. This 1000 micron orifice was large enough to allow venting without any measurable pressure increase in the fuel tank during the diurnal test. The fourth configuration was a combination of the limited flow orifice and the vent hose. Table 4.2-3 presents the results of this testing.

Table 4.2-3: Diurnal Test Results with Varied Venting Configurations

<i>Vent Configuration</i>	<i>Evaporative HC [g/gallon/day]</i>
cracked fuel cap	2.05
68 cm of $\frac{5}{8}$ " fuel hose	1.39
1000 micron orifice	1.47
1000 micron orifice + 68 cm of $\frac{5}{8}$ " fuel hose	1.34

The above data suggest that, at least for open vent fuel systems, the size and configuration of the venting system can have a significant effect on evaporative emissions. Therefore, the proposed test procedures require that the fuel tank be set up with a vent hose attached. This data suggests that diffusion emissions are minimal if the fuel tank is vented through a length of hose; therefore, we use the data on testing with a vent hose for our emission modeling (see Chapter 6). To further investigate this diffusion effect, we tested aluminum tank #1 with several venting configurations, at two constant temperature settings. Under these conditions, all of the measured evaporative emissions should be due to diffusion. As seen in Table 4.2-4, diffusion can be very high with too large of a vent opening unless a vent hose is used. The two lengths of vent hose tested did not show a significant difference in diffusion emissions. We believe that the vent hose limits diffusion by creating a gradual gradient in fuel vapor concentration.

Table 4.2-4: Diffusion Test Results with Varied Venting Configurations

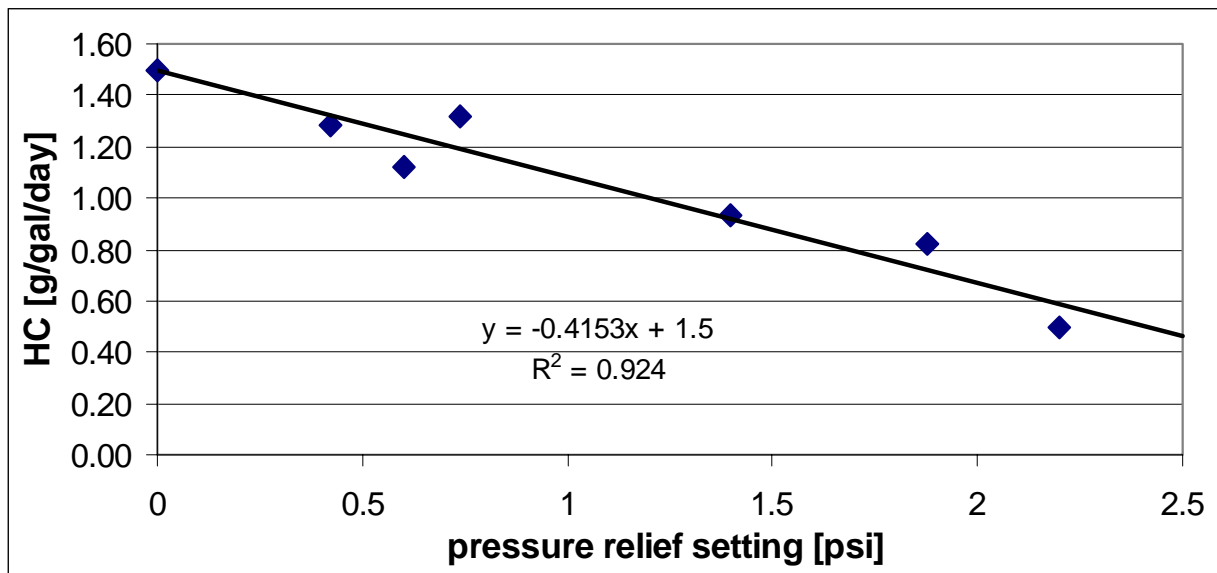
<i>Vent Configuration</i>	<i>22°C (72°F) Evaporative HC [g/gal/day]</i>	<i>36°C (96°F) Evaporative HC [g/gal/day]</i>
½" vent opening	5.65	10.0
68 cm of 5/8" fuel hose	0.11	0.18
137 cm of 5/8" fuel hose	0.07	0.24
1000 micron orifice	0.28	0.41

4.2.1.3 - Sealed System with Pressure Relief

By sealing a fuel tank, we can capture all of the evaporative emissions. However, this could cause large pressure build up in the tank. To control the amount of pressure built up into the tank, we looked at two types of pressure relief strategies: pressure relief valves and limited flow orifices. Because the Coast Guard requires that fuel systems not exceed 80 percent of their design capacity of 3 psi, we only looked at pressure relief strategies that would keep the pressure below 2.4 psi under worst case conditions.

For the pressure relief valve testing, we looked at several pressures ranging from 0.5 to 2.25 psi. The 2.25 psi valve was an off-the-shelf automotive fuel cap with a nominal 2 psi pressure relief valve and 0.5 psi vacuum relief valve. For the other pressure settings, we used another automotive cap modified to allow adjustments to the spring tension in the pressure relief valve. We performed these tests on the aluminum fuel tank to remove the variable of permeation. As shown in Figure 4.2-2, there was a fairly linear relationship between the pressure setting of the valve and the emissions measured over the proposed test procedure. At 1 psi, we believe a level of 1.1 g/gallon/day could be achieved.

Figure 4.2-2: Effect of Pressure Cap on Diurnal Emissions



Another strategy for maintaining a design pressure is to use a limited flow orifice on the vent. In our testing, we are looked at three orifice sizes: 25, 75, and 1,000 microns in diameter. Again, we are performed these tests, using the proposed test procedures, on aluminum tank #1 to remove the variable of permeation. To get these exact orifice sizes, we ordered from a company that specializes in boring holes with a laser device; however, these orifices were relatively inexpensive. It should be noted that a smaller tank would need a smaller orifice and a larger tank could use a larger orifice to build up the same pressure in the tank. The test results are presented in Table 4.2-5. For all of the tests with the limited flow orifices, no vent hose was attached.

Table 4.2-5: Diurnal Evaporative Emissions with Limited Flow Orifices

<i>Orifice Diameter (microns)</i>	<i>Peak Pressure [psi]</i>	<i>Evaporative HC [g/gallon/day]</i>
baseline (open vent with hose)	0.0	1.39
1000	0.0	1.47
75	1.6	1.16
25	3.1	0.24

By limiting the flow of the vapor from the tank, emissions were reduced with some pressure build up in the tank. However, because the vapor is flowing from the tank even at low pressure, this strategy is less effective for large emission reductions than a pressure relief valve

for a given tank pressure. In addition, the limited flow orifice would have to be sized for worst case conditions to prevent the tank from reaching too high of a pressure. This would limit the effectiveness of this strategy under typical conditions.

4.2.1.4 - Insulated Fuel Tank

By insulating the fuel tank, we can limit the temperature variation that the fuel in the tank is exposed to. By reducing the temperature variation, less vapor is formed due to fuel heating. In our preliminary testing, we insulated the flat, rotationally molded, fuel tank (plastic tank #2, 23 gallon capacity) using 3 inch thick construction foam with an R-value of 15 as defined by 16 CFR 460.5. This testing was performed with the fuel tank vent open to atmosphere. Table 4.2-6 presents the fuel temperatures and evaporative emissions over the three day test.

Consistent with the proposed test procedures, we tested this fuel tank over three diurnals and used the highest grams of the three 24 hour diurnals. This experiment resulted in a 50% reduction in emissions from baseline on the highest of these three days. The baseline emissions were measured to be 2.5 g/gallon/day; however it should be noted that for both the baseline test and the insulated tank tests we did not control for permeation or diffusion. Over this test, the emissions decreased for subsequent days. We believe this was due to the fuel temperature cycle stabilizing.

Table 4.2-6: Evaporative Emission Results for Insulated Flat, Plastic Tank

<i>Test Day</i>	<i>SHED Temperature</i>	<i>Fuel Temperature</i>	<i>Evaporative HC</i>
Day #1	22-36°C (72-96°F)	22-28°C (72-82°F)	1.2 g/gal/day
Day #2	22-36°C (72-96°F)	26-30°C (78-86°F)	1.0 g/gal/day
Day #3	22-36°C (72-96°F)	26-30°C (80-86°F)	0.8 g/gal/day

These results from this preliminary experiment are encouraging; however, we believe that it will be necessary to find a more appropriate insulation for this application. The construction foam is not designed to be durable when exposed to gasoline. Also, a thinner insulation would take up less space in a boat.

There is a certain amount of inherent insulation for a fuel tank installed in a boat. This is especially true for a boat that is stored in the water. The water acts as a cooling medium for the fuel tank, especially if it is installed in the bottom of the fuel tank. In addition, the thermal inertia of the fuel in the tank can act to dampen temperature variation imposed from the diurnal heating of the ambient air. The following charts present fuel and ambient temperature test data for two boats on trailers and two boats in the water.

Figure 4.2-3: Temperature Trace for Personal Watercraft on Trailer

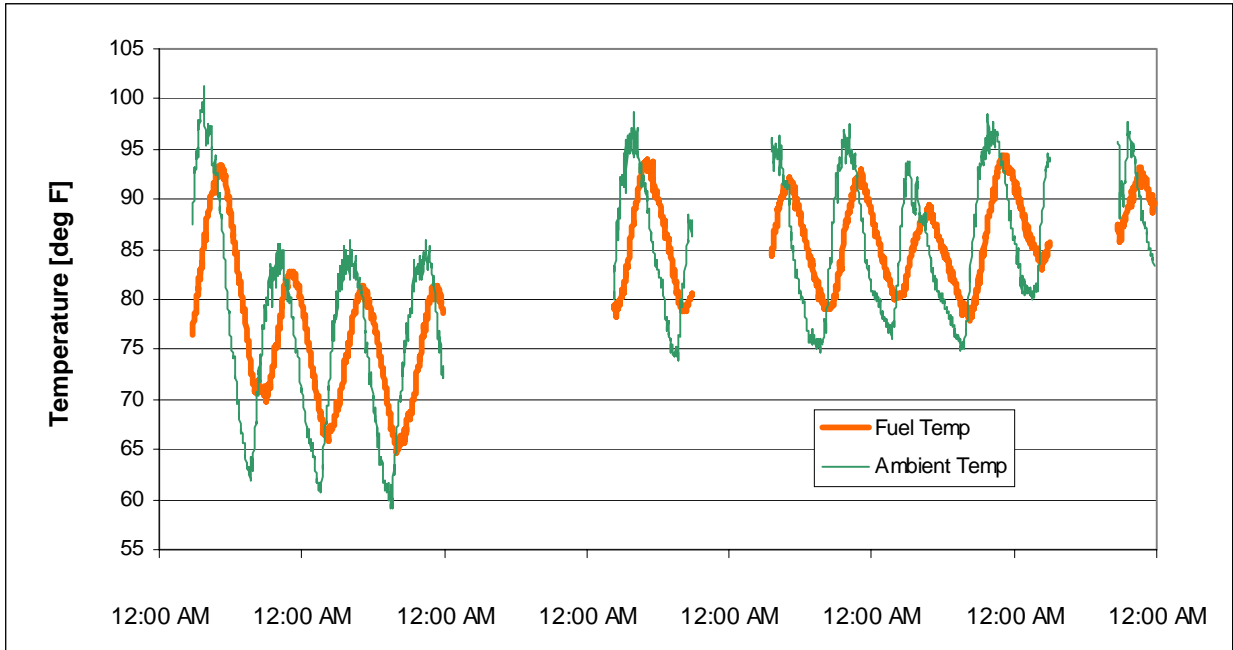


Figure 4.2-4: Temperature Trace for Runabout on Trailer

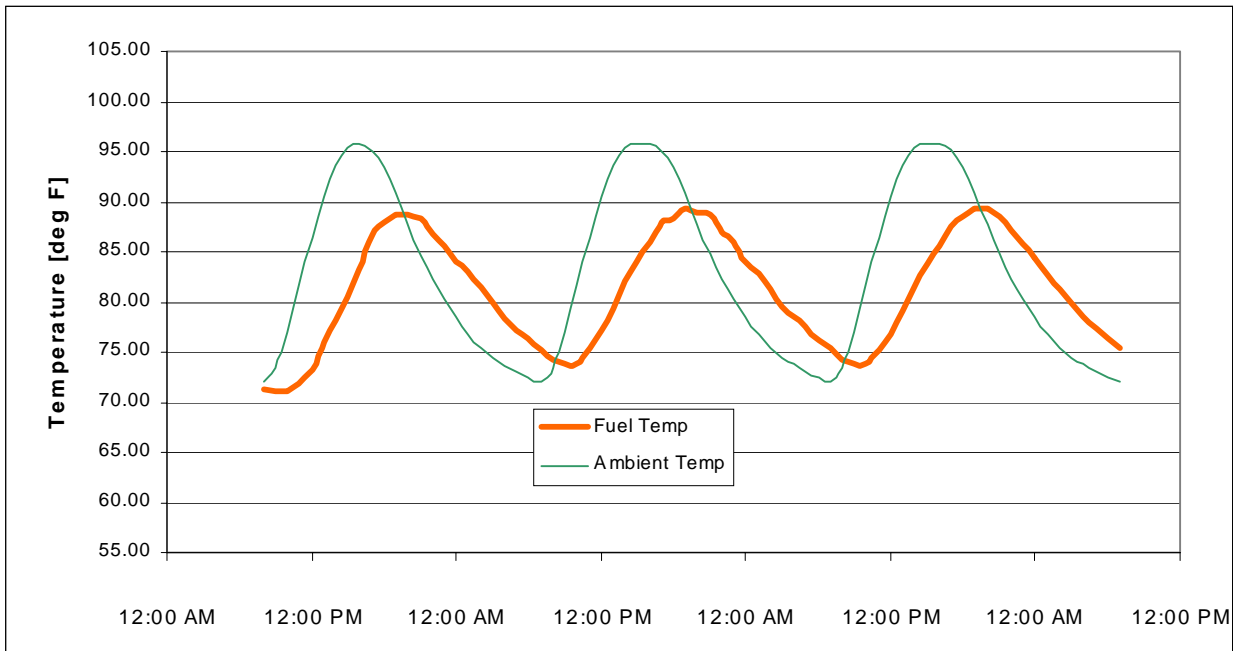


Figure 4.2-5: Temperature Trace for Runabout in Water

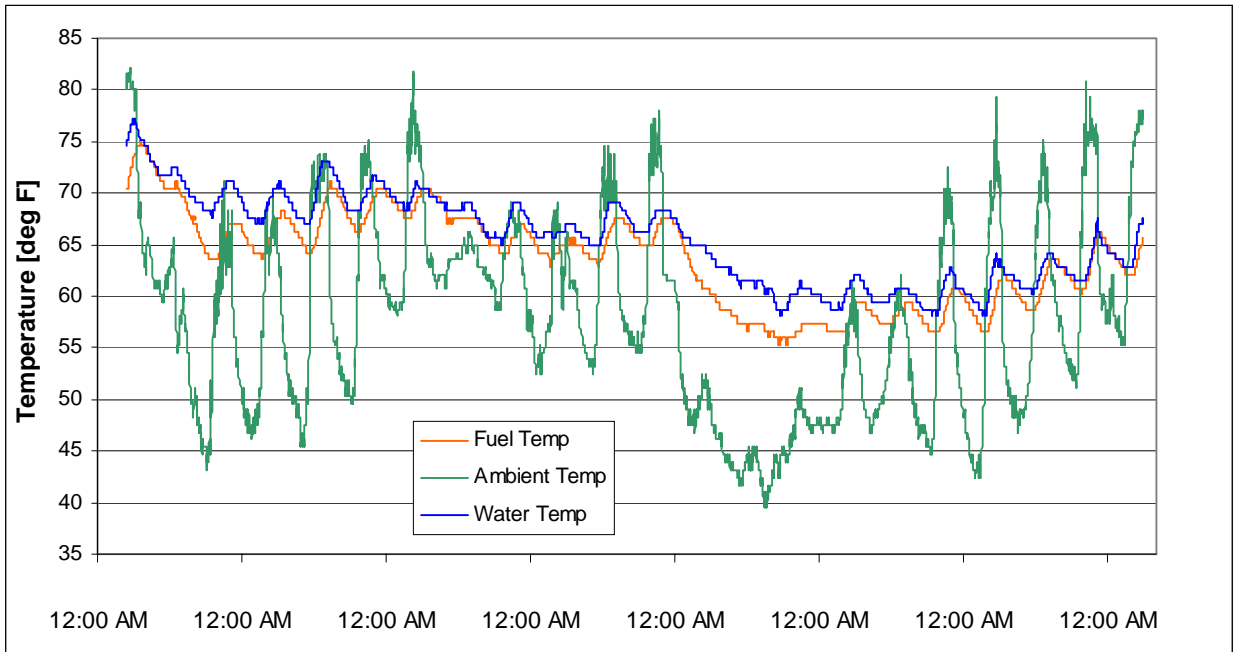
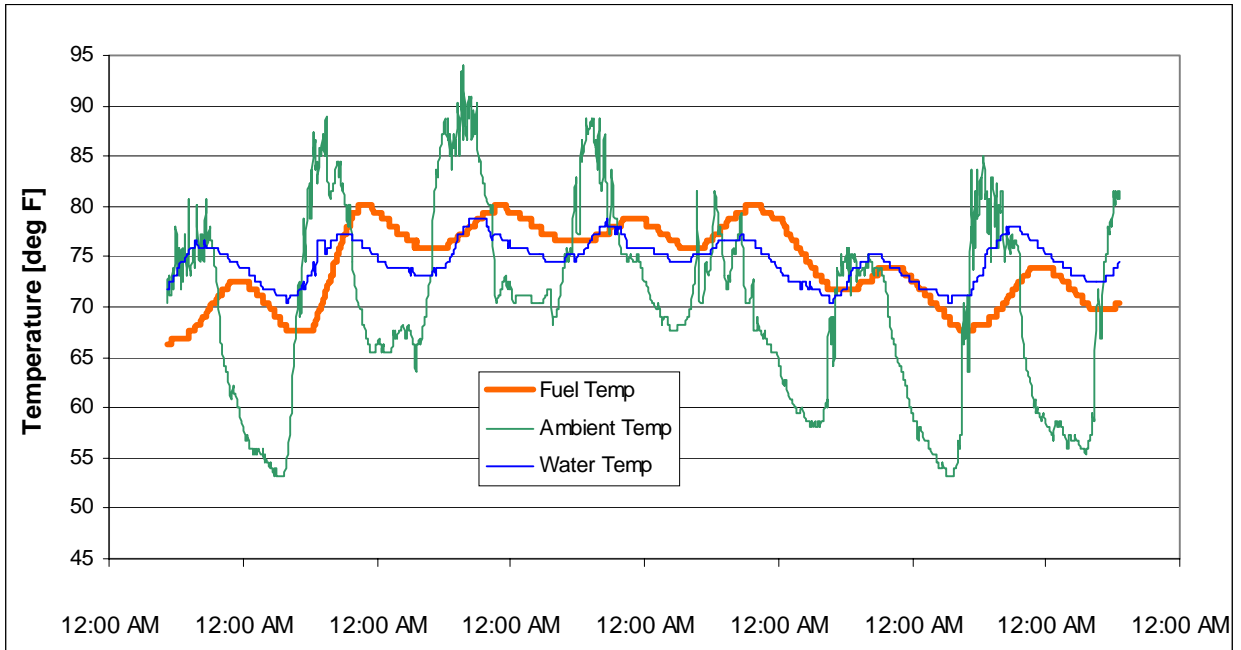


Figure 4.2-6: Temperature Trace of Deckboat in Water



4.2.1.5 - 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.¹ Once the fuel tank cools as ambient temperature goes down, the resulting vacuum in the fuel tank will open the bag back up.

