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Draft Regulatory Impact Analysis

Control of Air Pollution Emission Standards for New Nonroad Spark-Ignition Marine Engines

DRAFT

REGULATORY IMPACT ANALYSIS

Control of Air Pollution; Emission Standards for New Nonroad Spark-Ignition Marine Engines

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Members of the National Marine Manufacturers Association and many individual manfufacturers have provided EPA with input on the technical and economic aspects of the engines potentially impacted by the proposed emission standards. A number of manufacturers provided essential test data, production engines for testing, or prototype engines for testing. EPA sincerely appreciates the cooperation of industry in EPA's technical evaluation of these engines and equipment.

Introduction

This document presents the Regulatory Impact Analysis (RIA) for the Notice of Proposed Rulemaking for the establishment of Emission Standards for New Nonroad Spark-ignition Marine Engines, herein after referred to as the nonroad marine NPRM or the Proposal.

This RIA is organized into chapters and appendices. Chapter 1 presents the engineering evaluation EPA has undertaken to determine the possible technical solutions for emission reductions from these engines and the specific technology and the related cost of such solutions. Chapter 2 considers the aggregate costs of the Proposal and analyzes economic impacts. Chapter 3 quantifies the emission reduction benefits of the Proposal and assesses impacts on environmental and health effects of these emissions. Also, Chapter 3 presents the schedule of emission reductions and costs of the Proposal and relates them to one another in terms of cost-effectiveness. An appendix is provided which contain supporting data.

Chapter 1: Technology Assessment

This chapter presents an assessment of various emission control technology that may be applied to marine engines. The main focus of this regulation is a large reduction in hydrocarbons (HC) with a minimum increase in oxides of nitrogen (NOx). Standards will also be set for carbon monoxide (CO) and, for compression-ignition marine engines, smoke and particulate matter (PM). Emission control technology for each of these constituents will be discussed in this chapter.

Both current and potential emission control technology are discussed in detail along with the impact on pollutant level of each technology. Based on these emission control technology options, the lowest feasible emission standards are calculated. Engine modifications for emission reductions will also affect engine performance and maintenance. These impacts are discussed in this chapter as well as possible impacts on vessel design.

Standardized test procedures for exhaust emissions and durability are required for setting an emission standard and for assessing the impacts of emission control technology. Before the emission control technology options are discussed, an understanding of the test procedures is required. Therefore, this chapter begins with a discussion of the emission and durability test procedures.

1.1. Adequacy of Proposed Test Procedures

In order for EPA to successfully regulate exhaust emissions from marine engines, test procedures are required that can accurately measure emissions from new and in-use marine engines. This section will discuss the feasibility of existing test procedures to measure exhaust emissions for regulation and EPA modifications to these test procedures. In addition, durability demonstration program options will be discussed. These options include pre-sale testing and recall testing.

1.1.1. Emission Test Procedures

The marine exhaust emission test procedures proposed by EPA are based on test procedures developed by the marine industry and interested governments. Before adopting any test procedure, EPA must investigate the test procedure development and possible cases where the test procedures are not representative of in-use operation. In addition, EPA must determine when in-use representativeness must be compromised for test repeatability. The process leading to the proposed test procedures is discussed here.

1.1.1.1. Known Marine Duty Cycles–Two sets of test procedures have been established for determining exhaust emission levels from recreational marine engines. The duty cycles associated with each of these test procedures are composed of steady-state modes. For each mode, the speed and torque relationship is based on an assumed propeller curve.

In 1993, emission regulations were enacted for marine engines operated on Lake Constance in Europe(1). Lake Constance (also known as the Bodensee) is a major source of drinking water for Austria, Germany, and Switzerland. The purpose of these regulations is to protect water quality.

Hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) are regulated by the Bodensee Shipping Regulations or *Bodensee-*

Schiffahrts-Ordnug (BSO). These emission levels are determined using the BSO eight-mode steady-state test procedure. For the BSO regulations, spark-ignition and compression-ignition marine engines are tested with the same duty cycle and modal weightings.

The International Standards Organization (ISO) is developing test procedures for determining emissions from several classes of nonroad engines. For the ISO procedures, two separate five-mode duty cycles were developed for spark-ignition and compression-ignition light-duty marine engines. These duty cycles are known as the E4 and E5 cycles. ISO also developed an E3 cycle for heavy-duty marine engines.

The E4 duty cycle for spark-ignition marine engines was developed from operational data collected from 33 boats with outboard marine engines and three boats with sterndrive marine engines(2). Normalized speeds were calculated, and a time distribution at 10% normalized speed intervals was developed. This speed distribution was used to develop five operation modes with accompanying weighting factors. In addition, an empirical relationship was determined between speed and torque. This relationship was used to determine the torque for each mode. This duty cycle has a power factor of 0.207.

The E5 duty cycle for compression-ignition marine engines was developed from operational data collected from a combination of manufacturer-owned pleasurecraft and a Norwegian government study of commercial fishing boats. Using only data on engines with rated power of 370 KW or less from the Norwegian government study, thirteen different classes of commercial fishing boats were represented. The average power factors for the pleasurecraft and commercial fishing boats were 0.25 and 0.44 respectively, with a simple average of 0.345. Higher power factors are the result of displacement versus planing hulls on the vessels. Data from these engines were used to develop five steady-state operational modes with the appropriate weighting factors.

ISO's E3 cycle is similar to the E5 cycle. The modes are the same except that the higher power modes are more heavily weighted, and the idle mode is removed. This results in a power factor of 0.68.

Test procedures have also been developed for large constant speed ship engines. However, these engines are not within the scope of this proposal. The duty cycles discussed in this section are presented in Table 1-01.

Table 1-01: Steady-State Marine Duty Cycles

Mode	1	2	3	4	5	6	7	8
BSO Cycle for SI and CI Marine Engines								
Speed %	idle	40	50	60	70	80	90	100
Power %	0	10.1	17.7	27.9	41	57.2	76.8	100
Weight %	30	10	10	10	20	5	5	10
ISO E4 Cycle for SI Marine Engines								
Speed %	100	80	60	40	idle			
Power %	100	57.2	27.9	10.1	0			
Weight %	6	14	15	25	40			
ISO E5 Cycle for CI Marine Engines								
Speed %	100	91	80	63	idle			
Power %	100	75	50	25	0			
Weight %	8	13	17	32	30			
ISO E3 Cycle for Heavy-Duty Marine Engines								
Speed %	100	91	80	63				
Power %	100	75	50	25				
Weight %	20	50	15	15				

Compression-ignition marine engines will be required to demonstrate compliance to smoke standards. EPA has applied the Federal on-highway smoke test procedure to land-based nonroad CI engines(3). This smoke test procedure consists of an idle mode followed by an acceleration and deceleration, followed by another acceleration and an engine loading mode down to peak torque. This simulates a truck starting from rest, performing a gear shift, and then pulling a heavy load up a reasonably steep grade. EPA does not consider this "lugging" mode to be representative of in-use marine operation. Therefore, this smoke test procedure would have to be modified so that the lugging mode will not be applied to marine propulsion engines.

The Engine Manufacturers Association (EMA) has offered to help develop a smoke test procedure appropriate for marine engines. In addition, EMA has requested that non-propulsion engines, such as generators, be tested using the appropriate ISO duty cycles.