We tested the portable plastic fuel tank with a 1.5 gallon volume compensating bag made out of tedlar. Tedlar is a light, flexible, clear plastic which we use in our labs for collecting exhaust emissions samples. In our testing, the pressure relief valve never opened because the volume compensating bag was able to hold the vapor pressure below 0.8 psi for each of the three days. This testing supports the theory that a volume compensating bag can be used to minimize pressure in a fuel tank, which in turn, reduces emissions when used in conjunction with a pressure relief valve.

We did see an emission rate of about 0.4 g/gal/day over the 3 day test. The emission rate was fairly constant, even when the ambient temperature was cooling during the test. This suggests that the emissions measured were likely permeation through tank. If there were a leak, or if the permeation were through the bag, no hydrocarbons would have been measured during the cooling periods.

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 fluorosilicon fiber.

4.2.1.6 - Bladder Fuel Tank

A bladder tank is installed in the fuel tank to hold the fuel. Because this bladder is collapsible, there is no space above the fuel where vapor can form; therefore, there are essentially no diurnal emissions. During refueling, because the bladder is collapsed when empty, very little vapor is displaced into the atmosphere. At least one manufacturer is currently manufacturing bladder fuel tanks for use in marine applications and information on this system is available in the docket.¹ In addition, because the bladder can be made of a low permeability material, permeation emissions from a bladder tank are low compared to a plastic tank. We tested a marine bladder fuel tank in our lab for both diurnal and permeation emissions. Over the diurnal

¹ The Ideal Gas Law states that pressure and volume are inversely related. By increasing the volume of the vapor space, the pressure can be held constant.

test procedure we saw an emission rate of 0.2 g/gal/day. Based on the results of our permeation testing (see 4.2.2.1), this measured emission rate was likely due to permeation through the bladder and not due to diurnal losses. The manufacturer of this bladder tank is now working with a barrier film that will reduce permeation emissions by more than 90 percent (see 4.2.2.1).

4.2.1.7 - Fuel and Vapor Separator

Another technology that we intend to test is a floating fuel and vapor separator. We plan to test a fuel tank with non-permeable plastic balls covering the surface of the fuel. This strategy is used in some stationary applications and may show good results in a SHED. However, we are concerned that this technology may not be applicable to marine applications where the fuel may slosh past the floating plastic balls.

4.2.2 - Permeation Evaporative Emissions

As discussed in Chapter 3, permeation from plastic fuel tanks and rubber hoses makes up a large fraction of the evaporative emissions from marine fuel systems. This section discusses current emission rates from these sources as well as potential permeation control technology.

4.2.2.1 - Fuel Tanks

Baseline emissions

We are investigating the permeation rates of fuel through the walls of polyethylene fuel tanks. Initial indications are that polyethylene fuel tanks have very high permeation rates compared to those used in automotive applications. The Coast Guard tested three rotationally molded plastic tanks at 40°C (104°F) for 30 days.² The results are presented in Table 4.2-7. Because permeation emissions are a function of surface area and wall thickness, there was some variation in the permeation rates from the three tanks on a g/gal/day basis.

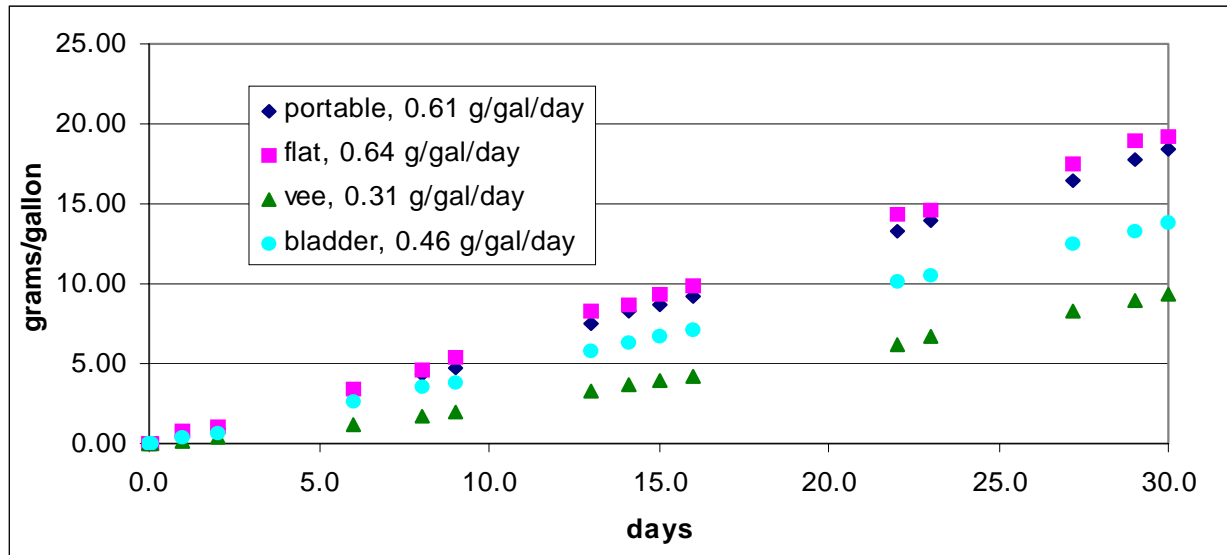
Table 4.2-7: Permeation Rates for Plastic Marine Fuel Tanks at 40°C

<i>Tank Capacity [gallons]</i>	<i>Permeation Loss [g/gal/day]</i>	<i>Average Wall Thickness [mm]</i>
12	1.48	5.3
18	1.39	5.6
18	1.12	6.9

We also tested four marine fuel tanks in our lab for permeation. They included the two cross-link fuel tanks and the portable fuel tank in Figure 4.2-1 as well as a bladder fuel tank. This test was performed over 30 days at 29°C (85°F) with gasoline. Prior to testing, the fuel

tanks had been stored with fuel in them for more than a month to stabilize the permeation rate. The permeation rates are presented in Figure 4.2-7. The flat plastic fuel tank showed a g/gal/day permeation rate that is consistent with the Coast Guard data in Table 4.2-7 (once corrected for temperature). However, the V-shaped tank showed about half of the permeation. This was likely due to the difference in geometry, primarily the thickness of the tank. Doubling the thickness of the tank would half the permeation rate. The portable fuel tank showed similar permeation rate as the flat cross-link tank. Although it is constructed of high-density polyethylene which has better resistance to fuel, the walls are considerably thinner because it is a smaller tank. For the same reason, the bladder tank showed g/gal/day permeation rates close to the plastic tanks. Although the bladder is constructed out of an aromatic polyester polyurethane sheet with a permeation which is considerably more resistant to fuel than polyethylene, the bladder thickness is less than a tenth of the thickness of the standard fuel tank.

Figure 4.2-7: Permeation Test Results on Four Marine Fuel Tanks at 29°C (85°F)



Permeation barrier technology

We are looking into low permeability tank materials. We are already aware that plastic automotive fuel tanks are capable achieving low permeation rates. This emission control is accomplished by forming multiple layers in the fuel tank through the blow molding process. Generally a low permeation barrier, such as nylon or ethyl vinyl alcohol, is sandwiched between layers of polyethylene. Another emission control strategy for blow molded tanks is the use of laminar barriers. In this technology, a polar polymer is mixed with the polyethylene in the blow molded process. As a result, non continuous barrier platelets form in the plastic which slow permeation by creating a longer path length for hydrocarbons passing through the tank wall. We believe that these strategies could be used with portable fuel tanks because these tanks are

generally blow-molded today.

As discussed in Chapter 3, the majority of plastic fuel tanks installed on boats are rotationally molded using a low density polyethylene. We are interested in testing barrier technologies and/or alternative materials that could be used with the rotational molding process. Barrier technologies include fluorination and sulfonation. The results from one study³ of these techniques on automotive high density polyethylene fuel tanks are shown below in Table 4.2-8. Because alcohol blended in the fuel can reduce the effectiveness of some strategies, this study looked at both gasoline and methanol blends. Table 4.2-8 presents the results with both gasoline and a 20 percent methanol blend. The 20 percent methanol blend is presented here because it was generally the worst case for each of these technologies. Fluorination consistently showed more than a 90 percent reduction in permeation emissions. We are planning to have a marine tank fluorinated so that we can test it for permeation in our lab.

Table 4.2-8: Permeation Rates for Low Permeation Fuel Tanks at Room Temperature

<i>Technology</i>	<i>Gasoline g/gal/day</i>	<i>20% Methanol g/gal/day</i>
High density polyethylene	0.13	0.12
Barrier platelets (Selar®)	0.06	0.07
Fluorination	0.01	0.01
Sulfonation	0.01	0.03
Multi-layer continuous barrier	0.01	0.03

To compare the above permeation rates to those in Table 4.2-7, they would have to be adjusted for temperature. As temperature increases, the permeation rates increase exponentially. For most materials, permeability increases by a factor of 2 or more for every 10°C increase in temperature.⁴ Therefore, the permeation rates in Table 4.2-8 may be four times as high at 40°C.

The California Air Resources Board (ARB) also investigated barrier platelets, fluorination, and sulfonation on portable fuel containers. This data is compiled in twelve data reports on their web site and is included in our docket.⁵ Table 4.2-9 presents a summary of this data which was collected using ARB Test Method 513.⁶ This permeation test method includes three stages: durability cycling, preconditioning, and testing in a variable temperature SHED. To ensure durability of the fuel container and surface treating, the fuel containers are cycled a minimum of 1000 times, over 8 hours, between 5 psi and -1 psi. The containers are then filled with gasoline and soaked for a minimum of four weeks to ensure that the permeation rate is stabilized. Actual permeation testing takes place in a variable temperature SHED. The fuel container is sealed and 24 hour variable temperature profile is applied that runs from 65°F to 105°F and back to 65°F.

The results of the ARB testing show that all three barrier technologies can be used to achieve significant reductions in permeation from plastic fuel containers. However, fluorination appeared to show the most consistent results. This variability is likely due to the quality of the barrier treatments. For instance, the effectiveness of the fluorination treatment would depend on the concentration of fluorine, temperature profile, vacuum, and length of time of the treatment process. We believe that it may be necessary to define certain parameters to ensure that these processes are applied appropriately for meeting the proposed standards.

Table 4.2-9: Permeation Rates for Low Permeation Fuel Containers Filled with California Reformulated Certification Fuel over a 65-105°F Diurnal

<i>Technology</i>	<i>Number of Tanks Tested</i>	<i>Average g/gal/day</i>	<i>Minimum g/gal/day</i>	<i>Maximum g/gal/day</i>
Low density polyethylene	1	0.99	0.99	0.99
High density polyethylene	12	0.85	0.49	1.63
Barrier platelets (Selar®)	16	0.44	0.05	0.98
Fluorination	37	0.08	0.03	0.25
Sulfonation	32	0.35	0.01	1.87

Over the first month or so of use, polyethylene fuel tanks can expand by as much as three percent due to saturation of the plastic with fuel. Manufacturers have raised the concern that this hydrocarbon expansion could affect the effectiveness of surface treatments like fluorination or sulfonation. We believe that this will not have a significant effect on the effectiveness of these surface treatments. During the treatment process, the tank is heated and therefore would be expanded. Also, as shown by the ARB data above, more than 95 percent reductions were achievable in some tanks even after being subjected to the pressure cycling and fuel soak. Fluorination, which showed the most consistent results resulted in more than a 90 percent reduction on average. As methods improve, even better permeation control could be achieved. The variability in the barrier processes can be reduced by specifically controlling the treatment process specifically for the tanks being treated. The tanks included in the ARB testing were generally included in larger batches of other products where the process was optimized for those other products. Also, more consistent fuel tank construction, including the makeup of the plastic used, would make it easier for the fluorinator or sulfonator to optimize their processes and reduce variability.

The U.S. Coast Guard has raised the issue that any process applied to marine fuel tanks to reduce permeation would also need to pass Coast Guard flame resistance requirements (33 CFR 183). We are not aware of any reason that the barrier technologies discussed above would affect the flame resistance of a marine fuel tank. In response to this concern, we sent a fluorinated fuel tank to a testing lab which certified the fuel tank as passing the U.S. Coast Guard flame resistance test.⁷

Material properties

We are also investigating the possibility of using nylon as a low permeation alternative in the rotational molding process. Based on our understanding of material properties, the use of nylon in the construction of these fuel tanks would reduce permeation by more than 95 percent when compared to cross-link polyethylene such as is used today. Table 4.2-10 presents permeation rates of various plastics (including barrier materials) on an ASTM specified gasoline (Fuel C) and a blend with 15% methanol (M15).⁸ Table 4.2-11 presents permeation rates for several materials used as barriers in automotive applications at 40°C.⁹ Table 4.2-12 presents data from the same study for three different temperatures using Fuel C. We are also assessing the durability of surface treatments. Specifically, we are evaluating the durability of sulfonation and fluorination on crosslink tanks and are assessing the viability of replacing crosslink materials with HDPE as an option if needed to address durability concerns associated with sloshing.

Table 4.2-10: Fuel System Material Permeation Rates at 23°C

Material	Fuel C, g-mm/m ² /day	M15, g-mm/m ² /day
High density polyethylene	35	35
Nylon 12, rigid	0.2	64
Ethylene vinyl alcohol	–	10
Polyacetal	–	3.1
Polybutylene terephthalate	–	0.4
Polyvinylidene fluoride	–	0.2

Table 4.2-11: Fuel System Material Permeation Rates at 40°C

Material Name	Composition	Fuel C g-mm/m ² /day	M15 g-mm/m ² /day
CARILON	aliphatic poly-ketone thermoplastic	0.06	13
EVOH - F101	ethylene-vinyl alcohol	<0.0001	3.5
EVOH - XEP380	ethylene-vinyl alcohol	<0.0001	5.3
HDPE	high density polyethylene	90	71
LDPE	low density polyethylene	420	330
Nylon 12 (L2101F)	plasticized fuel line grade	2.0	250
Nylon 12 (L2140)	plasticized fuel line grade	1.8	–
CELCON	acetal copolymer	0.38	–
THV - 500	terpolymer*	0.31	3.0
Dyneon E14659	fluoropolymer film	0.25	2.1
Dyneon E14944	fluoropolymer film	0.14	1.7
ETFE Aflon COP	ethylene-tetrafluoro-ethylene	0.24	1.8
m-ETFE	ethylene-tetrafluoro-ethylene	0.27	1.6
ETFE Aflon LM730 AP	ethylene-tetrafluoro-ethylene	0.41	2.6
FKM-70 16286	fluoroelastomer	11	–
GFLT 19797	fluoroelastomer	13	–

* tetra-fluoro-ethylene, hexa-fluoro-propylene, and vinylidene fluoride

Table 4.2-12: Fuel System Material Material Permeation Rates for Fuel C by Temperature

Material Name	40°C g-mm/m ² /day	50°C g-mm/m ² /day	60°C g-mm/m ² /day
CARILON	0.06	0.2	0.55
HDPE	90	190	310
Nylon 12 (L2140)	1.8	4.9	9.5
CELCON	0.38	0.76	1.7
FKM-70 16286	11	25	56
GFLT 19797	13	28	60

The manufacturer who supplied the bladder tank for our test program is now working with a lower permeability material known as THV. THV is a Teflon® based material that can be used to achieve more than a 95 percent reduction in permeation from current bladder fuel tanks made from polyurethane.¹⁰ In addition, THV is fairly resistant to ethanol. Table 4.2-13 compares fuel permeation rates for gasoline and a 10 percent ethanol at 60°C.

Table 4.2-13: Bladder Material Permeation Rates at 60°C

Barrier Film Material	Thickness mm	Gasoline g-mm/m ² /day	10% Ethanol g-mm/m ² /day
polyurethane	0.52	285	460
THV-200	0.35	–	54
THV-500	0.32	8.2	10.5

4.2.2.2 - Hoses

As discussed in Chapter 3, the majority of marine fuel hoses are constructed primarily of nitrile rubber with a chloroprene cover and are designed to meet the Coast Guard specification of 100 g/m²/day at 23°C for hoses where liquid fuel is normally continuously in the hose. We believe that permeation emissions from hoses can be reduced by more than 95 percent by using either thermoplastics blended into the rubber or a multi-layer hose construction with low permeation barrier layers. In fact, at least one company produces hoses of this type for marine applications. Table 4.2-14 presents permeation rates for various materials that could be used in hose construction. These hoses were tested at 23°C on ASTM Fuel C and a 15% methanol blend.¹¹ Fuel fill neck hoses are subject to a less stringent permeation standard (300 g/m²/day at 23°C) under the Coast Guard specifications because they are not normally continuously in contact with fuel. However, we are proposing to control permeation rates in fill neck hoses because hose exposed to air saturated with fuel vapor will permeate as much as hose exposed to liquid fuel. Although marine fill neck hoses are wrapped rather than extruded, we believe that barrier technology could be applied here as well. In fact, there are chemical hoses that employ several different material layers, which are manufactured using the same process as marine fill neck hoses. We intend to test several standard marine hoses and barrier hoses for permeation. We also intend to investigate fluorination as an option for reducing permeation through hoses.

Table 4.2-14: Hose Material Permeation Rates at 23°C

Material Name	Composition	Fuel C g-mm/m ² /day	M15 g-mm/m ² /day
NBR (33% ACN)	nitrile rubber	669	1,188
HNBR (44% ACN)	hydrogenated nitrile rubber	230	828
FVMQ	fluorosilicone	455	635
FKM Viton A200 (66%F)	fluoroelastomer	0.80	36
FKM Viton B70 (66%F)	fluoroelastomer	0.80	32
FKM Viton GLT (65%F)	fluoroelastomer	2.60	60
FKM Viton B200 (68%F)	fluoroelastomer	0.70	12
FKM Viton GF (70%F)	fluoroelastomer	0.70	3.0
FKM Viton GFLT (67%F)	fluoroelastomer	1.80	14
Teflon FEB 1000L	fluoroplastic	0.03	0.03
Teflon PFA 1000LP	fluoroplastic	0.18	0.13
Tefzel ETFE 1000LZ	fluoroplastic	0.03	0.20
Nylon 12 (GM grade)	plasticized fuel line grade	6.0	83

4.2.3 - Evaporative Emission Test Procedures

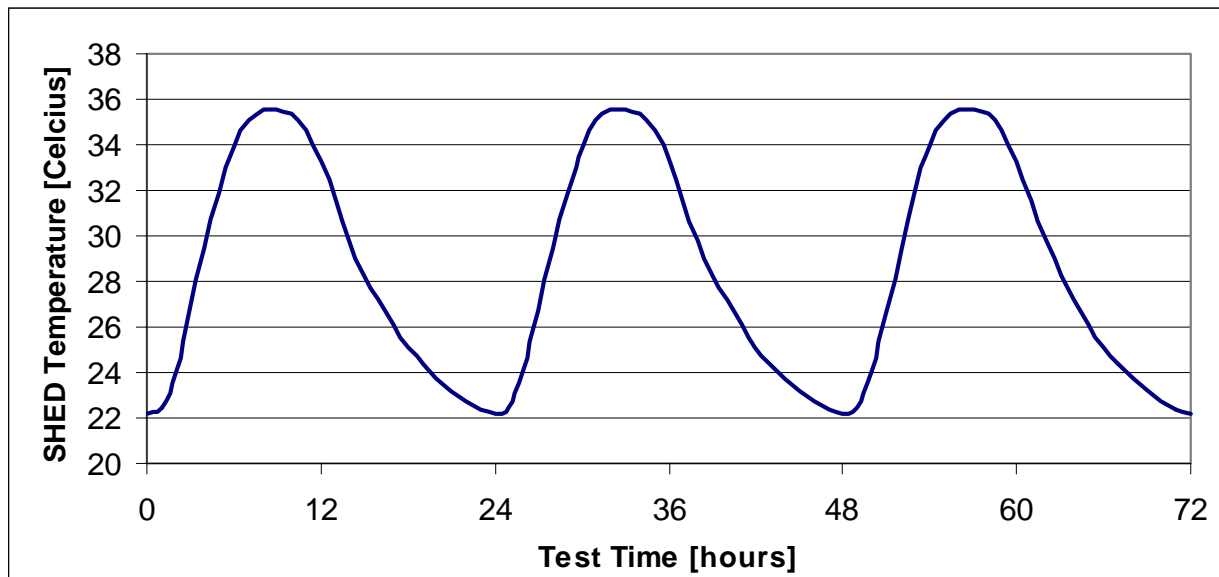
This section discusses test procedures for measuring evaporative emissions from fuel tanks and hoses.

4.2.3.1 - Diurnal Emission Testing

The evaporative emission test is intended to be representative of a single 22.2-35.6°C (72-96°F) day. Emissions would be measured in a Sealed Housing for Evaporative Determination (SHED) over a 72 hour period. The fuel tank is set up in the SHED with all of the hoses, seals and other components attached. The fuel tank is then filled and drained to 40 percent capacity with 9 RVP^m test fuel and soaked with an open vent until the fuel reached 22.2°C. Immediately after the fuel reaches this temperature, the SHED would be purged, and the diurnal temperature cycling would begin. The temperature cycle actually three repeats of a 24 hour diurnal trace and shown in Figure 4.2-8. The final g/gal/day result would be based on the highest grams of these three 24 hour cycles divided by the fuel tank capacity.

^m Reid Vapor Pressure (psi). This is a measure of the volatility of the fuel. 9 RVP represents a typical summertime fuel in northern states.

Figure 4.2-8: Three Day Temperature Trace for Diurnal Testing



This diurnal cycle is consistent with the test requirements for highway vehicles. However, the test procedure for highway vehicles includes engine operation and hot soaks (fuel system heating from the engine). The purpose of the engine operation is to purge the charcoal canister that collects evaporative emissions in highway applications. However, we are excluding engine operation from the evaporative test procedures for boats using SI marine engines because we do not anticipate the use of charcoal canisters in these applications.

For plastic fuel tanks, the tank would have to be filled and soaked for an appropriate period of time to ensure that permeation emissions are accurately reflected in the test procedure. We are proposing that the fuel tank be filled to capacity with 9RVP fuel and soaked for 30 days at a temperature between 20-30°C (68-86°F). The fuel would then be drained just prior to the beginning of the test described above.

4.2.3.2 - Fuel Tank Permeation Testing

In 33 CFR 183.620(i), Coast Guard sets a fuel tank permeation standard of 1.2 grams/day per cubic foot of compartment space. Testing to determine this permeation rate must be performed at 40°C (104°F) using ASTM reference fuel “C” (D-471-1979). In 1986, the Coast Guard performed a test program to measure permeation rates from three plastic fuel tanks.¹² As a part of this program, Coast Guard investigated several existing test methods and found them to be insufficient for their test program. In the end they decided to test the entire fuel tank in a closed chamber with tight temperature control. The closed chamber had a nitrogen purge to prevent saturation of the gas in the chamber with hydrocarbons. Fuel loss was measured using a gravimetric approach in which the tank was sitting on a sensitive scale.

We also are investigating whether we should require specific durability test procedures for fuel tanks. Such durability tests could include pressure-vacuum cycle testing, slosh testing, and temperature cycling. Examples of these tests are included in the docket.¹³

4.2.3.3 - Hose Permeation Testing

There are three primary methods that are used today for measuring permeation from fuel lines. The first is used for marine hoses while the other two are used for low permeability automotive fuel lines.

Coast Guard standards for marine fuel hoses (33 CFR 183) cite SAE recommended practice J1527¹⁴ which, among other things, includes test procedures for measuring permeation from marine fuel hoses. In this test procedure, a short section of hose is attached to a nonpermeable container (i.e. metal fuel can) and plugged. Fuel is added to the container and the mass of the entire unit is measured every 24 hours for 15 days and the peak fuel loss is determined. This testing is performed at $23 \pm 2^\circ\text{C}$ on both reference fuel "C" for the version of the SAE standard referenced in 33 CFR 183. However, SAE J1527 was revised in 1993 to include permeation standards for hoses tested on a fuel blend with 15% methanol. This test procedure is simple; however, it is sufficient for marine hoses because they have high permeation rates ranging from 100 to 600 g/m²/day depending on the hose class and the fuel used.

Recommended practice for automotive fuel tubing is defined in SAE J2260.¹⁵ The permeation requirements in this standard are one to two orders of magnitude lower than those defined for marine hoses. These permeation requirements are based on the same fuels as the revised SAE J 1527, but at a much higher temperature (60°C). At 60°C, permeation rates for a given material may be 16 times as high or higher than at 23°C based on the rule of thumb that permeation doubles for every 10°C increase in temperature. SAE J2260 refers to the permeation test procedures in SAE J1737.¹⁶

The procedures in SAE J1737 were designed to measure the low permeation rates needed in automotive applications to meet EPA evaporative emission requirements. There was concern that the weight loss measurement, such as used in SAE J1527, was not sensitive enough to measure these low permeation rates. In addition, this procedure requires exposing the material to be tested for hundreds of hours, depending on the material and fuel, to reach a steady-state permeation rate. In this procedure, fuel is heated to 60°C and circulated through a tube running through a glass test cell. Nitrogen around the tube in this test cell is used to carry the permeate to activated charcoal canisters. The canisters are weighed to determine their capture. Because the canister is much lighter than the reservoir/hose in the SAE J1527 configuration, a much more accurate measurement of the permeation loss can be made.

Some manufacturers of low permeability product are finding that as their emission rates decrease, they need more refined test procedures to accurately measure permeation. These manufacturers are finding that the weight of the charcoal canisters are much higher than the

permeate being measured. As an alternative to the gravimetric approach used in the above two procedures, even very low permeation emissions can be measured by a flame ionization detector and a SHED. As discussed earlier, SHED testing is generally used to measure evaporative emissions from whole automobile systems as well.

4.2.4 - 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 new emission standards for marine vessels. In this case, we would not expect evaporative emission controls to have any impact on noise from a marine vessel because noise from the fuel system is insignificant.

We anticipate that the proposed evaporative emission standards will have a positive impact on energy. By capturing or preventing the loss of fuel through evaporation, we estimate that the average boat will save about 44 gallons of fuel over its lifetime. This translates to a fuel savings of about 31 million gallons in 2030 when most boats used in the U.S. are expected to have evaporative emission control.

We believe that the proposed evaporative emission standards will have no negative impacts on safety, and may even have some benefits. All of the evaporative emission control technologies discussed in this document are capable of meeting the U.S. Coast Guard safety requirements for fuel systems described in 33 CFR 183. Even by using a sealed system with an automotive fuel cap, manufacturers would be well under the Coast Guard pressure requirements. We recognize that some fittings and valves may have to be redesigned if required to operate under pressure, but believe that this could easily be done by 2008. Several of the technologies that we believe could be used to meet the proposed standards would require low or no pressure build up in the fuel system. In addition, the reduction of fuel vapor in and around the boat could provide some benefits to boaters.

4.3 - Sterndrive/Inboard Marine

At this time we are not proposing exhaust emission standards for spark-ignition sterndrive and inboard (SD/I) marine engines. However, we are continuing our efforts to develop and demonstrate catalytic control on SD/I marine engines in the laboratory and in-use, and will place new information in the docket when it is available. In fact, we intend to follow with another rulemaking in the future that will address emissions from SD/I engines, and possibly other marine engines, once we have collected more information. This section presents information that we have collected on an SD/I engines and discusses issues associated with using catalysts in marine applications.

4.3.1 - Exhaust Emission Data from SD/I Engines

This section presents emission data that we have collected on SD/I marine engines. All of this data was collected during laboratory tests over the ISO E4 duty cycle. The first part of this section presents baseline emission data while the second part presents results from the first step of our catalyst development program.

4.3.1.1 - Baseline Emission Data

The vast majority of SD/I engines four-stroke reciprocating piston engines similar to those used in automotive applications. The exceptions are small sales of air boats using aircraft piston-type engines and at least one marinizer that uses Mazda rotary engines. More than half of the new engines sold are equipped with electronic fuel injection while the rest still use carburetors. The majority of the electronic fuel injection systems are multi-port injection; however, throttle-body injection is also widely used, especially on smaller engines.

Table 4.3-1 presents baseline emissions for four-stroke SD/I engines built up from automotive engine blocks.^{17,18,19,20,21} Five of these engines are carbureted, one uses throttle-body fuel injection, and three use multi-port fuel injection. One of the multi-port fuel injected engines was tested with three calibrations. Note that without emissions calibrations performed specifically for low emissions, the HC+NO_x emissions are roughly equal for the carbureted and fuel injected engines. Using the straight average, HC+NO_x from the carbureted engines is 15.6 g/kW-hr while it is 15.9 g/kW-hr from the fuel injected engines (14.8 g/kW-hr if the low HC calibration outlier is excluded).

Table 4.3-1: Baseline SD/I Exhaust Emission Data

Engine #	Power [kW]	Fuel Delivery System	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]
1	79	carburetor	11.2	8.0	281
2	91	carburetor	4.4	13.9	98
3	121	carburetor	8.5	6.0	247
4	158	carburetor	7.3	6.0	229
5	167	carburetor	8.0	5.7	174
6	196	carburetor	4.4	10.3	101
7	159	throttle-body fuel injection	2.9	8.7	42
8	185	multi-point electronic fuel injection	5.2	9.7	149
8	181	#8, low CO calibration	5.8	11.7	48
8	191	#8, low HC calibration	3.3	18.2	72
9	219	multi-point electronic fuel injection	4.7	9.4	160
10	229	multi-point electronic fuel injection	2.7	13.1	44

4.3.1.2 - Emission Data For Catalyst Development Test Program

In a joint effort with the California Air Resources Board, we contracted with Southwest Research Institute to perform catalyst development and emission testing on a SD/I marine engine.²² This test program was performed on a 7.4 L electronically controlled Mercruiser engine with multi-port fuel injection. Figure 4.3-1 illustrates the three primary catalyst packaging configurations we used. The upper right-hand picture shows a catalyst packaged in a riser extension which would be placed between the lower exhaust manifold and the exhaust elbow. This riser had the same outer dimensions as the stock riser extension produced by Mercury Marine. The upper left-hand picture shows a catalyst packaged in the elbow. The lower picture shows a larger catalyst that was packaged downstream of the exhaust elbow. All of these catalyst configurations were water jacketed to prevent high surface temperatures.

Figure 4.2-1: Three Catalyst Configurations Used in SD/I Test Program



Table 4.3-2 presents the exhaust emission results for the baseline test and three catalyst packaging configurations. For the riser catalyst we tested the engine with two cell densities, 60 and 300 cells per square inch (cps), to investigate the effects of back-pressure on power. The catalysts reduced in HC+NO_x in the range of 42% to 77% and reduced CO in the range of 46% to 54%. There were no significant impacts on power, and fuel consumption actually improved due to the closed-loop engine calibrations necessary to optimize the catalyst effectiveness. At the full power mode, we left the engine controls in open-loop and allowed it to operate rich to protect the catalysts from over-heating.

Table 4.3-2: Exhaust Emission Data on a SD/I Engine with Various Catalysts

<i>Catalyst Scenario</i>	<i>HC</i> [g/kW-hr]	<i>NOx</i> [g/kW-hr]	<i>CO</i> [g/kW-hr]	<i>Power</i> [kW]	<i>BSFC</i> [g/kW-hr]
baseline (no catalyst)	4.7	9.4	160	219	357
60 cpsi catalyst in riser	2.5	5.7	81	214	345
300 cpsi catalyst in riser	1.7	1.9	87	213	349
400 cpsi catalyst in elbow	2.8	1.1	81	217	337
200 cpsi catalyst downstream	2.1	1.2	83	221	341

The testing described above is our first step in developing and demonstrating catalysts that can reduce emissions from marine engines. However, this program only looked at catalysts operating in a laboratory. We are now engaged in a new test program which involves operating an engine in a boat with catalysts. The intent of this program is to address open issues associated with using catalysts in marine applications. These open issues are described below.

4.3.1.3 - Emission Data Using Exhaust Gas Recirculation

We have tested two engines over the ISO E4 marine test cycle with and without the use of exhaust gas recirculation (EGR).^{23,24} The first engine was a Ford heavy-duty highway engine. Although this was not a marine engine, it uses the same basic technology as SD/I engines. The second engine was a Mercruiser SD/I engine which is a marinized version of a GM heavy-duty highway engine. This is the same engine on which we performed the catalyst work; however, the baseline emissions are a little different because we rebuilt the head of the engine prior to the catalyst development work described above. This test data suggests that, through the use of EGR on a SD/I marine engine, a 40-50% reduction in NOx (30-40% reduction in HC+NOx) can be achieved. EGR was not applied at peak power in this testing because the throttle is wide open at this point and displacing fresh air with exhaust gas at this mode of operation would reduce power. We also did not apply EGR at idle because the idle mode does not contribute significantly to the cycle weighted NOx.

Table 4.3-3: Exhaust Emission Data Using EGR on the E4 Marine Duty Cycle

<i>EGR Scenario</i>	<i>HC</i> [g/kW-hr]	<i>NOx</i> [g/kW-hr]	<i>CO</i> [g/kW-hr]	<i>Power</i> [kW]	<i>BSFC</i> [g/kW-hr]
First Engine: baseline with EGR	2.7	13.4	26.5	145	326
	2.7	7.1	24.3	145	360
Second Engine: baseline with EGR	4.5	8.4	171	209	349
	4.5	4.8	184	209	356

4.3.2 - Open Issues for Using Catalysts in Marine Applications

Although we have demonstrated that catalysts can be used to reduce emissions in the laboratory, we believe there are several open issues with the application of catalysts in the marine environment. These issues include durability concerns, packaging constraints, water reversion, and safety considerations that are unique to marine applications.

4.3.2.1 - Packaging

Due to the design of marine exhaust systems, fitting a catalyst into the exhaust system may be difficult for many boat/engine designs. Often boat builders will strive to minimize the space taken up in the boat by the engine compartment. In addition, these exhaust systems are designed, for safety reasons, to avoid hot surface temperatures. For most SD/I engines, the surface temperature is kept low by running raw water through a jacket around the exhaust system. This raw water is then mixed with the exhaust before being passed out of the engine. To avoid a major redesign of the exhaust system, the catalyst must be placed upstream of where the water and exhaust mix. In addition, the catalyst must be insulated and/or water-jacketed to keep the surface temperatures of the exhaust low.

The above design constraints led to the catalyst packaging designs presented above in Figure 4.3-1. All of these catalysts were water-jacketed and placed in the exhaust manifold upstream of where the water and exhaust mix. Of these catalyst packaging configurations, it appears that the riser and elbow catalysts would be the easiest to package in a boat. The larger catalyst may be too long to fit in most applications, especially sterndrives where exhaust passes through the drive unit attached to the engine. Figure 4.3-2 illustrates where the riser catalyst would be fit in a typical marine exhaust system.

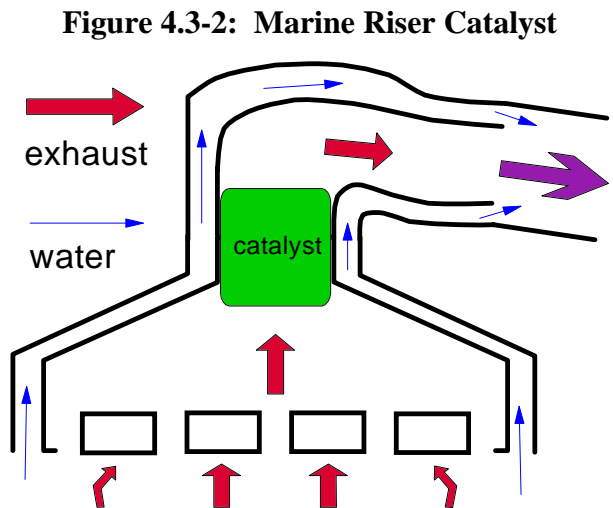


Figure 4.3-2: Marine Riser Catalyst

Another issue is maintaining high enough temperatures with a water-jacketed catalyst for the catalyst to react properly. The light-off temperature of these advanced catalysts is in the range of 250 to 270°C which was low enough for the catalysts to work effectively in our laboratory tests. However, it could be necessary for manufacturers to retard the spark timing at idle and low load for some engines to maintain this minimum temperature in the catalyst.

4.3.2.2 - Durability

Two aspects of marine applications that could affect catalyst durability are thermal load and vibration. Because the catalyst would be coupled close to the exhaust ports, it would likely see temperatures as high as 750 to 850°C when the engine is operated at full power. The bed temperature of the catalyst would be higher due to the reactions in the catalyst. However, even at full power, the bed temperature of the catalyst most likely wouldn't exceed the exhaust temperature by more than 50-100°C. In our laboratory testing, we minimized the temperature at full load by operating the engine with a rich air-fuel mixture. The temperatures seen were well within the operating range of new Pd-only catalysts which are capable of withstanding prolonged exposure to temperatures approaching 1100°C.²⁵

In on-highway applications, catalysts are designed to operate in gasoline vehicles for more than 100,000 miles. This translates to about 4,000-5,000 hours of use on the engine/catalyst. We estimate that, due to low annual hours of operation, the average useful life of SD/I engines is only about 10-20 percent of this value. This suggests that catalysts designed for automotive use should be durable over the useful life of a marine engine. However, we do not know the relative stress on the catalyst from an hour of automotive versus marine use. The testing that we are currently engaged in will include operation of the catalyst over a thermal aging cycle.

Use of catalysts in automotive, motorcycle, and hand-held equipment applications suggests that catalysts can be packaged to withstand the vibration in the exhaust manifold. We will learn more about the effects of vibration on a catalyst in our boat testing.

4.3.2.3 - Water Reversion

A third aspect of marine applications that could affect catalyst durability is the effect of water contact with the catalyst. There is concern that water could creep back up the exhaust passages, due to pressure pulses in the exhaust, and damage the catalyst and oxygen sensor. This damage could be due to thermal shock from cold water coming into contact with a hot catalyst ore due to salt deposition on the catalyst. One study was performed to investigate these catalyst durability effects on a two-stroke outboard.²⁶ The results of this study are summarized in Table 4.3-4.

Table 4.3-4: Summary of Marine Catalyst Durability Study

<i>Issue</i>	<i>Investigation</i>	<i>Result</i>
high catalyst temperatures	- compared base catalyst to catalysts aged for 10 hrs at 900 and 1050°C	- little change in conversion efficiency observed
salt water effects	- soaked catalysts in two seawater solutions and compared to base catalyst	- large drop in conversion efficiency observed
	- used intake air with a salt-water mist	- no effect on catalyst
fresh water effects	- soaked catalyst in fresh water and compared to base catalyst	- little change in conversion efficiency observed
	- flushed out catalyst with fresh water that was soaked in salt water	- washing catalyst removes salt and restores some performance
thermal shock of hot catalyst with cold water	- as part of the catalyst soaking tests, 900°C catalysts were soaked in both salt and fresh water	- no damage to the catalysts was reported
deterioration factor	- operated engine with catalyst for 300 hours of E4 operation	- only a 20% loss in conversion efficiency for a 2-stroke engine

The above study on catalysts in marine applications was performed supplemental to an earlier study.²⁷ The earlier study also showed that immersing the catalysts in salt water would hurt the conversion efficiency of the catalyst, but that operating in a marine environment would not. In addition, this earlier study showed that much of the efficiency loss due to salt on the catalyst could be reversed by flushing the catalyst with water. This paper also showed that with the catalyst activated, temperatures at full power were less than at mid power because the space velocity of the exhaust gases at rated speed was high enough to reduce the conversion efficiency of the catalyst.