1.1.1.2. Steady-State and Transient Test Options--A test procedure should be capable of serving two purposes: First, a test procedure must be repeatable so that useful results may be determined for comparing emission control technologies and for regulating emissions. Second, a test procedure must be representative of actual operation of the engine so that the emission results may be used for air quality analysis. One concern with a steady-state test procedure is that it overlooks transient operation that may be found in actual marine engine use.

NMMA(4) and EPA(5) have both collected test data regarding the sensitivity of transient operation on sterndrive marine engine exhaust emissions. HC, CO, and fuel consumption tended to increase as the engine experienced more transient operation while NOx tended to decrease under the same conditions. Both NMMA and EPA simulated transience by running the ISO E4 modes together in order, then in reverse order. The effects of increased transience were studied by increasing the cycle frequency in a given amount of time. This cycle is presented in Figure 1-01.

The NMMA and EPA studies do not agree on the amount of transience necessary to significantly affect emissions from the inboard marine engines. However, EPA is continuing research on inboard marine engines. No data has been collected on the effects of transient operation on emissions from outboard or personal watercraft marine engines.

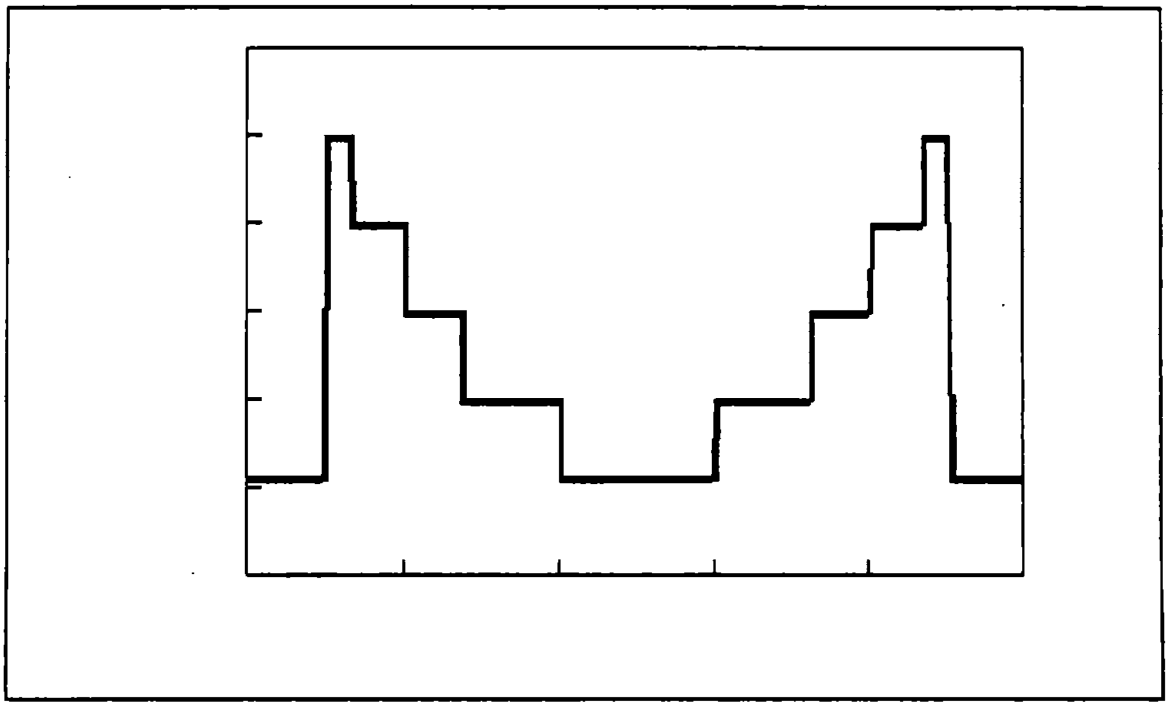

Figure 1-01: Marine Transient Cycle

EPA has not yet collected any information on the amount of transience seen in actual marine engine operation. Marine engines are used for diverse applications. Personal watercraft would be expected to be highly transient with their typical "stop and go" usage, while large commercial fishing vessels would be expected to run fairly steady. This information would be necessary to determine the need for and possibly develop a transient test procedure. In any case, a steady-state test should be capable of characterizing emissions well enough for a "technology-forcing" emission standard.

1.1.1.3 Emission Sampling and Test Set-Up Options--The most challenging aspect of testing marine engines seems to be how to take the emission sample. This difficulty rises as a result of water jacketing of the exhaust and actual mixing of cooling water and exhaust within the drive package. Water jacketing of the exhaust is required to meet Coast Guard surface temperature regulations while the mixing of water and exhaust is used to muffle noise from the engine.

The two established methods of sampling exhaust are raw and dilute. For the purpose of this document, raw sampling refers to inserting a probe into the exhaust stream and pulling out a portion of the exhaust during engine operation. Dilute sampling refers to pulling the entire exhaust stream through a critical flow venturi (CFV). Because the volume flow through the venturi must be constant, dilution air is used to offset the changes in exhaust flow.

Dilute sampling requires one less measurement than raw sampling for the calculation of exhaust emissions which results in less chance for measurement error. When dilute sampling is employed, the mass flow of the exhaust and dilution air is determined by the CFV; therefore, a single concentration measurement may be made with an error within approximately two percent.

For raw sampling only a small portion of the exhaust is sampled. The fuel flow into the engine must be measured in order to calculate the total mass flow. This method has the potential for larger additive errors especially at idle where fuel flows are minimized and are harder to measure accurately. In addition, because an exhaust stream may not be homogeneous, the exhaust sample may not be representative of the total exhaust from the engine.

Although a transient test has not been developed for marine engines, EPA has not ruled out the possibility of converting to a transient test procedure in the future. Raw sampling has not been proven to be acceptable for transient testing due to the lag time between fuel flow and emission measurements. A test facility using raw sampling would run the risk of becoming obsolete in the future.

Due to the unique exhaust systems in most marine engines, raw sampling does have one advantage to dilute sampling. For dilute sampling, the cooling water must be routed so that it does not mix with the exhaust. For raw sampling, the exhaust sample may be taken upstream of where the water and exhaust mix. The advantage of raw sampling is that addition of a probe should have smaller effects on the exhaust tuning than routing the cooling water away from the exhaust. Especially for two-stroke engines, the engine operation (power, fuel consumption, and emissions) is sensitive to the exhaust tuning.

Tied into the exhaust sampling method is the actual set-up of the engine in a test cell. Two major set-up options are crankshaft and propshaft testing. Crankshaft testing refers to removing the drive unit and applying the load directly to the crankshaft. Propshaft testing refers to applying the load to the output shaft of the drive unit. The significance of the drive unit on testing is a result of power losses in the gears and, more significantly, "tortuous" exhaust passages within the drive unit.

Crankshaft testing allows the reported emission results to be purely engine based. This way, the same engine used in both inboard and sterndrive packages would not have to be tested for each drive unit. In addition, dilute sampling is much simpler with crankshaft testing. Engine cooling water can be routed so not to mix with the exhaust and the total exhaust can be collected easily.

Propshaft testing is probably more representative of actual engine operation because of the effects of the drive unit on engine performance.

However, EPA has collected little data on the effects of the drive unit on emissions. EPA expects that the effects of exhaust tuning on emissions would be more significant for two-stroke engines than for four-stroke engines.

1.1.1.4 EPA Proposed Emission Test Procedures–EPA proposes the ISO E4 duty cycle for measuring HC, CO, and NOx from SI marine engines. A steady-state cycle was chosen over a transient cycle due to a lack of data on the appropriateness of a transient cycle. Because of the large reductions in hydrocarbons required by this regulation, EPA decided that any sensitivity of transience on hydrocarbons would be small in comparison. The ISO E4 was chosen over the BSO cycle because the extra three modes added by BSO to the duty cycle have not been shown to provide significant additional control[4].