Because salt deposition severely reduces the conversion efficiency of the catalyst, it is critical that salt water not reach the catalyst. This design problem is the primary goal of the catalyst and boat testing that we are currently performing. Manufacturers claim that the cooling water in the exhaust manifold jacket will work its way back up the exhaust stream and poison the catalyst if it is not packaged correctly. Although this water reversion may happen in some instances, we believe that this is an engineering design problem that can be solved given proper resources and time. Manufacturers already design their exhaust systems to prevent water from reaching the exhaust ports. If water did reach the exhaust ports in today's designs, significant durability problems would result from corrosion. Also, it would not take much water back-flow into the cylinder after engine shut-down to cause the engine to hydraulically lock the next time it was started. However, we believe that it would be valuable for us to demonstrate a catalyst on a

boat before proposing catalyst-forcing standards.

4.3.2.4 - Safety

We also want to ensure that the use of catalysts on boats will not impose new hazards to boaters. We have been working with the U.S. Coast Guard to identify potential safety problems with using catalysts in marine applications. The Coast Guard has stated that they have two concerns. First, they want to make sure that any additional heat load in the engine compartment will not add to the risk of fires, other safety hazards, or other detrimental impacts on the engine or components. Second, they want to make sure that the exhaust systems with catalysts will not lead to CO leaks due to additional joints in or maintenance of the exhaust system. These issues will be addressed in the upcoming boat testing.

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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 or vessel 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.

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 - Evaporative Emission Control from Boats

5.2.1.1 - Technologies and Estimated Costs

As discussed in earlier chapters, we believe that there is a wide range of technology that could be used to meet the proposed evaporative emission standards for marine vessels. Table 5.2.1-1 presents our best estimates of the costs of applying various evaporative emission control technologies to a boat with a thirty gallon fuel tank. These costs would generally be higher for a larger boat and lower for a smaller boat, but this is illustrative of a typical marine configuration.

The range of potential costs for bladder tanks are based on confidential conversations with a manufacturer of this product. This section looks at the costs for an average sized tank (32 gallons) with typical fuel hose lengths. Non-permeable material costs are based on conversations with manufacturers, current material costs, and engineering judgement. Tank insulation costs are based on typical costs for commercial insulating sheets with an R value of 15. To cost out the pressurized tank, we estimated that the material cost the tank is about ten percent of the total value. For a 32 gallon tank, approximately 25 to 35 pounds of plastic is used at a cost of about \$0.50 per pound. We estimate that if a manufacturer were to make changes to the geometry of the fuel tank to help withstand 1 psi of pressure without significant deflection, it could increase the material needed by 10 to 30 percent. Pressure relief valve and limited flow orifice costs are based on products available in automotive parts stores. Barrier hose technologies are based on incremental costs of existing products.³ Surface treatment costs are based on price quotes from a company that specializes in this fluorination costs⁴; shipping costs are also included. Finally, nylon tank costs are based on a material price of \$2.00 per pound. Finally, the cost of the pressure-free tank is based on the cost of materials that could be used for a volume compensating bag and the consideration of adding a new fitting to a fuel tank. The costs in Table 5.2.1-1 include a 29 percent manufacturer markup.

Table 5.2.1-1 Technologies Under Consideration and Costs for a 32 Gallon Tank

Technologies Under Consideration	In-Use Reductions	Cost Increase
bladder tank (commercial technology)	90% diurnal and permeation	\$65 - 194
tank insulation	25%+ of diurnal	\$13 - 26
1 psi pressurized tank: material relief valve/orifice	25-50% of diurnal	\$1 - 6 \$4 - 9
pressure-free tank (volume compensating bag)	50 - 100 % of diurnal	\$26 - 52
low-permeable barrier in fuel lines (8 ft.)	95%+ of permeation	\$6 - 13
low-permeable barrier in fill neck (2 ft.)	95%+ of permeation	\$3 - 6
fluorination or sulfonation of plastic fuel tank	95%+ of permeation	\$13 - 19
low-permeable material (nylon) for plastic fuel tank	95%+ of permeation	\$52 - 65

5.2.1.2 - Operating Cost Savings

Evaporative emissions are essentially fuel that is lost to the atmosphere. Over a the lifetime of a typical boat, this can result in a significant loss in fuel. The anticipated 70 percent reduction in evaporative emissions due to the proposed standards will result in significant fuel savings. Table 5.2.1-2 presents the value of the fuel savings for control of diurnal and permeation emissions. These numbers are calculated using an estimated fuel cost of \$1.10 per gallon (based on 1997-2002 pre-tax fuel prices)⁵ and fuel density of 6 lbs/gallon (for lighter hydrocarbons which evaporate first). The figures in Table 5.2.1-2 are for an average boat which we estimate has a 32 gallon fuel tank and a 20 year life. The total savings over 20 years is 44 gallons which translates to a discounted lifetime savings of 27 dollars.

Table 5.2.1-2 Fuel Savings Per Boat Due to the Proposed Standards

Average Parameters	Diurnal	Tank Permeation	Hose Permeation
Evaporative HC reduced [grams/year]	990	1,930	3,190
Evaporative HC reduced [gallons/year]	0.4	0.7	1.2
Fuel savings [gallons/life]	7	14	23
Undiscounted savings [\$/life]	\$8	\$15	\$25
Lifetime fuel savings (NPV, 7%)	\$4	\$9	\$14

5.2.1.3 - System Integration and Compliance Costs

We are proposing to allow manufacturers to use design based certification to the proposed performance standard as an alternative to evaporative emission testing. However, they will still need to integrate insulation or fluorination into their designs and there will be some engineering and clerical effort need to submit the required information for certification. We estimate a cost of \$10,000 for a manufacturer producing 50,000 fuel tanks per year. After the first year of certifying to our standards, manufacturers will be able to carry over the majority of the certification effort from year to year. Therefore, this cost will be greatly reduced after the first year of the program. If we treat the \$10,000 as a fixed cost and amortize it over five years, we get a cost per fuel tank of about four cents.

5.2.1.4 - Total Costs

To determine the total costs, we use the scenario that all boat builders will use low permeation fuel tanks and hoses and use a zero pressure limited flow orifice to control diurnal emissions. Because these technologies are well established, we do not apply a learning curve to future costs.

For a boat with a 32 gallon plastic fuel tank, we based cost of reducing fuel tank permeation on the fuel tank being fluorinated or sulfonated. This translates to a technology cost in the range of \$13 to \$19. In addition we consider the cost of low permeation barrier hose and fill neck. This adds another \$9 to \$19 to the hardware cost. We also estimate the cost of diurnal emission control by addition a cost of \$4-9 for the pressure relief valve and a material cost of \$1-6 to minimize deflection under 1 psi of pressure. Using the average costs, we get a total cost of \$43.

For a boat with a 32 gallon aluminum fuel tank, we estimate our costs based only on low permeation barrier hose and fill neck and the use of a pressure relief valve. No costs are included for fluorination or sulfonation because the aluminum tanks do not permeate fuel emissions. Using the average of the costs, we get a total cost of \$21.

Weighting the aluminum and plastic fuel tank costs we get an average cost of \$36 dollars for an average 32 gallon marine tank. Coupled with the discounted fuel savings of \$27 and certification costs, we get a discounted lifetime cost per vessel of \$9.

5.2.1.6 - Aggregate Costs for Marine Evaporative Emission Control

The above analyses developed incremental per-vessel cost estimates for boats powered by spark-ignition engines. Using these per-vessel 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 vehicle is operated over its life. This may

understate the time-value of the fixed costs because they are likely to be incurred before the vehicle is sold; however, this has a negligible effect on the results of this analysis. Table 5.2.1-3 presents a summary of this analysis. As shown in the table, aggregate net costs are \$22.5 million in 2008, but are then projected to decline as fuel savings continue to ramp-up as more vessels meeting the standards are sold. Long-term projections show that, starting in 2023, fuel savings offset the costs of meeting emission standards.

**Table 5.2.1-3
Summary of Annual Aggregate Costs and Fuel Savings for Marine SI
(millions of dollars)**

	2008	2010	2015	2020	2025
Total Costs	\$24.4	\$24.7	\$25.6	\$26.5	\$27.4
Fuel Savings	(\$1.8)	(\$5.5)	(\$14.6)	(\$23.1)	(\$29.7)
Net Costs	\$22.5	\$19.2	\$11.0	\$3.4	(\$2.3)

To project annual sales, we started with the 1998 population estimates presented in Chapter 6. We then backed out sales based on the useful life and growth estimates in Chapter 6. Table 5.2.2-4 provides a summary of the sales estimates used in the aggregate cost analysis. We then use the relationship between engine type and size to fuel tank size discussed in Chapter 6.

**Table 5.2.1-4
Estimated Annual Sales of Marine SI Fuel Tanks**

Application	1999	2006	2010	2020
Outboards	422,000	443,000	456,000	490,000
Personal Watercraft	115,000	121,000	124,000	133,000
Sterndrive/Inboards	91,000	95,000	98,000	105,000

To calculate annual aggregate costs, the sales estimates have been multiplied by the per-unit costs discussed above. This calculation takes into consideration vessel sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.2 - Highway Motorcycles

Costs estimated for Class 3 highway motorcycles were developed in cooperation with ICF Incorporated and Arthur D. Little - Acurex Environmental. The analysis was based upon an analysis completed by the California Air Resources Board (ARB) when they proposed new emission standards in October of 1998. The ARB standards, finalized in 1999 and applicable only to Class 3 motorcycles (280 cc and greater), will occur in two phases. A Tier-1 standard of

1.4 g/km HC+NO_x will apply to Class 3 motorcycles for the 2004 through 2007 model years, and a Tier-2 standard of 0.8 g/km HC+NO_x will apply to Class 3 motorcycles for the 2008 and later model years. These new standards may be met on a corporate-average basis. Our analysis, while following the general methodology used by the ARB, incorporates some changes to the methodology as well as some component cost estimates that differ from those used by the ARB.⁶

The ARB Staff Report estimated costs for two displacement ranges for Class 3 motorcycles: 280 to 699 cc and 700 cc and greater. Currently the smaller range is subject to an HC standard of 1.0 g/km in California, while the larger displacement range is subject to an HC standard of 1.4 g/km in California. In order to simplify the calculations, two specific engine displacements were used to compare with the ARB displacement categories. The ARB Staff Report indicates that the sales-weighted average for the 280cc to 699cc class was 600cc and the sales weighted average for the greater than 700cc category was 1200cc. EPA certification data shows that the national averages for the two displacement categories are 593cc and 1260cc, thus demonstrating that the ARB analysis is reasonably representative of national sales. These sales weighted averages were used in developing the cost estimates. The costs include a mark-up to the retail level.

The costs also account for the difference in production levels between the two displacement categories as represented by the 600 cc and 1200 cc engines. The California ARB used an average annual production level of 15,000 units for both categories. In this analysis we use 25,000 units per year for the 600 cc engine and 64,000 units per year for the 1200 cc engine.⁷

The analysis for Class 3 motorcycles combines the individual technology costs into a total estimated cost package. The composite analysis weights the costs by the projected percentage of use of the technologies both in the baseline and control scenarios to project industry-wide average per vehicle costs. The full analysis for Class 3 is followed by an analysis of costs for motorcycles under 50cc in Section 5.2.2.4.

5.2.2.1 - Technologies and Estimated Costs

Highway motorcycles are currently powered mostly by carbureted four-stroke engines. However, even in the absence of new regulation, the penetration of fuel-injected models is increasing, most likely due to the improvements in reliability, performance, and fuel economy that fuel injection can offer. EPA's motorcycle certification database for 2001 and 2002 model year motorcycles indicates that the most prevalent emission controls used to meet the current standards are engine modifications and mechanically-controlled secondary air injection. To an increasingly greater extent manufacturers are currently incorporating fuel injection and catalytic converters on some 2001 and 2002 models. Table 5.2.2-9 shows the increased use of these technologies in the 2002 model year relative to the 2001 model year, based on EPA certification data. For example, catalyst usage increased from 13 to 20 percent, and fuel injection usage increased from 37 to 47 percent, for the larger Class 3 motorcycles.

While manufacturers will use various means to meet the future standards, there are four basic types of existing emission control technologies on which we have based our cost analysis; engine modifications, electronic fuel injection, pulse air systems, and catalyst converters with oxygen (O2) sensors. These technologies are being used to varying degrees already and we would expect manufacturers to increase the use of these approaches to meet future standards. In general, we would expect emissions control strategies to include more precise fuel control, better fuel atomization and delivery, reduced engine-out emission levels from engine changes, and increased use of catalysts.

We have included the costs for increased use of engine modifications to meet the Tier 1 standards. We would expect this approach to be used on essentially all engine models. Engine modifications include changes such as improved cylinder honing for better oil control, modified cam profiles to provide increased valve overlap (providing internal exhaust gas recirculation), and piston modifications to improve ring land height, tumble and squish for reduced hydrocarbon emissions and better combustion. As shown in Table 5.2.2-1, we have estimated the per unit cost of engine modifications to be in the \$6 to \$8 range.

Table 5.2.2-1 Engine Modification Costs

Engine Size	600cc	1200cc
Variable Costs		
Improved Pistons	\$2	\$3
Number Required	2	2
Hardware costs	\$4	\$6
Markup @ 29%	\$1	\$2
Warranty Markup @ 5%	\$0	\$0
Total Component Costs	\$5	\$8
Fixed Costs		
R&D Costs	\$62,292	\$62,292
Tooling Costs	\$30,000	\$35,000
Units/yr.	25,000	64000
Years to recover	5	5
Fixed cost/unit	\$1	\$0
Total Costs (\$)	\$6	\$8

The combinations of low-emission technologies ultimately chosen by motorcycle manufacturers are dependent on the engine-out emission levels of the vehicle, the effectiveness of the prior emission control system, and individual manufacturer preferences. We believe manufacturers will increase their use of electronic fuel injection in order to achieve better fuel delivery control. We project that the use of electronic fuel injection will increase to meet the Tier-1 and Tier-2 standards, with an accompanying decline in the use of carburetion. Tables 5.2.2-2 and 5.2.2-3 provide estimates of the costs of carburetor systems and electronic fuel injection systems. To project the incremental costs of going to electronic fuel injection we have subtracted the costs of the carburetor systems. We have estimated the incremental costs of

electronic fuel control to be in the range of \$183 and \$191.

Table 5.2.2-2. Carburetor Costs

Engine Size	600cc	1200cc
Carburetor	\$60	\$60
Number Required	2	2
Hardware Cost to Manufacturer	\$120	\$120
Labor @ \$28 per hour	\$1	\$1
Labor overhead @ 40%	\$1	\$1
Markup @ 29%	\$35	\$35
Total Component Costs	\$157	\$157

Table 5.2.2-3. Electronic Fuel Injection Costs

Engine Size	600cc	1200cc
Variable Costs		
Injectors (each)	\$12	\$15
Number Required	2	2
Pressure Regulator	\$10	\$10
Intake Manifold	\$30	\$30
Throttle Body/Position Sensor	\$35	\$35
Fuel Pump	\$20	\$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	\$249	\$255
Labor @ \$28 per hour	\$4	\$4
Labor overhead @ 40%	\$2	\$2
Markup @ 29%	\$72	\$74
Warranty Markup @ 5%	\$12	\$13
Total Component Costs	\$339	\$348
Fixed Cost to Manufacturer		
R&D Costs	\$62,292	\$62,292
Tooling Costs	\$10,000	\$12,000
Units/yr.	25,000	64000
Years to recover	5	5
Fixed cost/unit	\$1	\$0
Total Costs (\$)	\$340	\$348

We are also projecting the increased use of pulse air systems and catalyst systems for both the Tier 1 and Tier 2 standards. We have estimated the cost of both a mechanical and an

electronically controlled pulse air system and have projected the use of the electronic system for motorcycles equipped with electronic fuel control systems. For catalysts, we would expect an increase in use both for Tier 1 and Tier 2. While we do not expect catalysts to be used on all models, they will likely remain a key tool for emissions control. We are also projecting the increased use of oxygen sensors and have tied the increase in their use to the use of catalysts. It seems reasonable to expect manufacturers to use oxygen sensors with catalysts to ensure stoichiometric engine operation. Tables 5.2.2-4 through 5.2.2-7 provide estimates for these technologies.

Table 5.2.2-4 Pulse Air Valve Costs

Engine Size	600cc		1200cc	
Pulse Air Valve Type	Mechanical	Electronic	Mechanical	Electronic
Variable Costs				
Pulse Air	\$8	\$12	\$8	\$12
Labor @ \$28 per hour	\$1	\$1	\$1	\$1
Labor overhead @ 40%	\$0	\$0	\$0	\$0
Markup @ 29%	\$3	\$4	\$3	\$4
Warranty Markup @ 5%	\$0	\$1	\$0	\$1
Total Component Costs	\$12	\$18	\$12	\$18
Fixed Costs				
R&D Costs	\$0	\$0	\$0	\$0
Tooling Costs	\$8,000	\$8,000	\$10,000	\$10,000
Units/yr.	25,000	25,000	64,000	64,000
Years to recover	5	5	5	5
Fixed cost/unit	\$0	\$0	\$0	\$0
Total Costs (\$)	\$12	\$18	\$12	\$18

Table 5.2.2-5. Catalyst Costs to Manufacturer

Emission Level		
Catalyst Volume (L)	0.3	0.60
Metallic Substrate	\$8.80	\$11.60
Washcoat	\$0.54	\$1.09
Precious Metals	\$5.65	\$11.30
Can (18 gauge 304 SS)	\$1.09	\$1.52
TOTAL MAT. COST	\$16.08	\$25.51
LABOR	\$11.20	\$11.20
Labor Overhead @ 40%	\$4.48	\$4.48
Supplier Markup @ 29%	\$9.21	\$11.94
Manufacturer Price	\$40.98	\$53.13

Table 5.2.2-6 Catalyst Costs

Engine Size	600cc	1200cc
Variable Costs		
Oxidation Catalyst	\$41	\$45
Labor @ \$28 per hour	\$1	\$1
Labor overhead @ 40%	\$1	\$1
OEM markup @ 29%	\$12	\$14
Warranty Markup @ 5%	\$2	\$0
Total Component Costs	\$57	\$61
Fixed Costs		
R&D Costs	\$54,750	\$54,750
Tooling Costs	\$10,000	\$10,000
Units/yr.	25,000	64000
Years to recover	5	5
Fixed cost/unit	\$1	\$0
Total Costs (\$)	\$58	\$61

Table 5.2.2-7 Oxygen Sensor Costs

Engine Size	600cc	1200cc
Variable Costs		
Oxygen Sensors	\$10	\$10
Number Required	2	2
Hardware costs	\$20	\$20
Markup @ 29%	\$6	\$6
Warranty Markup @ 5%	\$1	\$1
Total Component Costs	\$27	\$27
Fixed Costs		
R&D Costs	\$0	\$0
Tooling Costs	\$5,000	\$5,000
Units/yr.	25,000	64,000
Years to recover	5	5
Fixed cost/unit	\$0	\$0
Total Costs (\$)	\$27	\$27

5.2.2.2 - Compliance Costs

We estimate 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. As with other fixed costs, we amortized the cost over 5 years of engine sales to calculate per unit certification costs shown in Table 5.2.2-8. We are not projecting increased facility costs because manufacturers currently are required to certify and therefore have adequate test facilities. In addition, because California standards are schedule to be implemented 2 years

earlier than the EPA standards would be, we would expect actual average certification costs to be much lower than those estimated here. It is likely that data from the California program would be used by manufacturers for EPA certification.

Table 5.2.2-8 Estimated Per Unit Certification Costs

	Highway Motorcycles	
units/year	25,000	64,000
certification costs	\$0.26	\$0.10

5.2.2.3 - Highway Motorcycle Total Costs

The analysis below combines the costs estimated above into a total composite or average cost. 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. Baseline estimates were made based on the sales weighted current usage rate indicated by our certification database. The weighting between the two engine displacement ranges is also based on projected sales information submitted by manufacturers at time of certification. The table below presents the baseline technology usage for the most recent two model years for which we have data (2001 and 2002). The analysis uses the 2002 technology usage baseline, but the 2001 penetration of the various technologies is presented to illustrate the progress that already appears to be underway in implementation of technologies such as engine modifications, fuel injection, and catalyst-based systems. For example, almost half of the larger motorcycles (where most U.S. sales are) are fuel-injected as of the most recent model year, a trend that we expect to continue as manufacturers implement designs intended to meet the upcoming California and European standards, both of which are large motorcycle markets.

For electronic fuel injection, we are attributing half the cost to emissions control and the other half to improved performance. We believe this is appropriate because the technology provides substantial benefits in performance and reliability in addition to improved emissions. Discounting the cost by one-half also helps account for the current trend toward increased use of electronic fuel injection in the absence of more stringent federal emissions standards.

A summary of the estimated near-term and long-term per unit average incremental costs for highway motorcycles is provided in Tables 5.2.2-9 and 5.2.2-10. Long-term costs do not include fixed costs, which are retired, and include cost reductions due to the learning curve.

Table 5.2.2-9 Estimated Average Costs For Motorcycles (Tier 1)

		Cost	Baseline Usage Rate		Tier 1 Control Usage Rate	Incremental Cost
			2001	2002		
600 cc (17%)	engine modifications	\$6	60%	66%	100%	\$2
	electronic fuel injection*	\$92	20%	23%	40%	\$16
	mechanical pulse air valve	\$12	53%	48%	60%	\$1
	electronic pulse air valve	\$17	0%	0%	40%	\$7
	catalyst	\$58	10%	15%	15%	\$0
	O2 sensors	\$27	0%	1%	15%	\$4
	total	--	--	--	--	\$30
1200 cc (83%)	engine modifications	\$8	54%	53%	100%	\$4
	electronic fuel injection*	\$96	37%	47%	50%	\$3
	mechanical pulse air valve	\$12	39%	37%	50%	\$2
	electronic pulse air valve	\$17	0%	0%	50%	\$9
	catalyst	\$60	13%	20%	25%	\$3
	O2 sensors	\$27	5%	5%	25%	\$5
	total	--	--	--	--	\$26
Near Term Composite Incremental Cost		--	--	--	--	\$26
Long Term Composite Incremental Cost		--	--	--	--	\$17

* The electronic fuel injection costs have been discounted by 50 percent to reflect the portion of the cost attributed to emissions control.

Table 5.2.2-10 Estimated Average Costs For Motorcycles (Tier 2)

		Cost	Baseline Usage Rate	Tier 2 Control Usage Rate	Incremental Cost
600 cc (17%)	engine modifications	\$6	100%	100%	\$0
	electronic fuel injection*	\$92	40%	60%	\$18
	mechanical pulse air valve	\$12	60%	40%	(\$2)
	electronic pulse air valve	\$17	40%	60%	\$3
	catalyst	\$58	15%	50%	\$20
	O2 sensors	\$27	15%	50%	\$10
	total				\$49
1200 cc (83%)	engine modifications	\$8	100%	100%	\$0
	electronic fuel injection*	\$96	50%	60%	\$10
	mechanical pulse air valve	\$12	50%	40%	(\$1)
	electronic pulse air valve	\$17	50%	60%	\$2
	catalyst	\$60	25%	50%	\$15
	O2 sensors	\$27	25%	50%	\$7
	total				\$33
Near Term Composite Incremental Cost		--	--	--	\$35
Long Term Composite Incremental Cost		--	--	--	\$22

* The electronic fuel injection costs have been discounted by 50 percent to reflect the portion of the cost attributed to emissions control.

5.2.2.4 - Highway Motorcycles Under 50 cc

We are establishing standards that are in line with standards already established in the countries and regions that represent the major scooter markets in the world, and which produce millions of scooters. The US scooter market is tiny in comparison to those in other parts of the world and represents a very small market for scooter manufacturers. In costing out changes in technology, it is therefore reasonable to project that the research and development and tooling necessary to meet standards will occur in response to the standards in other countries, rather than EPA standards. US standards would ensure that clean scooters developed for major markets also are the ones brought into the US market rather than traditional 2-strokes. It is also reasonable to expect that the fixed costs of research and development and tooling are spread over the worldwide unit sales for those scooters. Therefore, we would expect those costs to be small on a per unit basis.

To establish cost estimates for under 50 cc motorcycles, we first looked at the detailed cost analysis performed for our Small SI Engine Phase 2 Standards rulemaking, in which the cost for converting from 2-stroke to 4-stroke was estimated to be about \$14 per unit for a small engine (about 25 cc).⁸ The unit basis for this analysis was 90,000 units. EPA's estimate was supported in comments received from one Small SI manufacturer that estimated a cost of about \$15 for production less than 1 million units and another that estimated a unit cost of about \$10.

We also searched available literature and found a report prepared for the World Bank that estimated the difference in cost between a 2-stroke to a 4-stroke 50 cc scooter to be about \$60 per unit.⁹ We believe the difference in the two cost estimates can be accounted for in the difference in engine displacement and manufacturer mark-up. The \$60 estimate appears to be reasonable for a baseline 4-stroke engine. We are assuming that the cost represents a long-term stabilized cost rather than the initial cost of production. To the extent the \$60 estimate reflects costs of initial production, the long-term costs may be somewhat lower due to the learning curve effect. Also, to the extent that some manufacturers currently may have initial costs that are somewhat higher than \$60, we believe that costs reductions are likely to take place prior to 2006, due to the learning curve effect and a substantial increase in production in response to the world markets. Costs are likely to be stabilized by 2006.

In addition to the cost of the scooter, manufacturers will also incur costs for certification. Our estimate of average certification costs is \$1.52 per vehicle based on average U.S sales per engine family of 4,300 units. We have used the same methodology and costs for certification used for motorcycles above 50 cc (see section 5.2.2.2 - Compliance Costs) because the requirements are the same. We have established average sales per vehicle line using U.S. sales information provided by the Motorcycle Industry Council for motorcycles under 50cc.

The average cost for motorcycles under 50 cc must account for the fact that some scooters are already equipped with 4-stroke engines and a portion of the market is likely to remain 4-stroke prior to 2006. For those, the costs for meeting the standards would essentially be the cost

of certification. Based on current our estimated sales split between two and four-strokes in the less than 50 cc market, we are projecting that 4-strokes will account for about 30 percent of sales prior to 2006.ⁿ Sales weighting the estimated cost for a 2-stroke of \$61.52 and the estimated cost for the 4-stroke of \$1.52 (for certification) results in an estimated average cost for motorcycles under 50cc of about \$44.

Switching from conventional 2-stroke engines to 4-stroke engines results in a fuel economy savings of at least 30 percent. We have estimated a net present value per vehicle lifetime savings of about \$8, using the factors provided in the table below.¹⁰

Table 5.2.2-11 Estimate Per vehicle Lifetime Fuel Use and Cost

	2-stroke	4-stroke
Annual Miles	650	650
Average Life	6	6
fuel consumption (miles per gallon)	70	91
Fuel cost	\$1.10	\$1.10
Discounted Lifetime Fuel Consumption	43.45 gallons	36.43 gallons
Discounted Lifetime Fuel Cost	\$47.80	\$40.07

5.2.2.5 - Highway Motorcycle Aggregate Costs

The above analyses developed incremental per vehicle cost estimates for highway motorcycles. Using these per vehicle costs and projections of future annual sales, we have estimated total aggregate annual costs for the highway motorcycle standards. To estimate future sales for Class 3 motorcycles, we started with 1999 sales of 387,000 units and projected out using a annual growth rate of 1 percent.¹¹ For motorcycles below 50cc, we estimated 2001 sales of about 30,000 units and also applied a compound growth rate of 1 percent.¹² Aggregate fuel savings for the motorcycles less than 50cc, has also been estimated based on the usage and fraction of the fleet converted to 4-stroke engines.¹³ Table 5.2.2-12 presents the results of this analysis. As shown in the table, annualized aggregate costs increase from about \$16 million in 2006 to about \$26 million in 2010 when the program is fully phased in. Costs are projected to then decline somewhat to about \$20 million as fixed costs are retired, after which costs are

ⁿ The approximate sales split is based on available information from MIC, discussions with industry, and the number of 4-stroke 50 cc models currently offered in the US by non MIC manufacturers and importers.

projected to gradually increase over time due to growth in vehicle sales.

Table 5.2.2-12 Annualized Aggregate Costs for Highway Motorcycles

Calendar Year	Total Cost (Millions \$)	Fuel Savings (Millions \$)
2004	0	0
2005	0	0
2006	12.16	0.02
2007	12.28	0.07
2008	10.24	0.11
2009	10.34	0.14
2010	23.61	0.17
2011	23.60	0.20
2012	20.81	0.22
2013	21.02	0.24
2014	18.76	0.25
2015	18.84	0.26
2016	19.03	0.27
2017	19.22	0.28
2018	19.41	0.29
2019	19.60	0.30
2020	19.80	0.30
2021	20.00	0.31
2022	20.20	0.32
2023	20.40	0.32
2024	20.60	0.33
2025	20.81	0.34

5.3 - Aggregate Costs

The above analysis presents unit cost estimates for each category of equipment included in the proposal. These costs represent the total set of costs the manufacturers will bear to comply with emission standards. With current and projected estimates of engine and equipment sales, we translate these costs into projected direct costs to the nation for the new emission standards in any year. The costs to manufacturers generally range from \$12 to \$42 million annually. The cost savings due to fuel savings start slowly, then increase as greater numbers of compliant engines and equipment enter the fleet. The net cost (i.e., the sum of the cost to manufacturers and the fuel savings) peaks at about \$36 million in 2010 and decreases to about \$11 million by 2025. Table 7-3.5 shows these aggregate costs for all years during the period between 2006 and 2027.

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 of Air Pollution from New Motor Vehicles 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. Trident Marine Hose, "Retail Price List 2001," Docket A-2000-01, Document No. IV-A-15.
4. "Information on Costs and Effectiveness of Fluorination Received from Fluoroseal," Memorandum from Mike Samulski to Docket A-2000-1, March 27, 2002, Docket A-2000-01, Document IV-B-03.
5. Energy Information Administration, www.eia.doe.gov/neic/hisotric/hpetroleum.htm, February 27, 2002, Docket A-2000-01, Document IV-A-16.
6. Arthur D. Little–Acurex Environmental. Memorandum from Lou Browning to Chris Lieske: On-Road Motorcycle Draft Final Cost Comparisons, June 22, 2001, Docket A-2000-01, Document II-G-145.
7. Arthur D. Little–Acurex Environmental. Memorandum from Lou Browning to Chris Lieske: On-Road Motorcycle Draft Final Cost Comparisons, June 22, 2001, Docket A-2000-01, Document II-G-145.
8. EPA Final Regulatory Impact Analysis, Phase 2 Final Rule: New Nonroad Handheld Spark-Ignition Engines At or Below 19 Kilowatts, March 2000, EPA420-R-00-004
9. "Air Pollution from Motor Vehicles, Standards and Technology for Controlling Emissions", Asif Faiz, Christopher S. Weaver, Michael Walsh, The World Bank, Washington DC, November 1996, Docket A-2000-01, Document IV-A-29.
10. "Spreadsheet for Modeling the Emissions Inventories from On-Highway Motorcycles <50cc under the Proposed Rule", Memorandum from Phil Carlson to Docket A-2000-01, April 12, 2002, Docket A-2000-01, Document IV-B-09.

11. Annual sales taken from the “2000 Motorcycle Statistical Annual”, Motorcycle Industry Council, Docket A-2000-01, Document II-D-03.

12. The Motorcycle Industry Council provided 2001 sales estimates for member companies of 17,166 for scooters below 50 cc. We were unable to find statistics for non-MIC companies which make up a sizable share of the market. To attempt to account for sales for these non-MIC companies we asked several companies for their estimate of the overall 50cc scooter market and have based our final sales estimates on the information they provided.

13. “Spreadsheet for Modeling the Emissions Inventories from On-Highway Motorcycles <50cc under the Proposed Rule”, Memorandum from Phil Carlson to Docket A-2000-01, April 12, 2002, Docket A-2000-01, Document IV-B-09.

CHAPTER 6: Emissions Inventory

6.1 - General Methodology

The following chapter presents our analysis of the emission impact of the proposed standards for marine vessels and highway motorcycles. This chapter also discusses the possible impact of exhaust emission control from sterndrive and inboard marine engines. 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. This analysis does not monetize the emission reductions or health benefits.

6.1.1 - Highway Motorcycle Emissions

The modeling of highway motorcycle >50cc emissions is typically done with our MOBILE model. However, the inputs for motorcycles >50cc used in the MOBILE model have not been updated in many years. In developing the proposal for highway motorcycles, we have come across new information on current emission levels, revised scrappage estimates, and revised mileage accumulation rates for such vehicles. Because of this new information, we developed a spreadsheet for modeling the effect of the proposed standards for highway motorcycles >50cc that incorporates this new information. In addition, a similar spreadsheet was developed for modeling the effect of the proposed standards for highway motorcycles <50cc (currently unregulated). A copy of both spreadsheets developed for modeling the effect of the proposed standards on highway motorcycles has been placed in the docket for this rulemaking.^{1,2}

6.1.2 - Marine 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 four 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.

-hot soak: These emissions are due to temperature changes due to heat from the engine.

Copies of the spreadsheets developed for modeling marine evaporative emissions are included in the docket.³ The calculations in these spreadsheets are described below.

6.1.2.1 - Diurnal Emissions

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.⁴

For diurnal emission estimates, we used the Wade equations^{5,6} to calculate grams of hydrocarbons emitted per day per volume of fuel tank capacity. The Wade 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:

$$\text{Vapor space (ft}^3\text{)} = ((1.15 - \text{tank fill}) \times \text{tank size}) / 7.841 \quad \text{(Eq. 6-1)}$$

where:

tank fill = fuel in tank/fuel tank capacity^o

tank size = fuel tank capacity in gallons

$$T_1 (\text{°F}) = (T_{\text{max}} - T_{\text{min}}) \times 0.922 + T_{\text{min}} \quad \text{(Eq. 6-2)}$$

where:

T_{max} = maximum diurnal temperature (°F) of the fuel

T_{min} = minimum diurnal temperature (°F) of the fuel

$$V_{100} (\text{psi}) = 1.0223 \times \text{RVP} + [(0.0357 \times \text{RVP}) / (1 - 0.0368 \times \text{RVP})] \quad \text{(Eq. 6-3)}$$

where:

V_{100} = vapor pressure at 100°F

RVP = Reid Vapor Pressure of the fuel

^o We use 50% fill for our calculations.

$$E_{100} (\%) = 66.401 - 12.718 \times V_{100} + 1.3067 \times V_{100}^2 - 0.077934 \times V_{100}^3 + 0.0018407 \times V_{100}^4 \quad (\text{Eq. 6-4})$$

$$D_{\min} (\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113) \times (100 - T_{\min})] \quad (\text{Eq. 6-5a})$$

$$D_{\max} (\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113) \times (100 - T_1)] \quad (\text{Eq. 6-5b})$$

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 6-4

$$P_I (\text{psi}) = 14.697 - 0.53089 \times D_{\min} + 0.0077215 \times D_{\min}^2 - 0.000055631 \times D_{\min}^3 + 0.0000001769 \times D_{\min}^4 \quad (\text{Eq. 6-6a})$$

$$P_F (\text{psi}) = 14.697 - 0.53089 \times D_{\max} + 0.0077215 \times D_{\max}^2 - 0.000055631 \times D_{\max}^3 + 0.0000001769 \times D_{\max}^4 \quad (\text{Eq. 6-6a})$$

$$\text{Density (lb/gal)} = 6.386 - 0.0186 \times \text{RVP} \quad (\text{Eq. 6-7})$$

$$\text{MW (lb/lb mole)} = (73.23 - 1.274 \times \text{RVP}) + [0.5 \times (T_{\min} + T_1) - 60] \times 0.059 \quad (\text{Eq. 6-8})$$

$$\begin{aligned} \text{Diurnal emissions (grams)} = & \text{vapor space} \times 454 \times \text{density} \times [520 / (690 - 4 \times \text{MW})] \\ & \times 0.5 \times [P_I / (14.7 - P_I) + P_F / (14.7 - P_F)] \\ & \times [(14.7 - P_I) / (T_{\min} + 460) - (14.7 - P_F) / (T_1 + 460)] \end{aligned} \quad (\text{Eq. 6-9})$$

where:

MW = molecular weight of hydrocarbons from equation 6-8

P_{IF} = initial and final pressures from equation 6-6

We use these same equations in our modeling of evaporative emissions from on-highway vehicles. However for on-highway applications we make a correction of 0.78 based on empirical data.⁷ Because this correction is based on automotive applications we do not apply this correction factor here. Instead we use a correction factor of 0.65 which is based on the data presented in Chapter 4 for non-permeable fuel tanks with a vent hose.

6.1.2.2 - Refueling Emissions

We used the draft NONROAD model (discussed below) 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.⁸ These calculations are a function of fuel vapor pressure, ambient temperature, and

dispensed fuel temperature. The refueling vapor generation equation is as follows:

$$\text{Refueling vapor (g/gal)} = \text{EXP}(-1.2798 - 0.0049 \times (T_d - T_a) + 0.0203 \times T_d + 0.1315 \times \text{RVP}) \quad (\text{Eq. 6-10})$$

where:

T_d = dispensed fuel temperature (°F)

T_a = ambient fuel temperature (°F)

RVP = Reid Vapor Pressure of the fuel (psi)

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.