EPA proposes the ISO E5 duty cycle for measuring HC, CO, NOx, and PM from CI marine engines. At this time, EPA is not aware of how the E3 duty cycle was developed. Therefore, all CI marine engines not regulated by IMO ship standards will be tested using the E5 duty cycle.

EPA believes that the modified (no "lugging" mode) Federal smoke procedures are reasonable for marine CI engine smoke control within the proposed timeline. While marine applications experience some differences in operation compared to on-highway applications, EPA has determined that the same technologies will be used to control smoke in nonroad applications as are used in on-highway applications. Therefore, the differences in marine and on-highway operation are not large enough to hold up this proposal for the significant time period required to develop a new smoke test procedure.

Inboard, sterndrive, and personal watercraft engines are proposed to be tested with a crankshaft set-up and dilute emission sampling. Crankshaft testing allows the test results to be purely engine-based, and it is the easiest way to collect a dilute sample. EPA considers dilute emission sampling to be superior to raw sampling due to lower measurement error and capability of sampling during a transient cycle. For CI engines, dilute sampling will be required in order to take a particulate sample.

Outboard marine engines have been reported to be significantly sensitive to exhaust tuning. In addition, a given marine outboard engine will be typically sold with a single drive unit. For these reasons, EPA proposes to allow propshaft testing with a raw emission sample. Dilute sampling may be necessary for CI outboard marine engines so that particulate and smoke testing will be possible.

1.1.2. Durability Test Procedures

When an engine is certified to meet a given set of emission standards, the engine is expected to comply with these standards throughout its useful life. Experience with on-highway engines has shown EPA that deterioration, over time, of the engine and emission control equipment can have a significant effect on emissions. Therefore, deterioration factors (DFs) must be developed to account for changes in emission characteristics over the useful life of the engine. EPA does not have sufficient data for determining the effects of deterioration on marine engines or on the emission control technology expected to be used to meet the requirements of this proposal. Therefore, a demonstration of emission control durability is necessary during the certification process.

1.1.2.1. Engine and Emission Control System Deterioration Factors—For spark-ignition marine engines, EPA is proposing a durability demonstration program similar to that used for spark-ignition on-highway heavy-duty engines. This program includes a requirement that for each engine family, the manufacturer shall determine emission deterioration factors for each pollutant based on testing of engines, subsystems, or components and/or sound technical judgment. The deterioration factors would be submitted to EPA and applied to the new engine emission results to determine compliance with the emission standards. The deterioration factors would be required to simulate deterioration for 360 hours of use for all spark-ignition marine engines. These factors would also be expected to simulate deterioration over a period of 10 years for all spark-ignition engines except personal watercraft, which would be expected to simulate 5 years.

For compression-ignition marine engines, no submission of durability demonstration test data or use of a deterioration factor will be necessary when certifying engine families that do not employ aftertreatment. For on-highway vehicle certification, EPA has found that NOx emissions from compression-ignition engines experience very little, if any, increase over time. Because the focus on CI engines is for NOx emissions, the requirement of durability demonstrations and deterioration factors during certification would impose an unnecessary cost burden on manufacturers.

Should a manufacturer choose to use exhaust aftertreatment to meet the emission standards for any engine family, deterioration factors would have to be determined and applied in the same manner as is currently done for on-highway CI engine durability demonstration. However, no durability demonstration or deterioration factors are required when an engine that was certified without aftertreatment is later retrofitted with an aftertreatment device or package. These retrofits are not designed to interfere with the original design and, therefore, should not result in worse emissions than the original design. Since the engine has already been demonstrated to be in compliance without the aftertreatment device, demonstration of the durability of a retrofitted aftertreatment device is not necessary.

1.1.2.2. Durability Demonstration--Once the manufacturer determines the form and the extent of engine and/or component selection and testing methodologies, deterioration factors may be established for a given engine family. These DFs would be applied to the new engine emission levels and the resulting emission levels would be required to comply with the emission standards (or the family emission limits). The manufacture would also be required to perform in-use testing for the recall program. EPA would use this in-use data to confirm the methodology for establishing deterioration factors. For example, if in-use testing indicates that an engine family's emission control system is deteriorating at a faster rate than predicted by the manufacturer's DF, EPA would challenge the use of the manufacturer's methodology for determining DFs for other engine families. The manufacturer would have to revise it's methodology for determining DFs or provide data and information to support the use of the DF generation methodology for other engine families.

EPA believes that this approach will best ensure that marine emission control systems will be designed and built to be durable. This program requires manufacturers to assess deterioration of emission control before such engines enter into commerce. Therefore, systems with inadequate durability can be identified and corrected before they are used on the waterways. Also, this approach provides a means of determining the adequacy of the deterioration factor methodology through actual in-use data.

1.1.2.3. Representation of Available Fuel–Although the certification fuel is representative of fuel sold for on-highway applications, marine engines may come across fuel with different blends. The fuel found in most marinas is not required to meet the same quality and environmental standards as fuel supplied for use in on-highway applications. Finally, there is no guarantee that all two-stroke oils will perform equally in marine engines.

Manufacturers have informed EPA of some of the problems associated with non-certification fuels and oils. Fuel with too high of a volatiliy may cause vapor lock. Old fuel may result in plugged injectors. On-highway reformulated fuels may have detrimental effects on rubber or metal not designed for use with alcohol. Low grade oil in an engine designed for TCW3 oil may result in unsatisfactory lubrication of the piston and gears. All of these conditions affect the durability of the marine engine.

EPA recommends that manufacturers specify the fuel and oil in the engine owner's user manual that are required for the proper operation of the engine. Whatever fuel is used by the boat owner will be considered typical of in-use operation unless the manufacture has a strong argument to the contrary for that particular engine. EPA expects the manufacturers to design their engines to operate on fuels typically used in marine engine applications.

1.2 Emission Control Technology

This section describes in detail the current technology and the potential emission control technologies as well as pollutant levels for each technology for spark-ignition marine engines. For compression-ignition engines, EPA refers the reader to the Regulatory Support Document entitled "Control of NOx and Smoke Emissions From Nonroad Compression-Ignition Engines Greater Than or Equal to 50 Horsepower (37.5 Kilowatts)" contained in Docket No. A-91-24. Since EPA believes that marine compression-ignition engines are similar in design to currently regulated nonroad compression-ignition engines, the current technologies and potential emission control technologies described in the > 50 horsepower nonroad RSD are expected to be reasonably applicable to marine compression-ignition engines.

1.2.1. Current Technology

1.2.1.1. Outboard and Personal Watercraft Spark-Ignition Engines--The current technology for outboard and personal watercraft engines is predominantly crankcase fuel/air/oil scavenged two-stroke. This technology was used on the first outboard marine engines produced and continues to be used today. After combustion of the air/fuel/oil mixture, the resulting exhaust gases are "pushed" or "scavenged" from the cylinder by the crankcase air/fuel/oil charge. Thus a portion of the air/fuel/oil charge exits the cylinder along with the exhaust gases resulting in extremely high hydrocarbon emission levels. Up to 25-30 percent of the fuel consumed by such engines can exit the cylinder unburned.

Another technology used in the market today, although only making up about 0.1 percent of the current market, is 4-stroke technology. Currently two manufacturers produce 4-stroke outboard engines.