6.1.2.3 - Permeation Emissions

For our permeation emissions modeling, we used the emission data presented in Chapter 4 to determine the mass of hydrocarbons permeated through plastic fuel tanks and rubber fuel hoses on boats. Because permeation is very sensitive to pressure, we used Arrhenius' relationship⁹ to adjust the emission factors by temperature:

$$P(T) = P_0 \times \text{EXP}(-\alpha / T) \quad (\text{Eq. 6-11})$$

where:

T = absolute temperature

$P(T)$ = permeation rate at T

P_0 and α are constants

We determined the constants by relating the equation to the known properties of materials used in fuel tanks and hoses (presented in Chapter 4). In general, permeation doubles with every 10°C increase in temperature.¹⁰

6.1.2.3 - Hot Soak Emissions

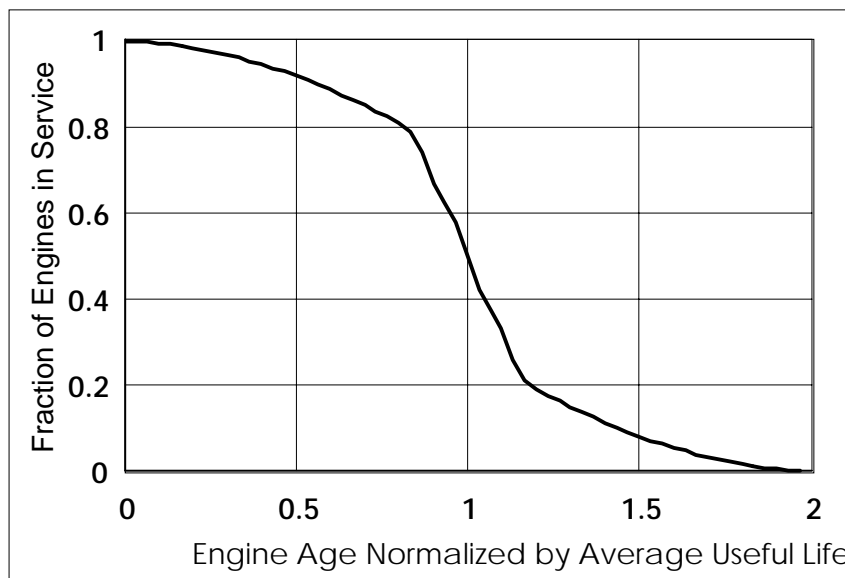
To get a rough estimate of hot soak emissions from marine vessels we used data collected on 612 light duty vehicles.¹¹ We then applied this emission factor to our estimates of boat operation discussed below.

6.1.3 - SD/I 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.

Figure 6.1.1-1: Normalized Scrapage Curve



For the inventory calculations in this rule, SD/I marine engines were 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:

$$Emissions = \sum_{ranges} (population \times power \times load \times annual\ use \times emission\ factor) \quad (Eq.6-12)$$

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.

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. Further discussion of this scrappage curve is available in the NONROAD documentation.¹²

6.2 - Effect of Emission Controls by Engine/Vehicle Type

The remainder of this chapter discusses the inventory results for highway motorcycles, marine vessels, and SD/I engines. Also, this section describes inputs and methodologies used for the inventory calculations that are specific to each engine/vehicle class.

6.2.1 - On-highway Motorcycles

As noted above, we projected the annual tons of exhaust HC, CO, and NO_x, from on-highway motorcycles using one spreadsheet for on-highway motorcycles <50cc and a second spreadsheet for on-highway motorcycles >50cc. Both of the spreadsheets are based on the MOBILE model and incorporate new information on current emission levels, updated scrappage rates, and updated mileage accumulation rates for on-highway motorcycles. This section describes inputs to the calculations that are specific to on-highway motorcycles then presents the resulting emissions inventories. 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 on-highway motorcycles exhaust emissions. These inputs are annual use, average operating life, and population. Based on data received from an industry trade group, we developed annual usage rates (i.e., mileage accumulation rates), and average operating life estimates for on-highway motorcycles.^{13,14} The average operating lifetimes were estimated to be 6.0 years for on-highway motorcycles <50cc and 12.5 years for on-highway motorcycles >50cc. Due to limited information on motorcycles <50cc, an average mileage accumulation rate of 650 miles/year was used for each year of operation (based on survey information provided by the industry trade group). The annual mileage accumulation rates for motorcycles >50cc used in the analysis (based on the results of a motorcycle user survey provided by the industry trade group) are contained in Table 6.2.1-1. The average mileage accumulation rate over the lifetime of a typical motorcycle >50cc is estimated to be 2,907 miles/year.

Table 6.2.1-1
Mileage Accumulation Rates for On-highway Motorcycles >50cc

Age (yrs)	Annual Mileage
1	3,308
2	3,320
3	3,751
4	3,330
5	1,920
6	2,884
7	3,021
8	3,475
9	4,131
10	3,977
11+	2,032

Source: Motorcycle Industry Council User Survey

In order to generate emission inventories for on-highway motorcycles, the spreadsheets developed for this analysis calculate a fleet-average emission factor (in grams per mile) and multiply the result by the total vehicle miles traveled (VMT) estimate for the appropriate portion of the highway motorcycle fleet (i.e., <50cc and >50cc) in a given year. The on-highway motorcycle fleet VMT estimates used for this analysis are summarized in Table 6.2.1-2. The on-highway motorcycle >50cc fleet VMT estimates were developed for our recent rulemaking for model year 2007 and later heavy-duty engines and vehicles standards.¹⁵ The 2001 VMT estimate for on-highway motorcycles <50cc was calculated based on the estimated 2001 population of on-highway motorcycles <50cc multiplied by the average mileage accumulation rate of 650 miles/year. VMT estimates for future year on-highway motorcycles <50cc were grown at the same rate as on-highway motorcycles >50cc.

Table 6.2.1-2
On-Highway Motorcycle Fleet VMT in Specific Calendar Year (Millions of Miles)

<i>Category</i>	<i>2000</i>	<i>2005</i>	<i>2010</i>	<i>2020</i>	<i>2030</i>
On-Highway Motorcycles <50cc	75	88	102	130	158
On-Highway Motorcycles >50cc	11,469	13,466	15,562	19,885	24,208

The current fleet of on-highway motorcycles <50cc is powered by mostly two-stroke engines. Beginning in 2002, a number of new vehicles (estimated to be about 30% of the new sales) are being powered by four-stroke engines. The baseline (i.e., pre-control) emission factors for two-strokes used in the spreadsheet analysis for on-highway motorcycles <50cc are based primarily on the results of testing uncontrolled two-stroke mopeds.¹⁶ (Because the emission factors for baseline two-stroke mopeds are the average of over one hundred vehicles of different ages, the emission levels are assumed to be a fleet average level and so no deterioration is added to the average levels cited in the report.) The baseline four-strokes now being introduced are assumed to have emission factors at the levels described below for Tier 1 vehicles. (As noted in Chapter 4, the Tier 1 standards are expected to result in the conversion of two-strokes to four-strokes. We believe that existing four-stroke designs would meet the proposed Tier 1 standards.) The HC and CO emission factors for Tier 1 on-highway motorcycles <50cc are based on the proposed HC and CO standards factoring in the effect of deterioration under certification conditions. The estimated emission factors also assume that manufacturers will include a compliance margin (estimated to be 20 percent) when certifying. (For NO_x, where we are not proposing a standard, we have assumed that four-strokes emit at the level of uncontrolled small 4-stroke motorcycles taken from a separate report.¹⁷) The deterioration factors for Tier 1 on-highway motorcycles <50cc are based on the data for the smallest motorcycles used in the MOBILE model. Table 6.2.1.-3 contains the emission factors and deterioration rates for on-highway motorcycles <50cc used in the spreadsheet analysis.

Table 6.2.1-3

Zero-Mile Level Emission Factors and Deterioration Rates for On-Highway Motorcycles <50cc

<i>Control Category</i>	<i>THC</i>		<i>CO</i>		<i>NOx</i>	
	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>
Baseline (Pre-control) - two-strokes	9.66	0	16.1	0	0.10	0
Baseline (Pre-control) - four-strokes	1.27	1.31	15.5	2.53	0.32	0
Tier 1	1.27	1.31	15.5	2.53	0.32	0

The baseline (i.e., Tier 0) emission factors used in the spreadsheet analysis for on-highway motorcycles >50cc are based on the average certification levels of current on-highway motorcycles >50cc. The baseline deterioration rates were taken from the MOBILE5 model. In order to estimate the control HC+NOx zero-mile level emission level for Tier 1 on-highway motorcycles, we took the proposed Tier 1 HC+NOx standard of 2.26 grams per mile (g/mi) and multiplied it by 0.68, which is the ratio of the baseline zero-mile HC level based on certification data compared to the baseline (i.e., Tier 0) HC standard. (We do not currently have a NOx standard for on-highway motorcycles >50cc.) Because we are proposing an HC+NOx standard for on-highway motorcycles >50cc, we have assumed that the Tier 1 HC/NOx split will remain the same as the baseline HC/NOx split. Because we do not currently regulate NOx for on-highway motorcycles >50cc, we based the HC/NOx split on current on-highway motorcycle >50cc certification data from the California Air Resources Board which does have a NOx standard. For the Tier 1 deterioration rates, we applied a factor of 0.67, which is the ratio of the pre-control HC zero-mile level compared to the estimate Tier 1 HC zero-mile level. For Tier 1 on-highway motorcycles >50cc, the NOx deterioration rate was assumed to be zero (i.e., no deterioration in NOx emissions). (The MOBILE model currently estimates no deterioration in NOx emissions for on-highway motorcycles.) To estimate the emission factors and deterioration rates for Tier 2 on-highway motorcycles >50cc, the Tier 1 emission factors and deterioration rates were multiplied by a factor of 0.57, which is the ratio of the proposed Tier 1 to proposed Tier 2 HC+NOx standards. Table 6.2.1-4 presents the emission factors and deterioration rates used in the spreadsheet analysis for on-highway motorcycles >50cc. (Because we are not proposing to change the CO standard for on-highway motorcycles >50cc, the CO emission factors and deterioration rates are the same for baseline and control cases.)

Table 6.2.1-4
Zero-Mile Level Emission Factors and Deterioration Rates for On-Highway Motorcycles >50cc

<i>Control Category</i>	<i>THC</i>		<i>CO</i>		<i>NOx</i>	
	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>	<i>ZML, g/mi</i>	<i>DR, g/mi/10k mi</i>
Baseline (Tier 0)	1.44	0.70	17.4	2.46	0.70	0
Tier 1	1.02	0.49	17.4	2.46	0.52	0
Tier 2	0.58	0.28	17.4	2.46	0.30	0

The Tier 1 standards for on-highway motorcycles are proposed to take effect in 2006. The Tier 2 standards for on-highway motorcycles >50cc are proposed to take effect in 2010.

Another piece of information needed to develop the fleet average gram per mile emission factors is information on the scrappage/survival rates of on-highway motorcycles. For our spreadsheet analyses, we used scrappage/survival rate information provided by an industry trade group.^{18,19} Table 6.2.1-5 presents the scrappage/survival rate information used in the spreadsheet models for on-highway motorcycles.

Table 6.2.1-5
Scrapage/Survival Rates for On-highway Motorcycles

Age	Fraction Surviving		Age	Fraction Surviving	
	<50cc	>50cc		<50cc	>50cc
1	0.94	0.99	14	-	0.40
2	0.88	0.97	15	-	0.34
3	0.79	0.96	16	-	0.29
4	0.71	0.94	17	-	0.25
5	0.60	0.91	18	-	0.18
6	0.50	0.88	19	-	0.12
7	0.36	0.82	20	-	0.09
8	0.28	0.75	21	-	0.06
9	0.23	0.71	22	-	0.04
10	0.13	0.66	23	-	0.03
11	0.08	0.60	24	-	0.01
12	0.05	0.55	25	-	0
13	-	0.45	-	-	-

Source: Motorcycle Industry Council

One final adjustment included in the spreadsheets, is an adjustment to account for temperature effects on emissions. In order to account for these impacts, the current MOBILE5 model was run at ambient temperature conditions of 75°F and at typical summertime temperature ambient conditions. The MOBILE5 outputs (in grams per mile) were compared for the two runs. The results showed that HC emissions decreased by 1 percent under summertime conditions, CO increased by 20 percent, and NOx emissions decreased by approximately 8 percent. These adjustments were applied to the emission factors in the spreadsheets.

6.2.1.2 - Reductions Due to the Proposed Standards

We anticipate that the proposed standards for on-highway motorcycles will result in a 50% reduction in both exhaust HC inventories and NOx inventories by the year 2020. Tables 6.2.1-6 through 6.2.1-8 present our projected exhaust HC, CO, and NOx, emission inventories for on-highway motorcycles (including both <50cc and >50cc vehicles) and the anticipated

emission reductions from the proposed standards. (Because we do not expect CO reductions from the proposal, only the baseline CO inventories are shown below.)

Table 6.2.1-6
Projected Exhaust HC Inventories and Reductions for On-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	35,000	35,000	0	0%
2005	40,000	40,000	0	0%
2010	46,000	41,000	5,000	9%
2020	58,000	29,000	29,000	50%
2030	71,000	28,000	43,000	61%

Table 6.2.1-7
Projected Exhaust CO Inventories for On-Highway Motorcycles (short tons)

Calendar Year	Baseline
2000	331,000
2005	387,000
2010	448,000
2020	572,000
2030	697,000

Table 6.2.1-8
Projected Exhaust NOx Inventories and Reductions for On-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	8,000	8,000	0	0%
2005	10,000	10,000	0	0%
2010	11,000	10,000	1,000	9%
2020	14,000	7,000	7,000	50%
2030	17,000	7,000	10,000	59%

6.2.1.3 - Per Equipment Emissions from On-highway Motorcycles

The following section describes the development of the emission estimates on a per piece of equipment basis over the average lifetime of a typical on-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 on-highway motorcycle, information on the emission level of the vehicle, the annual usage rate of the vehicle, and the lifetime of the vehicle 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 emission levels of a piece of equipment over the lifetime of a typical on-highway motorcycle were presented in Table 6.2.1-3 and Table 6.2.1-4. A brand new on-highway motorcycle emits at the zero-mile level presented in the tables. As the on-highway motorcycle ages, the emission levels increase based on the pollutant-specific deterioration rate. Deterioration continues throughout the lifetime of the vehicle and the amount of deterioration is directly proportional to the number of miles accumulated on the on-highway motorcycle.

As described earlier in this section, the annual usage rate for an on-highway motorcycle <50cc is estimated to be 650 miles per year and the average lifetime is estimated to be 6.0 years. For on-highway motorcycles >50cc, the annual usage rate is estimated to be 2,907 miles per year and the average lifetime is estimated to be 12.5 years.

Using the information described above, we calculated the lifetime HC or HC+NO_x emissions from typical on-highway motorcycles for both current (i.e., pre-control for <50cc and Tier 0 for >50cc) vehicles and vehicles meeting the proposed standards. Table 6.2.1-9 presents the lifetime HC or HC+NO_x emissions for typical on-highway motorcycles on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.1-10 presents the corresponding lifetime HC or HC+NO_x emission reductions for the proposed standards. (HC estimates are shown for on-highway motorcycles <50cc because we are not proposing a NO_x standard. HC+NO_x estimates are shown for on-highway motorcycles >50cc because we are proposing combined HC+NO_x standards.)

Table 6.2.1-9
Lifetime Emissions from a Typical On-highway motorcycle (short tons)

Control Level	<50cc Motorcycles		>50cc Motorcycles	
	Exhaust HC		Exhaust HC+NOx	
	Undiscounted	Discounted	Undiscounted	Discounted
Current (Pre-control for <50cc)	0.031	0.026	-	-
Current (Tier 0 for >50cc)	-	-	0.141	0.093
Tier 1	0.007	0.006	0.100	0.066
Tier 2	-	-	0.057	0.038

Table 6.2.1-10
Lifetime Emission Reductions from a Typical On-highway motorcycle (short tons)

Control Increment	<50cc Motorcycles		>50cc Motorcycles	
	Exhaust HC		Exhaust HC+NOx	
	Undiscounted	Discounted	Undiscounted	Discounted
Current (Pre-control) to Tier 1	0.024	0.020	-	-
Current (Tier 0) to Tier 1	-	-	0.041	0.027
Tier 1 to Tier 2	-	-	0.043	0.029

6.2.2 - Evaporative Emission Control from Boats

We projected the annual tons of hydrocarbons evaporated into the atmosphere from boats using spark-ignition (SI) marine engines using the methodology discussed above in Section 6.1.2. These evaporative emissions include diurnal, refueling, hot soak, and permeation emissions. Although the proposed standards do not specifically require the control of refueling and permeation emissions, we model them here because some of the technology that could be used to meet the proposed standards could result in reductions in refueling and permeation evaporative emissions. This section describes inputs to the calculations that are specific to boats and presents our baseline and controlled national inventory projections for evaporative emissions.

6.2.2.1 - Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for SI marine evaporative emissions. 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. We assumed that the national fuel tank distribution would be a function of the engine distribution. Table 6.2.2-1 presents the SI marine engine population estimates for 1998. To predict sales growth in future years we use the growth rates in the draft NONROAD model.²⁰ This is a linear growth rate, but is roughly equivalent to a compound growth rate of 0.7 percent from 2008 to 2028. These growth projections are consistent with historical boat sales recorded by the National Marine Manufacturers Association.²¹ The equivalent compound growth rate of recorded sales of motorboats from 1980 to 2000 is about 1 percent.

Table 6.2.2-1
1998 Spark-Ignition Marine Engine Population by Region

<i>Region</i>	<i>Outboards and Personal Watercraft</i>	<i>Sterndrive and Inboards</i>	<i>Total</i>
Northeast	3,530,000	651,000	4,180,000
Southeast	1,420,000	261,000	1,680,000
Southwest	355,000	65,400	420,000
Midwest	626,000	115,000	741,000
West	661,000	122,000	783,000
Northwest	3,530,000	650,000	4,180,000
Total	10,130,000	1,865,000	11,990,000

The draft NONROAD model breaks this engine distribution further into ranges of engine sizes. Outboards are divided into 10 power ranges, personal watercraft are divided into 5 power ranges, and SD/I are divided into 9 power ranges. For each of these power ranges we apply a fuel tank size for our evaporative emission calculations. To determine fuel capacity as a function of engine power we looked at data on 870 boats using outboard and SD/I engines.²² This data included total engine power for the boat and fuel tank capacity for boats ranging from 10 to 58 feet in length. From this data we determined a relationship between engine horsepower and fuel tank size which will be used in the next draft version of NONROAD and is used for this analysis. For personal watercraft we use the existing draft NONROAD default of gallons = 0.24 x rated horsepower, which is consistent with sales literature published for personal watercraft.

6.2.2.1.1 - Diurnal

For diurnal emission calculations, we also needed to make a distinction between portable and installed fuel tanks. This is because most, if not all, portable fuel tanks have valves that the user can close when the boat is not in use. We estimated that if these valves can be closed

whenever the boat is not in use, that about 90 percent of the diurnal vapor would be contained. This 90 percent estimate is based on the assumption that most users close the fuel vents when the boat is not in use. Also we assumed that all fuel tanks under 12 gallons are portable tanks.

Another effect that we consider in our diurnal emission modeling is the relationship between ambient temperature and fuel tank temperature throughout the day. Based the limited test data presented in Chapter 4, we have found that the fuel temperature swings are generally not as large as the associated ambient temperature swings. This is especially true for boats stored in the water. For boats stored out of the water (i.e. trailer boats) we modeled the fuel temperature swing to be 65 percent of ambient and for boats stored in the water we used a fuel temperature swing of 20 percent of ambient. For example, on a 72-96°F day, we modeled fuel temperature to be 76-92°F for a trailer boat and 82-86°F for a boat in the water. In our current modeling, we treat portable tanks as exposed to ambient air. We treat the smallest installed tanks as being on trailer boats and the largest tanks as being on boats stored in the water. For the sizes in between we use a linear interpolation of the fraction of boats stored in the water. We are interested in collecting better information on the fractions of boats stored in and out of the water.

Table 6.2.2-2 presents baseline and controlled emission factors for the proposed certification test conditions and for a typical summer day with low vapor pressure fuel and a 50 percent full tank. (This comparison is for illustrative purposes; as discussed above, we modeled daily temperature for 365 days over 6 regions of the U.S.) Decreasing temperature and fuel RVP and increasing fill level all have the effect of reducing the diurnal emission factor. In addition, Table 6.2.2-2 shows the effect of tank installation and boat location on the emission factors. Effectively insulating the tank through installation in a boat or exposing the tank to a cooling medium by storing the boat in the water reduce the fuel temperature swing compared to ambient. This, in turn, reduces the emission factors compared to test conditions.

Table 6.2.2-2
Evaporative Emission Factors for Test Conditions and Typical Summer Day

<i>Tank Type</i>	<i>Boat Location</i>	<i>Certification Test Conditions 72-96°F, 9 RVP* Fuel, 40% fill</i>	<i>Typical Summer Day 60-84°F, 8 RVP* Fuel, 50% fill</i>
Baseline Scenario (open vent)			
exposed	–	1.50 g/gallon/day	0.55 g/gallon/day
installed	trailer	0.90 g/gallon/day	0.34 g/gallon/day
installed	water	0.26 g/gallon/day	0.10 g/gallon/day
Control Scenario (closed vent with 1.0 psi pressure relief valve)			
exposed	–	1.09 g/gallon/day	0.39 g/gallon/day
installed	trailer	0.49 g/gallon/day	0.19 g/gallon/day
installed	water	0.00 g/gallon/day	0.00 g/gallon/day

* Reid Vapor Pressure [psi]

The proposed certification test procedure is designed to represent a day on which high amounts of ozone formation would be likely. These are generally the days when the need for hydrocarbon reductions is the greatest, but the contribution due to evaporative emissions is the highest. For automotive applications, where activated charcoal is used to collect hydrocarbons, designing for a three day test under these conditions ensures that equivalent emission control will be gained under less severe circumstances. This is also true for bladder fuel tanks, and to some extent, insulated fuel tanks. For sealed tanks with limited flow orifices, less of a percent emission reduction may be seen in-use than over the certification test. This is because the orifice must be sized to prevent over-pressure of the system under worst case conditions, so it may not be effective under typical conditions. However, for sealed tanks with pressure relief valves (with or without volume compensating bags), we would expect the percent hydrocarbon reduction in use to be much better than over the test procedure. This is because a valve designed for limited hydrocarbon breakthrough on the proposed test procedure may not have any breakthrough under less severe conditions when less pressure is formed in the tank. Therefore, although the closed vent with a 1 psi pressure relief valve results in little more than a 25 percent reduction in diurnal emissions over the proposed test procedure, we estimate that this technology would result in more than twice this reduction on average in use. The effects of ambient conditions and fuel tank exposure with an open vent and with a 1 psi valve in the vent are illustrated above in Table 6.2.2-2.

6.2.2.1.2 - Refueling

We used the draft NONROAD model to determine the amount of fuel consumed by spark-ignition marine engines. This draft model assumes annual operation of 34.8 hours for outboards, 77.3 hours for personal watercraft, and 47.6 hours for SD/I. Table 6.2.2-3 presents the fuel consumption estimates we used in our modeling. For 1998, the draft NONROAD model estimated that spark-ignition marine engines consumed about 1.3 billion gallons of gasoline.

Table 6.2.2-3
Fuel Consumption Estimates used in Refueling Calculations [kg/kW-hr]

<i>Technology</i>	<i>OB/PWC</i>	<i>SD/I</i>
carbureted two-stroke	0.79	–
fuel-injected two-stroke	0.59	–
carbureted four-stroke	0.59	0.43
fuel-injected four-stroke	–	0.34

For the refueling emission calculations, we had to consider the differences in dispensed fuel temperature for an above ground versus below ground fuel storage system. At most marinas, the fuel is stored above ground due to the water table level while most gas stations store their fuel underground. For our calculations, we assumed that the dispensed fuel temperature at marinas

was the same as ambient temperature. Our understanding is that most trailer boats are filled up at local gas stations, while larger boats need to fill up at marinas. To account for this we modeled boats with engines greater than 37 kW as marina fill-ups while the rest we modeled as gas station fill-ups. While this is a simplified approach, the results are fairly insensitive to this assumption. Table 6.2.2-4 presents emission factors for two conditions.

Table 6.2.2-4
Refueling Emission Factors for Two Summer Day Conditions

<i>Evaporative Control</i>	<i>84°F dispensed fuel, 78°F ambient temperature, 9RVP Fuel, 20% fill</i>	<i>72°F dispensed fuel, 68°F ambient temperature, 9RVP Fuel, 20% fill</i>
underground fuel tank	4.25 g/gallon	3.84 g/gallon
marina (above ground)	3.88 g/gallon	3.61 g/gallon

* Reid Vapor Pressure

6.2.2.1.3 - Permeation

We are in the process of collecting information on permeation rates from marine fuel tanks and hoses. Based on the data presented in Chapter 4, we developed the emission factors presented in Table 6.2.2-5. Fuel tank permeation was based on emission rates at 40°C is expressed in terms of g/gallon/day. Hose permeation was based on emission rates at 23°C and is based on g/m²/day. To show the effect of temperature on permeation rates, we present emission rates at both temperatures. For aluminum fuel tanks, we modeled no permeation through the tank.

Table 6.2.2-5
Fuel Tank and Hose Permeation Emission Factors

<i>Material</i>	<i>23°C (73°F)</i>	<i>40°C (104°F)</i>
Polyethylene fuel tanks	0.40 g/gal/day	1.33 g/gal/day
Fluorinated polyethylene fuel tank	0.02 g/gal/day	0.07 g/gal/day
Class 1 rubber hose (fuel lines)	100 g/m ² /day	330 g/m ² /day
Class 2 rubber hose (fill necks)	190 g/m ² /day	630 g/m ² /day
Multi-layer barrier hose	5 g/m ² /day	16 g/m ² /day

Based on the above emission factors, and a distribution of fuel tank sizes, materials, and hose lengths, we were able to estimate evaporative emissions due to permeation. Our distribution of fuel tank sizes is discussed later in this chapter and our distribution of plastic versus aluminum tanks is based on the sales information presented in Chapter 2. Our estimates

of hose lengths are based on the few boats that we have used in our testing; we are interested in collecting more information on the length of fuel hoses used in boats.

6.2.2.1.4 - Hot Soak

Our estimate of the average hot soak emission level was 0.48 grams per hot soak event for automotive sized fuel tanks (roughly 20 gallons on average). Based on the hours per year of operation discussed above, we estimate about 25 hot soak events per boat per year.

6.2.2.2 - Reductions Due to the Proposed Standard

We anticipate that the proposed standards will result in about an 82 percent reduction in total evaporative emissions from new boats. This is based on reductions from new boats of 95 percent fuel tank permeation, 95 percent hose permeation, and 57 percent diurnal venting. The total percent reduction increases as older boats are replaced with boats meeting the proposed standards. Refueling emissions are projected to decrease at in early years due to better fuel economy through the introduction of new engine technology (presented in Table 6.2.2-3). However, projected sales growth eventually offsets this effect. Figure 6.2.2-1 and the following tables present our emission inventory projections.

Figure 6.2.2-1: Projected National Evaporative HC from Boats Using SI Marine Engines

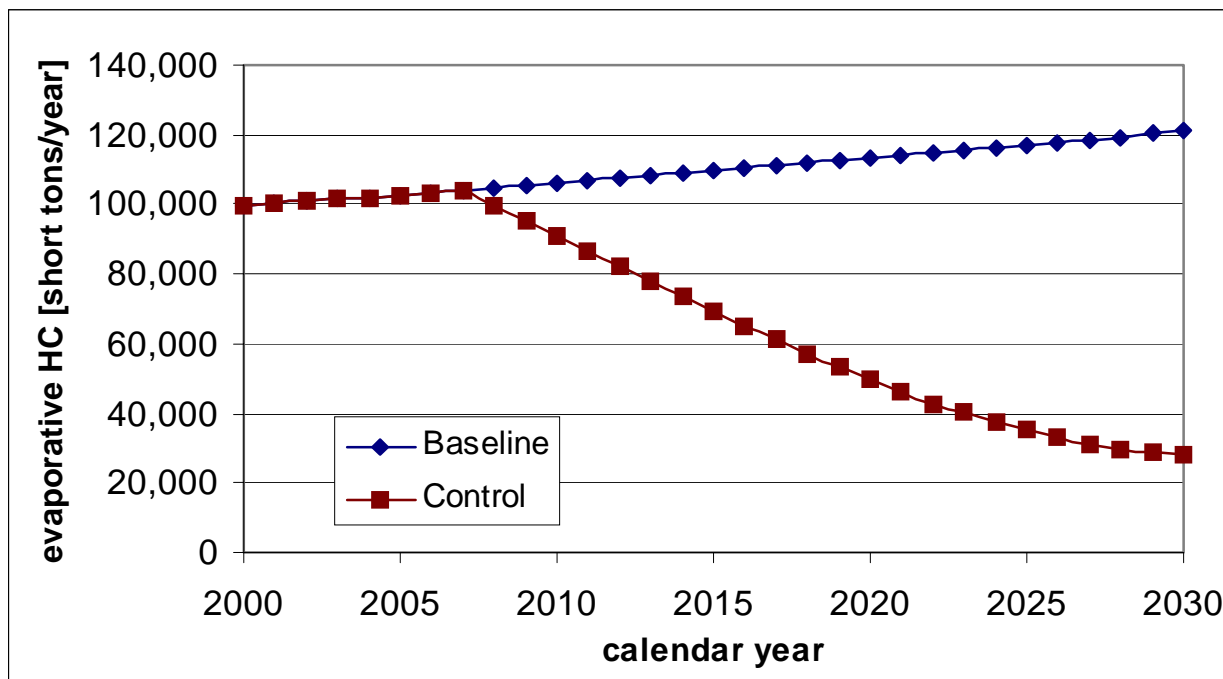


Table 6.2.2-6

Projected Baseline Evaporative Emissions for Boats [short tons]

<i>Calendar Year</i>	<i>Diurnal</i>	<i>Tank Permeation</i>	<i>Hose Permeation</i>	<i>Refueling</i>	<i>Hot Soak</i>	<i>Total</i>
2000	22,700	26,600	43,200	6,700	260	100,000
2005	23,600	27,700	44,900	6,600	270	103,000
2010	24,500	28,700	46,500	6,400	280	106,000
2020	26,300	30,800	49,900	6,400	300	113,000
2030	28,100	32,900	53,300	6,700	320	121,000

Table 6.2.2-7

Projected Controlled Evaporative Emissions Due to Proposed Standards [short tons]

<i>Calendar Year</i>	<i>Diurnal</i>	<i>Tank Permeation</i>	<i>Hose Permeation</i>	<i>Refueling</i>	<i>Hot Soak</i>	<i>Total</i>
2000	22,700	26,600	43,200	6,700	260	100,000
2005	23,600	27,700	44,900	6,600	270	103,000
2010	22,000	23,800	39,000	6,400	280	91,400
2020	15,600	10,000	17,700	6,400	300	49,900
2030	12,800	3,300	5,200	6,700	320	28,300

Table 6.2.2-8

Projected Reductions in Evaporative Emissions Due to Proposed Standards [short tons]

<i>Calendar Year</i>	<i>Diurnal</i>	<i>Tank Permeation</i>	<i>Hose Permeation</i>	<i>Total</i>	<i>Percent Reduction</i>
2010	2,540	4,930	7,590	15,100	14%
2020	10,700	20,800	32,200	63,800	56%
2030	15,300	29,600	48,100	93,000	77%

6.2.2.3 - Per Boat Evaporative Emissions

In developing the cost per ton estimates in Chapter 7, we need to know the lifetime emissions per boat. The lifetime emissions are based on the projected lives of 21 years, 10 years, and 20 years for OB, PWC, and SD/I respectively. We determine annual per boat evaporative emissions by dividing the total annual evaporative emissions for 2000 in by the boat populations shown in Table 6.2.2-1 (grown to 2000). Using this approach allows us to essentially weight the per boat emission factors for variation in tank sizes and materials. Per boat emission reductions are based on the modeling described above. Table 6.2.2-9 presents these results with and without the consideration of a 7 percent per year discount on the value of emission reductions.

Table 6.2.2-9
Typical Lifetime Evaporative Emissions Per Boat (tons)

Engine Class	Baseline		Control		Reduction	
	Undiscounted	Discounted	Undiscounted	Discounted	Undiscounted	Discounted
OB	0.145	0.080	0.027	0.015	0.118	0.065
PWC	0.068	0.051	0.017	0.013	0.051	0.039
SD/I	0.311	0.176	0.047	0.027	0.264	0.150
All Boats	0.158	0.091	0.028	0.016	0.130	0.074

6.2.3 - Sterndrive and Inboard Marine

We projected the annual tons of exhaust HC, CO, and NO_x from SD/I marine engines using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to SD/I marine engines then presents the results. Even though we are not proposing to regulate these engines in this rulemaking, we intend to revisit these engines once in a future rulemaking in the time frame of the first technology review to be performed by the California Air Resources Board (2005). Therefore, we present the baseline inventory here and perform an analysis of what the emission reductions could be if we were to finalize catalyst-based or EGR-based standards in the future.

6.2.3.1 - Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for SD/I 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 20.7 percent, an annual usage factor of 47.6 hours, and an average operating life 20 years for all SD/I engines. The draft NONROAD model includes current and projected engine populations. Table 6.2.3-1 presents these population estimates for selected years.

Table 6.2.3-1
Projected Recreational SD/I Population by Year

<i>Year</i>	<i>2000</i>	<i>2005</i>	<i>2010</i>	<i>2020</i>	<i>2030</i>
population	1,870,000	1,940,000	2,010,000	2,160,000	2,310,000

We used the data presented in Chapter 4 to develop the baseline emission factors. Because the industry is currently making a transition from carburetors to electronic fuel injection (EFI) for most SD/I engines, we present baseline emission factors for both technologies. We

included this phase-in of EFI technology in our baseline estimates. More detail on the emission factors, deterioration factors, and phase-in of electronic fuel injection used in the draft NONROAD model may be found in the docket.²³ Table 6.2.3-2 presents the emission factors used in this analysis for new engines and for engines deteriorated to the regulatory useful life (10 years).

Table 6.2.3-2
Emission Factors for SD/I Marine Engines

<i>Engine Technology</i>	<i>HC [g/kW-hr]</i>		<i>NOx [g/kW-hr]</i>		<i>CO [g/kW-hr]</i>	
	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>
baseline carbureted	7.9	8.9	7.2	7.3	210	240
baseline EFI	4.0	4.6	11.4	11.5	96	110

6.2.3.2 - Baseline Emissions from SD/I Marine Engines

Table 6.2.3-3 presents our projected exhaust emission inventories for SD/I. There is some decrease in HC and CO over time due to the introduction of electronic fuel injection. Through the use of electronic fuel injection, manufacturers are able to better control their fuel metering which allows them to calibrate for leaner operation to get better fuel economy. However, there is an increase in NOx over time (beyond the projected growth) due to the tradeoff between calibrating an engine for HC and NOx. The net effect of these leaner calibrations on combined HC+NOx is minimal in the range of air-fuel ratios that we expect manufacturers to use in their designs.

Table 6.2.3-3
Projected Exhaust Emissions from SD/I Marine Engines [short tons]

<i>Calendar Year</i>	<i>HC</i>	<i>NOx</i>	<i>HC+NOx</i>	<i>CO</i>
2000	23,100	19,900	43,000	629,000
2005	21,800	22,700	44,400	589,000
2010	20,200	25,800	46,000	540,000
2020	17,600	31,700	49,300	456,000
2030	17,500	35,100	52,600	446,000

6.2.3.3 - Analysis of Catalyst-based Approach

The California Air Resources Board (CARB) is going ahead with catalyst-forcing standards of 5 g/kW-hr HC+NOx. These standards are contingent on a two technology reviews, but are planned to be implemented on the following phase-in schedule: 45% in 2007, 75% in 2008, and 100% in 2009. In the near term, CARB also has a engine cap of 16 g/kW-hr HC+NOx

in 2005 for SD/I marine engines. Although we are not proposing these standards today, we will participate in the technology reviews and consider setting similar standards nationally based on data from these reviews and other sources. This section presents our analysis of what the emission benefits would be if the California approach was implemented nationally.

For the emission factors under the cap, we assumed that the manufacturers would design their engines to meet the proposed standard at regulatory useful life with a small compliance margin beginning with the 2005 model year. To determine the HC and NOx split for a standard of 16 g/kW-hr HC+NOx, we used the HC and NOx data presented in Chapter 4 from SD/I engines that are near this level. Also, we used the deterioration factors in the draft NONROAD model.

For the catalyst control scenario, we considered the CARB standards and implementation schedule. To determine the HC and NOx levels individually under the combined standard, we used the data presented in Chapter 4 from catalysts on SD/I engines. Consistent with our modeling of Large SI catalyst-based standards, we assumed a compliance margin of 10 percent. However, we used deterioration factors based on the rates in the MOBILE model for trucks with catalysts. Table 6.2.3-4 presents the emission factors used in this analysis for new engines and for engines deteriorated to the regulatory useful life (10 years).

Table 6.2.3-4
Emission Factors for SD/I Marine Engines with Catalysts

<i>Engine Technology</i>	<i>HC [g/kW-hr]</i>		<i>NOx [g/kW-hr]</i>		<i>CO [g/kW-hr]</i>	
	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>
emission calibrated EFI	4.0	4.6	9.8	9.9	96	110
marine catalyst	1.7	2.3	2.1	2.3	83	92

The following three tables present our projected impacts of a catalyst-based approach. We believe that the application of a catalyst will result in a reduction of 67% HC+NOx from new engines compared to baseline. We also anticipate that there would also be some CO benefits from using a catalyst.

Table 6.2.3-5
Projected Exhaust HC Reductions for SD/I Marine Engines with Catalyst Approach [short tons]

<i>Calendar Year</i>	<i>Baseline</i>	<i>Control</i>	<i>Reduction</i>	<i>% Reduction</i>
2000	23,100	23,100	0	0%
2005	21,800	21,800	0	0%
2010	20,200	19,200	1,040	5%
2020	17,600	12,700	4,920	28%
2030	17,500	8,720	8,750	50%

Table 6.2.3-6
 Projected NOx Reductions for SD/I Marine Engines with Catalyst Approach [short tons]

<i>Calendar Year</i>	<i>Baseline</i>	<i>Control</i>	<i>Reduction</i>	<i>% Reduction</i>
2000	19,900	19,900	0	0%
2005	22,700	22,400	200	1%
2010	25,800	21,200	4,610	18%
2020	31,700	14,700	17,000	54%
2030	35,100	8,570	26,600	76%

Table 6.2.3-7
 Projected CO Reductions for SD/I Marine Engines with Catalyst Approach [short tons]

<i>Calendar Year</i>	<i>Baseline</i>	<i>Control</i>	<i>Reduction</i>	<i>% Reduction</i>
2000	629,000	629,000	0	0%
2005	589,000	589,000	0	0%
2010	540,000	534,000	5,920	1%
2020	456,000	427,000	28,800	6%
2030	446,000	393,000	52,500	12%

6.2.3.4 - Analysis of EGR-based Approach

Because the California standards are subject to two technology reviews, it is possible that the catalyst-based standards may not go into place in the 2007-2009 time frame. If that were the case, an alternative to catalyst-based emissions reductions could be achieved through the use of exhaust gas recirculation (EGR). This section presents our analysis of what the emission benefits would be if an EGR-based approach was implemented nationally in 2009.

For the EGR control scenario, we use a standard of 10 g/kW-hr HC+NOx in 2009. To determine the HC and NOx levels individually under the combined standard, we used the data presented in Chapter 4 from EGR on SD/I engines. We used the same compliance margin and multiplicative deterioration rates as the above analysis. Table 6.2.3-8 presents the emission factors used in this analysis for new engines and for engines deteriorated to the regulatory useful life (10 years).