1.2.1.2 Sterndrive and Inboard Spark-ignition Engines—The current technology used on nearly all spark-ignition marine sterndrive and inboard engines is 4-stroke. Most of these engines are derived from marinizing truck or automobile engine blocks. Marinizing often includes the addition of intake manifolds, fuel systems, and water jacketed exhaust manifolds to automotive or truck engine blocks.

Currently, the majority of sterndrive and inboard spark-ignition engine utilize carbureted fuel systems. However, there is a trend toward the increased application of electronic fuel injection (EFI) for these engines.

1.2.2. Potential Emission Control Technology

1.2.2.1. 4-stroke Technology--One relatively clean (that is, low hydrocarbon emissions) technology that is feasible for outboard and personal watercraft engines is 4-stroke technology. This technology eliminates the exhaust gas scavenging by the crankcase air/fuel/oil mixture, thus significantly reducing hydrocarbon emissions. Four-stroke technology has been used for years for automotive applications as well as nonroad engine applications such as sterndrive and inboard marine engines and lawn and garden spark-ignition engines. However, 4-stroke technology will most likely be limited to engines under about 100 hp since the weight increases from the added components may be prohibitive for the larger outboard engines.

1.2.2.2. Direct Injection 2-Stroke Technology—Direct injection 2-stroke technology is another potentially feasible technology for application on outboard and personal watercraft engines to significantly reduce hydrocarbon emissions. This cleaner type of 2-stroke technology directly injects the fuel into the combustion chamber, thus avoiding the air/fuel/oil scavenging losses inherent with current technology 2-stroke engines. For direct injection designs, exhaust gases are pushed out, or scavenged from the combustion chamber with the air/oil mixture from the crankcase, not the air/fuel/oil crankcase mixture that is used to scavenge current technology 2-strokes. This not only results in significant hydrocarbon emissions reduction, but also improves fuel economy. There are a number of different variations of direct injection technologies. Two main grouping are those that use air assisted (pneumatic) systems to inject fuel and those that are not air assisted that rely on mechanical means to develop the necessary injection pressures. An example of an air assisted system, developed by Orbital Corp. of Australia is discussed in more detail in the following.

Orbital's Small Engine Fuel Injection System (SEFIS): This technology consists of applying a Small Engine Fuel Injection System (SEFIS) consisting of a Fuel and Oil Metering Pump (FOMP) and a Direct Cylinder Injector (DCI). The FOMP controls the amount of fuel and oil delivered to the engine. The oil is measured as a function of engine speed and fuel flow. Because the FOMP injects oil into the air intake, fuel and oil are not mixed in the fuel tank. The fuel injection is accomplished by an air assisted (pneumatic) fuel injector used to achieve a stratified charge. The air and fuel are injected into the cylinder. Electronic control of the injection timing is used to prevent scavenging losses at high loads and excessive fuel dispersion at light loads (to control hydrocarbons and stability).

A third technology that EPA believes to be potentially feasible for reducing hydrocarbon emissions from outboards and personal watercraft is catalyst technology. Catalysts have been used for reducing emissions from automobiles since the mid 1970's. Catalysts can also be used for marine applications, but there are a number of technological hurdles that must be overcome.

A main complication with the use of catalysts with marine engines is that water is mixed with the exhaust for engine surface temperature reduction to comply with U.S. Coast Guard regulations and for noise reduction purposes. Catalysts would have to be designed to be located upstream of the point where water is introduced into the exhaust system. Also, especially for outboard and personal watercraft engines, severe packaging constraints make the application of catalysts very challenging. One last point is that since these engines can often operate at wide open throttle for extended periods of time, high catalyst temperatures limit the conversion efficiency levels to which the catalysts can be designed. Catalysts along with the closed loop electronic fuel injection systems used for automobile applications often achieve greater than 90 percent hydrocarbon conversion efficiency. However, automobiles do not operate for extended periods of time at wide open throttle where catalysts temperatures can cause severe catalyst deactivation or safety hazards. Therefore, for marine applications, catalyst conversion efficiency may need to be limited to lower conversion efficiency levels (70-80 percent) due to these temperature concerns.

EPA also considered a number of other emission control techniques to reduce emissions from outboard and personal watercraft engines. These include recalibration of current technology 2-stroke engines and electronic fuel injection on current technology 2-strokes. These methods are expected to achieve much less emission reduction (see the section "Control Technology Pollutant Levels" below) compared to the other technologies.

1.2.3 Control Technology Pollutant Levels

1.2.3.1 Outboard and Personal Watercraft Engines--Several technologies were considered for reduction of HC emissions from current two-stroke outboard and personal watercraft engines: conversion to four-stroke, direct-injection two-stroke, recalibration of current two-strokes, and the use of catalytic convertors. In determining the benefits from these technologies, EPA has compared emissions rates (on a brake specific work basis) from current two-stroke outboard and personal watercraft engines without these emission control technologies to estimates and test data from engines with these emission control technologies. Most of this data was received from the marine engine manufacturers. EPA has also made independent estimates as well and both are summarized in Table 1-02.

Table 1-02
EPA and Marine Engine Manufacturer Range of Estimates of Potential Hydrocarbon Emission Reduction, per Engine, for Current Two-Stroke Outboards and Personal Watercraft

Technology	HC Percent Reduction Estimate Ranges, per Engine Mass Specific Emission Rate (%)
Conversion to Four-Stroke	75-95
Two-stroke direct injection	75-90
Recalibration of current two-strokes	8-20
Catalytic convertors on current two-strokes	65-75
Electronic Fuel Injection on current two-strokes	15-25
Electronic Fuel Injection w/ Catalytic convertor on current two-strokes	65-75

EPA's estimate for per engine mass emission rate reductions of carbon monoxide (CO) for personal watercraft and outboards ranges between 8 and 45 percent for most technologies, depending on the engine size. The direct injection two-stroke technology is the one exception. Due to the lean-burn nature of direct injection, EPA expects this technology to result in a per engine reduction in the brake specific emission rate of CO to be between 40 and 80 percent, depending on the particular engine size.

One inherent result of current air-fuel crankcase scavenged two-stroke engines is the low emission rate for oxides of nitrogen (NOx). The primary source of NOx in spark-ignited engines is the oxidation of atmospheric nitrogen. The chemical reactions for production of NOx have large activation energies, therefore NOx formation is strongly dependent on temperature. In addition, since NOx is formed by the oxidation of N_2, NOx formation is also dependent on the availability of oxygen, (excess oxygen results from lean air-fuel ratios (A/F)). The condition at which the air-fuel ratio is chemically balanced for full combustion is called stoichiometry. At a rich A/F, when there is not enough oxygen present to fully burn the fuel, NOx formation will be low relative to the same engine running under lean A/F, when there is more oxygen than necessary to fully burn the fuel. The current state of the marine outboard and personal watercraft industry has developed around the two-stroke, crankcase-scavenged, spark-ignition power source. These engines are run at A/Fs on the rich side of stoichiometry, resulting in relatively low combustion temperature, incomplete combustion, and, therefore, low NOx production.

However, the richness of the charge does not explain why current two-stroke engines have lower mass emission rates of NOx than comparably powered four-strokes running at the same A/F. The explanation lies in the exhaust remaining in the combustion chamber of two-stroke engines from the previous power stroke. This exhaust, which was not completely scavenged by the air-fuel intake mixture, acts as internal exhaust gas recirculation (EGR). EGR is a well documented technique used to lower NOx production in four-stroke spark-ignition engines. EGR acts as a diluent to the fresh charge in the cylinder, reducing peak burned gas temperatures, and thereby reducing NOx formation.