Table 6.2.3-8
 Emission Factors for SD/I Marine Engines with EGR

<i>Engine Technology</i>	<i>HC [g/kW-hr]</i>		<i>NOx [g/kW-hr]</i>		<i>CO [g/kW-hr]</i>	
	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>	<i>new</i>	<i>10 yrs</i>
exhaust gas recirculation	3.3	3.7	5.4	5.5	96	110

The following two tables present our projected impacts of an EGR-based approach on HC and NOx. We believe that the application of EGR would result in a reduction of nearly 40% HC+NOx from new engines compared to baseline. We would not expect any significant changes in CO due to the use of EGR.

Table 6.2.3-9

Projected Exhaust HC Reductions for SD/I Marine Engines with EGR Approach [short tons]

<i>Calendar Year</i>	<i>Baseline</i>	<i>Control</i>	<i>Reduction</i>	<i>% Reduction</i>
2000	23,100	23,100	0	0%
2005	21,800	21,800	0	0%
2010	20,200	20,000	200	1%
2020	17,600	16,200	1,400	8%
2030	17,500	14,800	2,700	15%

Table 6.2.3-10

Projected NOx Reductions for SD/I Marine Engines with EGR Approach [short tons]

<i>Calendar Year</i>	<i>Baseline</i>	<i>Control</i>	<i>Reduction</i>	<i>% Reduction</i>
2000	19,900	19,900	0	0%
2005	22,700	22,700	0	0%
2010	25,800	24,200	1,600	6%
2020	31,700	22,000	9,600	30%
2030	35,100	18,500	16,700	47%

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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 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 consider that the cost and cost-per-ton estimates for future proposed mobile source programs could 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 might 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 - Evaporative Emission Control from Boats

This section provides our estimate of the cost per ton of evaporative emissions reduced for boats. The analysis relies on the per vessel costs estimated in Chapter 5 and the estimated lifetime emissions reductions (tons) presented in Chapter 6. All costs and emission reductions are discounted to the year of sale of the boats at a rate of 7 percent. Table 7.1.2-1 presents the cost per ton with and without consideration of the significant fuel savings that will result from evaporative emission control assuming a 7 percent discount rate. The cost per ton results assuming a 3 percent discount rate are presented in Table 7.1.2-2. As shown in these tables, the fuel savings more than offset the cost of the evaporative emission control technology.

Table 7.1.2.-1
Estimated Marine Vessel Cost Per Ton of HC Reduced
(7 percent discount rate)

	Total Cost Per Boat	Lifetime Fuel Savings Per Boat (NPV)	Lifetime Reductions Per Boat (NPV tons)	Discounted Per Boat Cost Per Ton without Fuel Savings (\$/ton)	Discounted Per Boat Cost Per Ton with Fuel Savings (\$/ton)
dirunal	\$9	(\$4)	0.012	\$745	\$382
tank permeation	\$12	(\$9)	0.023	\$523	\$160
hose permeation	\$14	(\$14)	0.039	\$367	\$4
aggregate	\$36	(\$27)	0.074	\$478	\$115

Table 7.1.2.-2
Estimated Marine Vessel Cost Per Ton of HC Reduced
(3 percent discount rate)

	Total Cost Per Boat	Lifetime Fuel Savings Per Boat (NPV)	Lifetime Reductions Per Boat (NPV tons)	Discounted Per Boat Cost Per Ton without Fuel Savings (\$/ton)	Discounted Per Boat Cost Per Ton with Fuel Savings (\$/ton)
dirunal	\$9	(\$6)	0.016	\$555	\$192
tank permeation	\$12	(\$11)	0.031	\$390	\$27
hose permeation	\$14	(\$19)	0.052	\$273	(\$90)
aggregate	\$36	(\$36)	0.100	\$356	(\$7)

7.1.3 - On-Highway Motorcycles

This section provides our estimate of the cost per ton of emissions reduced for on-highway motorcycles. For on-highway motorcycles <50 cc, we have calculated cost per ton on the basis of HC only because we are only proposing an HC standard. For on-highway motorcycles >50 cc, we have calculated cost per ton on the basis of HC plus NOx because we are proposing HC plus NOx standards. The analysis relies on the per vehicle costs estimated in Chapter 5 and the estimated net present value of the per vehicle lifetime emissions reductions (tons) presented in Chapter 6.

Table 7.1.3.-1 presents the cost per ton estimates for the proposed standards for on-highway motorcycles <50cc. As described in Chapter 5, we expect a decrease in operating costs (i.e., decreased fuel costs) as manufacturers convert from 2-stroke to 4-stroke designs to meet the proposed standards. Therefore, Table 7.1.3-1 presents cost per ton estimates both without and

with the fuel savings included for both a 7 percent and 3 percent discount rate.

**Table 7.1.3.-1
Estimated On-Highway Motorcycle <50cc Cost Per Ton of HC Reduced**

Discount Rate	Cost per Vehicle (NPV)	Lifetime Fuel Savings (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)
7%	\$43.50	\$7.70	0.020	\$2,130	\$1,750
3%	\$43.50	\$8.50	0.022	\$1,950	\$1,570

As described in Chapter 5, the estimated per vehicle costs for on-highway motorcycles >50cc change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton for both the Tier 1 and Tier 2 standards, with the Tier 2 estimates incremental to Tier 1. The results of the analysis are presented in Table 7.1.3.-2 assuming a 7 percent discount rate. The cost per ton results assuming a 3 percent discount rate as presented in Table 7.1.3.-3.

**Table 7.1.3.-2
Estimated On-Highway Motorcycle >50cc Cost Per Ton of HC+NOx Reduced
(7 percent discount rate)**

Standard	Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton (\$/ton)
Tier 1 - Near-term	\$26	0.027	\$970
Tier 1 - Long-term	\$17		\$640
Tier 2 - Near-term	\$35	0.029	\$1,230
Tier 2 - Long-term	\$22		\$770

**Table 7.1.3.-3
Estimated On-Highway Motorcycle >50cc Cost Per Ton of HC+NOx Reduced
(3 percent discount rate)**

Standard	Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton (\$/ton)
Tier 1 - Near-term	\$26	0.034	\$770
Tier 1 - Long-term	\$17		\$510
Tier 2 - Near-term	\$35	0.036	\$980
Tier 2 - Long-term	\$22		\$620

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 2001 Dollars)¹

<i>Program</i>	<i>\$/ton</i>
Tier 2 vehicle/gasoline sulfur	1,437 - 2,423
2007 Highway HD diesel	1,563-2,002
2004 Highway HD diesel	227 - 444
Off-highway diesel engine	456 - 724
Tier 1 vehicle	2,202 - 2,993
NLEV	2,069
Marine SI engines	1,255 - 1,979
On-board diagnostics	2,480
Marine CI engines	26 - 189

By comparing the cost per ton values presented in 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 are in or below the range of these other programs. It is true that some previous programs have been more cost efficient than the motorcycle program we are proposing today. However, it should be expected that the next generation of standards will be more expensive than the last, because 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 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^p, the Agency compiled a list of

^p 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

additional known technologies that could be considered in devising new emission reductions strategies.² Through this broad review, over 50 technologies were identified that could reduce NO_x, VOC, or PM. The cost-effectiveness of these technologies averaged approximately \$5,000/ton for VOC, \$13,000/ton for NO_x, 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 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 NO_x + 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 evaporative requirements for boats, 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 evaporative emission controls from boats. (The numbers presented in Table 7.3-1 are not discounted.)

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 Evaporative Emission Requirements for Boats

Year	Evaporative HC Benefits (short tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2008	4,981	\$24,352,501	\$1,808,029	\$22,544,472
2009	10,008	\$24,529,461	\$3,632,959	\$20,896,502
2010	15,051	\$24,706,422	\$5,463,449	\$19,242,973
2011	20,093	\$24,887,920	\$7,293,723	\$17,594,197
2012	25,130	\$25,069,418	\$9,122,336	\$15,947,082
2013	30,173	\$25,250,916	\$10,952,755	\$14,298,161
2014	35,176	\$25,432,414	\$12,768,878	\$12,663,536
2015	40,177	\$25,613,912	\$14,584,108	\$11,029,804
2016	45,139	\$25,793,142	\$16,385,542	\$9,407,600
2017	50,050	\$25,972,371	\$18,168,163	\$7,804,208
2018	54,781	\$26,151,600	\$19,885,677	\$6,265,923
2019	59,310	\$26,330,830	\$21,529,628	\$4,801,202
2020	63,758	\$26,510,059	\$23,144,174	\$3,365,885
2021	67,965	\$26,689,288	\$24,671,245	\$2,018,043
2022	71,954	\$26,868,517	\$26,119,472	\$749,045
2023	75,543	\$27,047,747	\$27,422,051	(\$374,304)
2024	78,823	\$27,226,976	\$28,612,596	(\$1,385,620)
2025	81,837	\$27,406,205	\$29,706,991	(\$2,300,786)
2026	84,675	\$27,586,569	\$30,736,918	(\$3,150,349)
2027	87,295	\$27,766,933	\$31,687,988	(\$3,921,055)

Table 7.3-2 presents the sum of the costs and emission benefits over the twenty year period after the evaporative emission requirements for boats 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. It should be noted that these cost per ton figures are a little higher than those presented above on a per-engine basis. This difference is because the per-engine analysis relates costs to their resulting benefits while the stream of costs analysis compares costs incurred to benefits achieved in a fixed time frame. In other words, many of the costs incurred prior to 2027 will not achieve benefits until after 2027.

Table 7.3-2
Annualized Cost and Emission Benefits for the Period 2008-2027
due to the Proposed Evaporative Emission Requirements for Boats

	Evaporative HC Benefits (short tons)	Cost w/o Fuel Savings (Million \$)	Fuel Savings (Million \$)	Cost w/ Fuel Savings (Million \$)
Undiscounted 20-year Value	1,002,000	\$521.2	\$363.7	\$157.5
Discounted 20-year Value	456,100	\$290.9	\$165.6	\$125.4
Annualized Value	43,100	\$27.5	\$15.6	\$11.8

Table 7.3.-3 presents the year-by-year cost and emission benefits for the proposed on-highway motorcycle requirements. (The numbers presented in Table 7.3-3 are not discounted and include the benefits and savings for all on-highway motorcycles, including those <50cc and those >50cc.)

Table 7.3-3
Cost and Emission Benefits of the Proposed On-Highway Motorcycle Requirements

Year	HC+NOx Benefits (short tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	503	\$12,164,486	\$24,176	\$12,140,310
2007	1,622	\$12,283,740	\$67,997	\$12,215,743
2008	3,051	\$10,241,347	\$106,724	\$10,134,624
2009	4,478	\$10,341,370	\$141,465	\$10,199,904
2010	5,985	\$23,608,149	\$171,344	\$23,436,804
2011	8,629	\$23,601,656	\$197,498	\$23,404,158
2012	11,721	\$20,812,513	\$217,751	\$20,594,762
2013	15,006	\$21,019,555	\$235,520	\$20,784,035
2014	18,082	\$18,760,779	\$251,815	\$18,508,964
2015	21,664	\$18,838,943	\$263,984	\$18,574,959
2016	24,516	\$19,027,333	\$274,101	\$18,753,232
2017	27,585	\$19,217,606	\$282,971	\$18,934,635
2018	30,953	\$19,409,782	\$289,553	\$19,120,230
2019	34,249	\$19,603,880	\$296,134	\$19,307,746
2020	36,513	\$19,799,919	\$302,715	\$19,497,204
2021	38,701	\$19,997,918	\$309,296	\$19,688,622
2022	40,726	\$20,197,897	\$315,877	\$19,882,020
2023	42,603	\$20,399,876	\$322,458	\$20,077,418
2024	44,314	\$20,603,875	\$329,039	\$20,274,836
2025	45,914	\$20,809,914	\$335,620	\$20,474,294

Table 7.3-4 presents the sum of the costs and emission benefits over the twenty year period after the requirements for on-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 7.3-4
Annualized Cost and Emission Benefits for the Period 2006-2025
due to the Proposed On-Highway Motorcycle Requirements

	HC+NOx Benefits (short tons)	Cost w/o Fuel Savings (Million \$)	Fuel Savings (Million \$)	Cost w/ Fuel Savings (Million \$)
Undiscounted 20- year Value	457,000	\$370.7	\$4.7	\$366.0
Discounted 20- year Value	193,000	\$199.6	\$2.3	\$197.3
Annualized Value	18,200	\$18.8	\$0.2	\$18.6

Table 7.3-5 presents the aggregate year-by-year cost and emission benefits for both of the programs contained in the proposal. (The numbers presented in Table 7.3-5 are not discounted.)

Table 7.3-5
 Cost and Emission Benefits of the Proposed Requirements
 for All Equipment Categories covered by the Proposal

Year	HC+NOx Benefits (short tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	503	\$12,164,486	\$24,176	\$12,140,310
2007	1,622	\$12,283,740	\$67,997	\$12,215,743
2008	8,032	\$34,593,848	\$1,914,753	\$32,679,096
2009	14,486	\$34,870,831	\$3,774,424	\$31,096,406
2010	21,036	\$48,314,571	\$5,634,793	\$42,679,777
2011	28,722	\$48,489,576	\$7,491,221	\$40,998,355
2012	36,851	\$45,881,931	\$9,340,087	\$36,541,844
2013	45,179	\$46,270,471	\$11,188,275	\$35,082,196
2014	53,258	\$44,193,193	\$13,020,693	\$31,172,500
2015	61,841	\$44,452,855	\$14,848,092	\$29,604,763
2016	69,655	\$44,820,475	\$16,659,643	\$28,160,832
2017	77,635	\$45,189,977	\$18,451,134	\$26,738,843
2018	85,734	\$45,561,382	\$20,175,230	\$25,386,153
2019	93,559	\$45,934,710	\$21,825,762	\$24,108,948
2020	100,271	\$46,309,978	\$23,446,889	\$22,863,089
2021	106,666	\$46,687,206	\$24,980,541	\$21,706,665
2022	112,680	\$47,066,414	\$26,435,349	\$20,631,065
2023	118,146	\$47,447,623	\$27,744,509	\$19,703,114
2024	123,137	\$47,830,851	\$28,941,635	\$18,889,216
2025	127,751	\$48,216,119	\$30,042,611	\$18,173,508
2026	132,089	\$48,604,582	\$31,079,119	\$17,525,463
2027	136,056	\$48,995,126	\$32,036,770	\$16,958,356

Table 7.3-6 presents the sum of the costs and emission benefits over the twenty-two year period after all of the 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-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 2006 for on-highway motorcycles and concludes in 2008 for the proposed evaporative emission requirements for boats.)

Table 7.3-6
 Annualized Cost and Emission Benefits for the Period 2006-2027
 due to the Proposed Requirements for All Equipment Categories

	HC+NOx Benefits (short tons)	Cost w/o Fuel Savings (Million \$)	Fuel Savings (Million \$)	Cost w/ Fuel Savings (Million \$)
Undiscounted 22- year Value	1,555,000	\$934.2	\$369.1	\$565.1
Discounted 22- year Value	615,800	\$464.3	\$147.1	\$317.2
Annualized Value	55,700	\$42.0	\$13.3	\$28.7

Chapter 7 References

1. Gross Domestic Product Implicit Price Deflator, U.S. Department of Commerce, Bureau of Economic Analysis, <http://www.stls.frb.org/fred/data/gdp/gdpdef>, April 12, 2002, Docket A-2000-01, Document IV-A-31.
2. “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, Docket A-2000-01, Document II-A-77.

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. In preparing this IRFA, we looked at both the effect of this proposal for marine vessels and highway motorcycles and an earlier proposal for nonroad large SI engines, recreational vehicles, and CI recreational marine engines (October 5, 2001, 66 CFR 51098). Prior to issuing these proposals, 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
Fuel Tank Manufacturers	336211	<1000 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 - Highway Motorcycles

Of the numerous manufacturers supplying the U.S. market for highway motorcycles, Honda, Harley Davidson, Yamaha, Kawasaki, Suzuki, and BMW are the largest, accounting for 95 percent or more of the total U.S. sales. All of these companies except Harley-Davidson and BMW also manufacture off-road motorcycles and ATVs for the U.S. market. Harley-Davidson is the only company manufacturing highway motorcycles exclusively in the U.S. for the U.S. market.

Since highway motorcycles have had to meet emission standards for the last twenty years, EPA has good information on the number of companies that manufacture or market highway motorcycles for the U.S. market in each model year. In addition to the big six manufacturers noted above, EPA finds as many as several dozen more companies that have operated in the U.S. market in the last couple of model years. Most of these are U.S. companies that are either manufacturing or importing motorcycles, although a few are U.S. affiliates of larger companies in Europe or Asia. Some of the U.S. manufacturers employ only a few people and produce only a handful of custom motorcycles per year, while others may employ several hundred and produce up to several thousand motorcycles per year.

8.2.3 - Marine Vessels

Marine vessels include the boat, engine, and fuel system. The evaporative emission controls discussed above may affect the boat builders and/or the fuel tank manufacturers. 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.

8.2.3.1 - 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. At least 1,200 of these companies install engines that use gasoline fueled engines and would therefore be subject to the evaporative emission control program discussed above. More than 90 percent 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.

Based on information supplied by a variety of recreational boat builders, fuel tanks for boats using SI marine engines 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.

8.2.3.2 - Small Marine Fuel Tank Manufacturers

EPA has determined that total sales of tanks for gasoline marine applications is approximately 550,000 units per year. The market is broken into manufacturers that produce plastic tanks and manufacturers that produce aluminum tanks. EPA has determined that there are at least seven companies that make plastic fuel tanks with total sales of approximately 440,000 units per year. EPA has determined that there at least four companies that make aluminum fuel tanks with total sales of approximately 110,000 units per year. All but one of these plastic and aluminum fuel tank manufacturers is a small business as defined under SBA SIC Code 3713.

8.2.3.3 - 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.

8.2.3.4 - Small Gasoline Engine Marinizers

EPA has determined that there are at least 24 companies that manufacture SD/I gasoline engines (including airboats and jet boats) for recreational vessels. Seventeen of the identified companies are considered small businesses as defined by SBA SIC code 3519. These 17 companies represent approximately 6 percent of recreational gasoline marine engines sales for 2000. Approximately 70-80 percent of gasoline SD/I engines manufactured in 2000 can be attributed to one company. The next largest company is responsible for about 10-20 percent of 2000 sales.

8.2.4 - 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.

Other SERs, representing manufacturers of marine engines, noted that the U.S. Coast Guard regulates vessel tanks, most notably tank pressure and anti-siphoning requirements for carburetted engines. Tank manufacturers would have to take these requirements into account in designing evaporative control systems. The Panel recommends that EPA continue to work with the Coast Guard to evaluate the safety implications of any proposed evaporative emissions standards and to avoid interference with Coast Guard safety regulations.

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. Five 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.

(d) Marine Vessel Tanks: Most of this sector involves small fuel tank manufacturers and small boat builders. The Panel recommends that the program be structured with longer lead times and an early credit generation program to enable the fuel tank manufacturers to implement controls on tanks on a schedule consistent with their normal turnover of fuel tank molds.

(e) Highway Motorcycles: California ARB has found that California's Tier 2 standard is potentially infeasible for small manufacturers. Therefore, the Panel recommends that EPA delay making decisions on the applicability to small businesses of Tier 2 or other such revisions to the federal regulations until California's 2006 review is complete.

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.