Currently unregulated two-stroke crankcase-scavenged outboard and PWC engines have NOx emission rates which range from 0.5 g/kW-hr up to 4.0 g/kW-hr. EPA estimates that the two primary technologies which will be used to meet the proposed standard, conversion to four-stroke engines and two-stroke direct injection, will both result in an increase in the level of NOx produced by outboard and PWC engines. In order to meet the proposed level of hydrocarbon emissions, EPA estimates that manufacturers will need to recalibrate their engines to run at leaner air-fuel ratios, resulting in higher combustion temperatures, more complete combustion, and some increase in NOx formation. In addition, four-stroke technology has little "internal EGR" which could reduce NOx emission rates. On a per engine basis, depending on the engine size and technology used to meet the proposed hydrocarbon standard, the mass-specific emission rate of NOx will increase to values in the range between 4 and 12 g/kW-hr. However, EPA estimates the overall average NOx for outboard and personal watercraft engines to be 6 g/kW-hr after HC standards are met. Some of this increase in NOx emissions can be counter-balanced by use of forced EGR technology.

1.2.3.2. Sterndrive and Inboard Engines--EPA has examined a range of technologies for the control of exhaust emissions from sterndrive and inboard spark-ignited engines. These technologies include the following; recalibration of current carbureted and electronic fuel injection (EFI) engines for maximum emission reduction benefit, conversion of current carbureted marine engines to electronic port fuel injection, and the application of oxidizing (or three-way) catalytic convertors to current four-stroke spark-ignited marine engines. Table

1-03 shows the range of hydrocarbon reductions estimated by EPA and industry on a per engine basis for the three technologies investigated by EPA.

Table 1-03
Range of Estimates of Potential Hydrocarbon Emission Reduction per Engine, for Current Sterndrive and Inboard Engines

Technology	HC Percent Reduction Estimate Ranges, per Engine Mass Specific Emission Rate (%)
Recalibration of Current Engines	8-20
Electronic Fuel Injection	8-20
Application of Catalytic Convertors	65-75

EPA has determined that recalibration of current engines is the most cost effective approach.

1.2.4. Technology Costs--This section describes technology costs. The results of the technology cost analysis is used with the pollutant levels associated with the various technologies as presented in the previous section to arrive at the presentation of marginal cost-effectiveness which will be presented in section 1.2.5. Lowest Feasible Emission Standards.

1.2.4.1. Industry Cost Data Submissions--For purposes of setting the emission standard, EPA used cost estimates as submitted by industry. EPA reviewed the data for reasonableness. EPA feels that the industry data is reasonable and is likely to be a good estimate of the total extent of costs due to regulation. Costs may be different for a number of reasons, including changes in product offerings, consumer popularity of engines with emission control, how supply and demand actually determine price, if maintenance costs are different than estimated, if the submitted data contained cost over- or under-estimates based on uncertainty, or similar occurrences. Industry has indicated uncertainty as to whether the costs submitted represent the total extent of costs to be expected. Industry as a whole seems to be concerned that the cost of bringing prototype engines into full production may be underestimated in their submissions. Also, industry has not submitted cost estimates relating to durability concerns. Overall, the extensive amount of data which was submitted appears a fair estimate.

Industry submitted confidential data to National Economic Research Associates, Inc., (NERA) for analysis and allowed EPA full access to the same data. Information was submitted for over 90% of the sales in the market, including sales of outboards, personal watercraft, and sterndrive/inboard engines. Information was only submitted with respect to engine families marketed in the U.S..

The following types of data were submitted.

- identification of engine family and sales-weighted hp
- 1990 U.S. sales volume per outboard and sterndrive/inboard engine family
- 1993 U.S. sales volume per personal watercraft engine family
- uncontrolled emission rates (g/kw-hr) for HC, NOx, CO, and fuel consumption at the rated power output
- potential engine control technologies
- controlled emission rates (g/kw-hr) by technology for HC, NOx, CO, and fuel consumption at the rated power output
- technology or generic costs associated with the development and licensing of a new technology
- changes in capital costs--incremental changes in emissions testing, tooling, equipment, and research and development associated with each HC control technology
- changes in factory parts costs--estimates of specific and miscellaneous costs, additions and subtractions associated with production costs, include variable hardware costs
- changes in other variable engine costs--royalty payments on a per piece basis, additional emissions testing, added product support, and added warranty. Combined with "changes in factory parts costs," these represent all variable cost additions.

The following are assumptions used in calculating costs.

- All costs are reported in 1993 dollars.
- Fixed costs to the manufacturers of emission control technology (capital costs) are assumed to be recoverable over 10 years. These capital costs are amortized at 7 percent.
- The lifetime of outboard engines ranges from 28 to 54 years according to power output. The lifetime of sterndrive and inboard engines is 40 years. Personal watercraft engines are assumed to last **20** years.
- Outboards are used annually, on the average for 34.8 hours. Sterndrive/inboards are used 47.6 average hours annually. For Personal watercraft the average annual usage is 77.0 hours.
- The discount rate for purposes of calculating present value is 3%.
- Dealer costs are 24% of manufacturer costs.
- Maintenance costs are relative to engine size and are based on confidential data provided by Mercury Marine.
- Fuel price is assumed to be $1.49 per gallon. This is based on $1.25 per gallon for gasoline and $.24 per gallon for oil.
- Fuel usage is 1.02 gallons per horsepower per year, based on Coast Guard data on fuel consumption.

1.2.4.2. Technology Cost Per Engine Family—Due to the concern over confidentiality, specific cost estimates for different technologies cannot be presented. For several technologies, it is the case that it would be cost-effective for only one manufacturer to introduce a technology and not cost-effective for any other manufacturers. Further, for some technologies there is only one manufacturer developing the technology. Therefore, to present either costs or cost-effectiveness would seem likely to impinge on the confidentiality of the information submitted. As EPA is required to keep confidential any information pertaining to specific manufacturer's cost, EPA does not feel that cost or cost-effectiveness information can be presented with respect to a specific type of technology.

The technology cost estimates will only address technology costs to the engine manufacturer. Clearly, the consumer will face additional cost components. Dealer markup and maintenance costs are expected to increase, yet consumers should realize decreases in fuel and oil expense due to the control technologies in general. These costs which are not experienced by the engine manufacturer are included in the aggregated cost estimate of the rulemaking, the consumer cost estimate, and the program cost-effectiveness. Only the engine manufacturer cost was used to evaluate marginal cost-effectiveness. This implies that the costs not experienced by the engine manufacturer (e.g., dealer markup, maintenance cost, fuel savings) do not affect the relative product mix choices of engine manufacturers. It is probably fair to make this assumption as manufacturers have indicated varying opinions regarding the relative importance ratings of fuel savings and maintenance increases on consumer purchase decisions. However, although EPA will not use these non-manufacturer cost components to determine the lowest feasible emission standard, one would expect that if fuel savings and maintenance cost increases are important to consumers, then the manufacturers will factor these costs into their product offering decisions.

If EPA were to include these non-manufacturer costs in the marginal cost-effectiveness estimates, the result would be as follows. First, the inclusion of dealer markup would not affect the relative ranking of marginal cost-effectiveness or the judgement on the lowest feasible average emission standard. Second, four-stroke technology should achieve slightly more fuel savings than 2-stroke direct injection technology. Third, maintenance cost increases generally tend to offset the fuel savings experienced. The result of the effects of fuel savings and maintenance cost increases may be to change the relative ranking of marginal cost-effectiveness slightly, may generally shift the entire marginal cost-effectiveness curve up slightly, yet should not affect the judgement on the lowest feasible emission standard as the shape of the marginal cost-effectiveness curve should not change significantly.

Therefore, due to concerns over confidentiality of data and the costs manufacturers will use to make product offering decisions, EPA will present an example of how manufacturer technology costs are calculated for a fictitious engine family. The result of this type of calculation is used in an analysis of cost-effectiveness per engine family which is presented in section 1.2.5., Lowest Feasible Emission Standard. This calculation is an estimate of the increase in manufacturer cost expected to be incurred for all the engines sold in the engine family in a given year of sales.

As exemplified in Table 1-04, capital costs are annualized as if the manufacturer had to take out a loan to cover the increase at a 7% rate of interest. It is assumed that the amortized capital costs are recovered over the approximate ten year average production period for an engine family. Essentially, this method assumes that the true cost of incurring capital expenses is related to the earnings which the capital costs could have produced if used differently than as an investment in emission reduction technology. The variable costs were aggregated for the engine family according to the total amount of sales.

Table 1-04
Sample Cost Calculation
(Fictitious Engine Family)

		calculation	result
1	output (kW)		100
2	U.S. sales in model year		1,000
3	capital costs for engine family		$2,500,000
4	variable cost per engine unit		$100
5	amortized capital cost to be recovered over engine sales in this model year	(3) x .14 = this year's payment on a loan used to cover the increased capital cost where the annual interest rate is 7% and the production period of the engine family is 10 years	$350,000
6	total annual increase in variable engine costs	(4) x (2)	$100,000
7	manufacturer's total annualized cost for this engine family	(5) + (6)	$450,000
8	total cost to the manufacturer per engine	(7) / (2)	$450

Although EPA cannot present the actual technology costs specific to the different control technologies in this document, it is acceptable to present the overall costs without identifying which technologies or engine families those costs apply to. In this way EPA can present the magnitude of the engine family specific costs without revealing any confidential information. Presented in Figure 1-02 is the marginal annualized engine manufacturer cost per engine family. Marginal costs are appropriate when comparing several technologies which could be applied to an engine family, each resulting in varying degrees of emission control relative to baseline emission levels. For example, technology A for an engine family may cost X dollars to apply yet only result in a 25% decrease in emissions relative to the baseline level. Technology B could be applied to the engine family costing X+Y dollars and resulting in a 80% decrease in emissions relative to the baseline level. Therefore, the marginal cost for technology A for this engine family is X dollars. The marginal cost for technology B for this engine family is (X+Y)-X dollars, or simply Y dollars. According to this methodology, the actual manufacturer

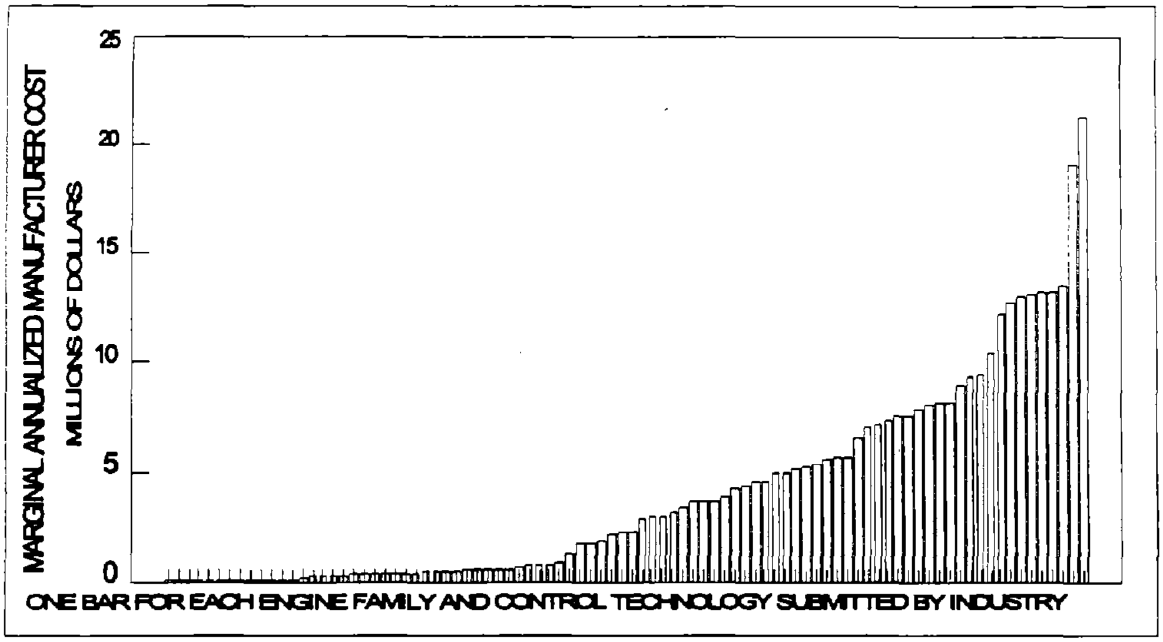

Figure 1-02
ACTUAL MARGINAL MANUFACTURER COSTS

marginal costs per engine family are ranked and presented in Figure 1-03. Marginal costs do not imply that the technologies are additive. In other words, it may not be the case that technology B can be added to an engine which already has technology A. Technology B may be entirely different type of engine, such as a 4-stroke engine whereas technology A may be 2-stroke control technology. The main reason for calculating marginal costs is to determine how much more cost would have to be incurred to produce a more stringent control technology.

1.2.5. Lowest Feasible Emission Standards--The chosen standards structure is that of averaging and trading of emission levels with respect to exceedances and shortfalls to an average emission standard. With this chosen standards structure, EPA's goal is to set the average standard at the lowest feasible level of emission reduction relative to baseline levels. Therefore, EPA set about looking for the emission reduction level by means of a percentage emission reduction from baseline levels beyond which further emission reduction are not cost-effective. Essentially, this implies that the provisions for averaging and trading of emission reductions are considered in setting the emission standards.

In order to determine the degree of emission reduction which can be achieved most cost-effectively from this source, it is most appropriate to consider the marginal cost-effectiveness of achieving emission reductions on an engine family basis for the entire sales fleet. This was done by rationing the annualized marginal cost per engine family on a technology basis to the relative emission reduction effectiveness of the technology over the useful lives of the engines sold in one model year. The annualized marginal cost methodology was presented in the previous section. The relative emission reduction effectiveness calculation methodology was presented in section 1.2.3. , Impacts on Pollutant Levels. The result of the rationing is the marginal cost-effectiveness per engine family with respect to each technology, as presented in Figure 1-03. The actual data submitted by manufacturers is used to develop the curve presented in Figure 1-03.

Clearly, this graph shows that it would not be cost-effective to set an average emission standard above an 85% emission reduction target, as this is above the "elbow" of the curve, i.e., where the curve bends sharply upward. Beyond the elbow of the curve, each additional increment of emission reduction costs disproportionately more and more. In fact, this data indicates that a 90% emission reduction is unachievable. On the other hand, the curve is relatively flat below an 80% level of reduction. Based on the shape of this curve alone, EPA is inclined to accept 80% as a good judgement for the target level of emission reduction from outboards and personal watercraft.

However, it must be acknowledged that the use of this curve to set an emission standard implies perfect knowledge regarding costs and corresponding effectiveness of control for different pollution control technologies. Moreover, to achieve the emission standards set on the basis of such a curve, the market for emission reduction credits is assumed to be perfectly competitive. However, the market for marine engines is oligopolistic and thus expectations that the emission market will be perfectly competitive are perhaps not justified. If the emission reduction credit market is not perfect, it is unlikely that the target reduction level would be precisely achieved. Assuming industry compliance, the result could be in overcontrol of emissions from the perspective of this marginal cost-effectiveness curve. With overcontrol, costs would rise more quickly than would emission reductions. In order to provide a "hedge" against this kind of unproductive overcontrol of emissions, a 75% level of reduction appears to be the best choice for an emission reduction target. Setting the emission reduction target at a 75% level of reduction ensures that if small amounts of overcontrol of emissions occurs, the overcontrol is not unduly cost-ineffective. Although EPA thinks that the probability of overcontrol may be higher at 75% than 80% level of reduction, the supply of credits should not be as tight at 75%. If the market does not exhibit perfect trading, then at a 75% level of production it is still cost effective for a manufacturer to produce additional controlled engine families to ease the supply of credits to the market.

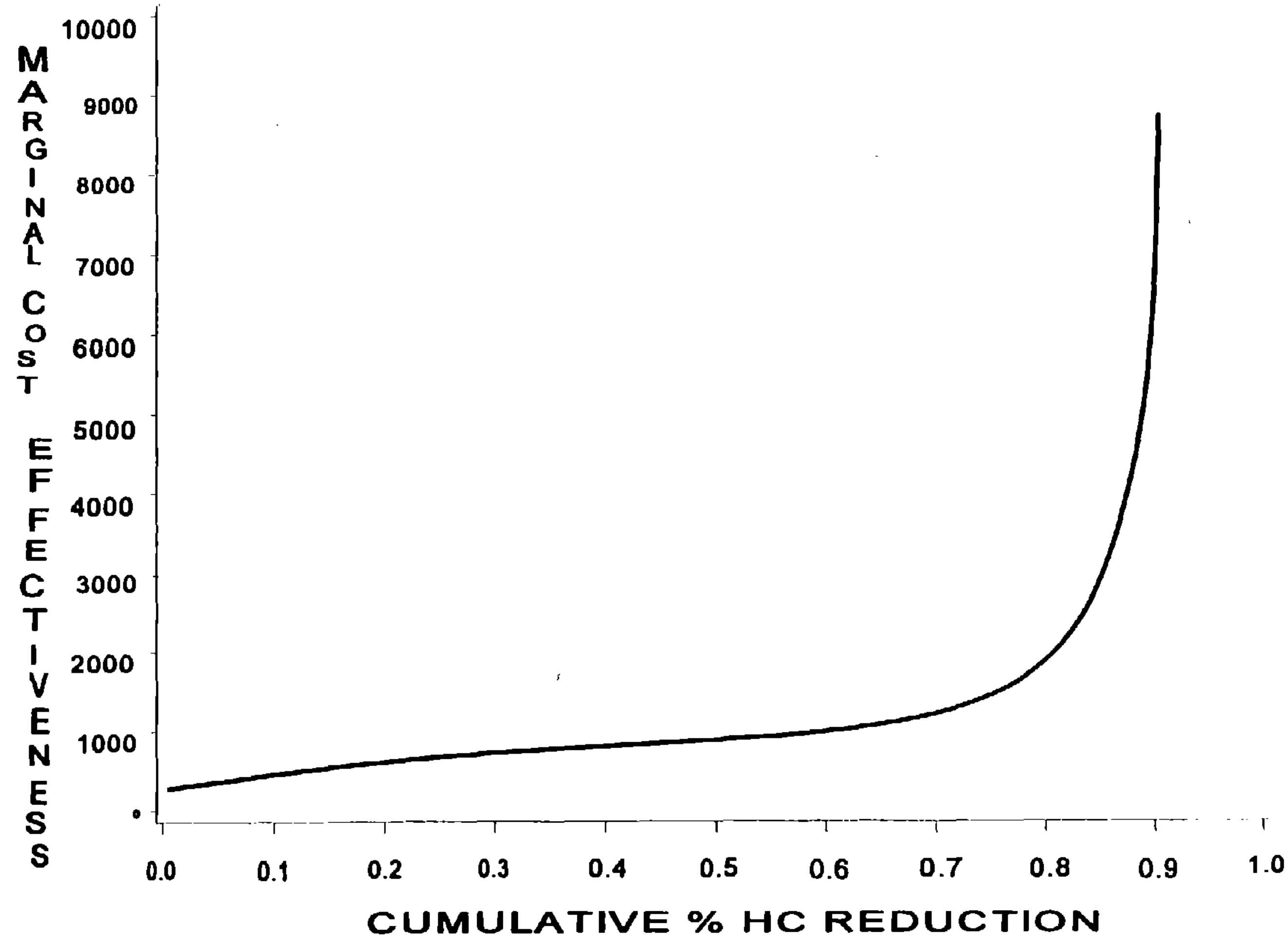

Figure 1-04
Per Engine Family Marginal Cost-Effectiveness Curve
Outboards and Personal Watercraft

Table 1-05
Outboard Technology Market Mix

Technology	Before Regulation	After Phase-In
2-stroke, closed crankcase, carbureted or crankcase electronic fuel injection	99.0%	15.3%
4-stroke, closed crankcase, carbureted or crankcase electronic fuel injection	1.0%	31.0%
2-stroke, closed crankcase, carbureted or crankcase electronic fuel injection, ignition changes	0.0%	1.3%
2-stroke, closed crankcase, carbureted or crankcase electronic fuel injection, catalyst	0.0%	3.2%
2-stroke, closed crankcase, direct injection air assisted	0.0%	20.3%
2-stroke, closed crankcase, direct injection, not air assisted	0.0%	28.9%

Table 1-06
Personal Watercraft Technology Market Mix

Technology	Before Regulation	After Phase-In
2-stroke, closed crankcase, carbureted or crankcase electronic fuel injection	100.0%	2.3%
2-stroke, closed crankcase, carbureted or crankcase electronic fuel injection, carburetor changes	0.0%	3.1%
4-stroke, closed crankcase, carbureted or electronic fuel injection	0.0%	94.6%

Table 1-07
Sterndrive and Inboard Technology Market Mix

Technology	Before Regulation	After Phase-In
4-stroke, closed crankcase, carbureted or electronic fuel injection	100.0%	0.0%
4-stroke, closed crankcase, carbureted or electronic fuel injection, recalibration	0.0%	100.0%

1.2.6. Resultant Technology Market Mix--Upon setting the average emission standard at a 75% level of reduction, the technology market mixes presented in Tables 1-05, 1-06, and 1-07 result. These market mixes are derived directly from the marginal cost-effectiveness curve presented in the preceding section.

1.3. Performance Impacts

1.3.1. Fuel Consumption--For outboard and personal watercraft engines, the use of technologies that significantly reduce hydrocarbon levels should also result in significant fuel savings. Current technology two-stroke crankcase air/fuel/oil scavenged engines, which are very widely used for outboard and personal watercraft applications, do not use fuel efficiently. An unburned air/fuel/oil mixture is used to push out, or "scavenge" the exhaust gas from the cylinder. As a result, a substantial portion of the unburned fuel and oil is pushed out of the cylinder with the exhaust gases. This combustion technology can result in wasting more than 25-35 percent of the fuel consumed. These losses will be greatly alleviated by using direct injection technology or 4-stroke technology to meet the hydrocarbon emission standards. The regulations are likely to encourage the widespread use of 4-stroke technology, direct injection technology, or other "clean" technologies to alleviate the problem. These technologies use a more complete combustion process and do not use air/fuel scavenging of exhaust. As a result, more fuel will be burned in the engine instead of being exhausted unburned, and work done per unit of fuel will be increased.

For example, based on manufacturer data from 1991, EPA estimates that changing outboard engines from two-stroke to four-stroke technology will result in an average decrease in fuel consumption of approximately 31.5 percent. EPA expects similar results from engines that use direct injection technology. However, aftertreatment technologies, such as catalysts, used to reduce hydrocarbon emissions are not expected to significantly impact fuel consumption. So, to the extent that catalysts are used to meet the emission standards, no fuel savings would be realized using this technology as an add-on to current technology two-stroke engines.

1.3.2 Weight and Performance—The primary performance effect from the conversion from two-stroke crankcase- scavenged engines to four-stroke engines is the decrease in power to weight ratio. Based on information available on currently marketed two- and four-stroke outboard engines, EPA estimates the weight of the power unit for both outboards and PWC's will increase between 23 and 35 percent for a given rated power. Power to weight impacts resulting from the use of two-stroke direct injection technology should be minimal. EPA estimates the additional weight increase from the added components necessary for two-stroke direct injection technology will result in power unit weight increases between 5 and 10 percent for a given rated power.

EPA considers the use of catalytic convertors (with limited conversion efficiency) on two-stroke crankcase-scavenged engines as a technologically feasible and cost effective control method for outboards and PWC. The increase in packaging size will add some additional weight to the engine; however, EPA does not believe this weight increase will be as great as is involved with the conversion to four-stroke engines. EPA does not believe there will be any significant performance changes to engines with the application of catalytic convertors other than the decrease in power to weight ratio.

1.3.3. Noise--Although noise on engines with emission reduction technologies has not been examined, the Agency expects no negative impact on noise due to emission control technologies. Noise levels are expected to remain the same as on current technology engines.

1.3.4. Safety--The federal agency that regulates safety issues for marine vessels is the U.S. Coast Guard. The regulations promulgated by the Coast Guard fall into three general categories: ensuring the safety of passengers (regulations for personal flotation devices, and so forth), reducing the risk of fire hazards (regulations for electrical systems, fuels systems, and ventilation systems), and, for larger vessels, ensuring vessel integrity (strength and adequacy of design, construction, choice of materials for machinery, boilers, pressure vessels, and safety valves and piping)[1].

It is EPA's view that the proposed regulations do not violate or conflict with Coast Guard safety mandates. The regulations proposed in this rulemaking could be affected by two sets of Coast Guard regulations: (1) compartment ventilation requirements and (2) fuel tank ventilation requirements.

Coast Guard regulations require that boats with compartments not open to the air and containing a permanently installed gasoline engine with a cranking motor be equipped with power-assisted ventilation. This ventilation system is necessary because gasoline fumes may accumulate in these

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1 See Memorandum to the Docket regarding marine safety issues on recreational boats.

compartments through evaporation, posing a fire hazard when the engine is started. The Coast Guard also mandates that compartments that contain: (1) an enclosed engine, (2) openings between it and a compartment that requires ventilation, (3) permanently installed fuel tanks, (4) a fuel tank with a vent that opens into the compartment, or (5) a nonmetallic fuel tank be equipped with natural ventilation to the exterior of the boat. The regulations proposed in this rulemaking do not require any systems that would violate any of the Coast Guard requirements. If EPA determines that evaporative emissions regulations are necessary, EPA will work with the Coast Guard to ensure that safety is not compromised.

Second, Coast Guard regulations mandate fuel tank vents on all fuel tanks. Since fuel gauges are not well-calibrated on boats, in part because fuel tanks come in so many sizes and shapes, and since boat operators want to be sure they have a full tank when they leave the dock, refueling often continues until some fuel spills out of the tank. The vent is to ensure that the spillage does not fall in the boat, creating a fire hazard. However, fuel vents also permit the release of evaporative emissions. Coast Guard representatives expressed concern about closed fuel systems that could be mandated to reduce these evaporative emissions. Closed fuel systems are not currently permitted under Coast Guard regulations and could cause a potential safety hazard. Again, the regulations proposed in this rulemaking do not require any systems that would violate any of these requirements, since EPA has decided not to regulate evaporative emissions at this time. However, EPA intends to continue working with the Coast Guard and boat manufacturer groups to encourage closure of this vent at most times and especially when fueling is completed.

At the same time, the proposed regulations give rise to a safety issue that has not yet been considered by the Coast Guard. In discussions with EPA, representatives of the Coast Guard expressed concern about the use of fuel injection systems on marine engines.[2] In these systems, the fuel must be under pressure in the fuel line. This is a potential safety hazard that could be dangerous, especially when the craft is far from shore. Although the regulations proposed in this preamble do not specifically call for fuel injection systems, it is the case that marine engine manufacturers already include these systems on some engines and may use them more in response to these regulations. For this reason, it is important for EPA and the Coast Guard to consider the safety issues relevant to fuel injection systems.

1.3.5. Maintenance--Section 1.2 details the emission control technologies EPA believes will be used to reduce HC emissions from marine engines. For outboard and personal watercraft engines, EPA believes manufacturers will primarily use one of three control technologies; conversion to four-stroke, direct injection two-stroke, or the application of catalytic convertors to current engines. Any additional maintenance costs discussed qualitatively below have been included in EPA's cost analysis for this rule, including training for service dealership technicians. In general, EPA believes most end-users do not service their own marine engines, engines are generally serviced by marine engine service and repair shops. End users may do routine items such as spark plug and air filter cleaning/replacing. EPA does not anticipate any of the technologies used to meet the emission requirements of this rule will require a change in the routine maintenance practices of the end-user. The one exception would be the need for routine oil and oil filter changes for four-stroke engines.

The conversion of crankcase-scavenged two-stroke to four-stroke engines will require additional maintenance skills and tools for the repair shop technicians. The added parts that make a four-stroke engine work, a valve

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2 See Memorandum to the Docket, cited previously.

train, cam shaft, oil pump, etc., will require additional knowledge for technicians. EPA does not anticipate that four-stroke marine engines will require repairs on a more frequent basis than current crankcase-scavenged two-stroke engines. In addition, many marine engine repair shops also sell and repair other types of recreational or lawn and garden engines, such as all-terrain vehicles, lawn mowers, motorcycles, etc. Many of these equipment types are powered by four-stroke engines, so technicians may not need additional training on the operation and maintenance practices for four-stroke engines.

The application of direct injection two-strokes will be a new technology for the marine maintenance and repair industry. The type of additional training, diagnostic equipment, and repair tools necessary to work on DI two-strokes will depend on the particular type of DI used by a given engine manufacturer, but whatever the type of DI used, it will be a new technology for the marine servicing dealer. EPA anticipates that marine engine manufacturers will spend a considerable amount of funds in the retraining of their serving dealers to handle the need for technicians who are knowledgeable in the servicing of DI two-stroke engines. EPA does not anticipate that DI two-stroke engines will require more frequent servicing than current production crankcase-scavenged two-stroke engines.

The application of catalytic convertors to crankcase- scavenged two-stroke engines should not require any additional maintenance requirements for the end user or servicing dealerships. EPA's experience with on-highway applications using catalytic convertors has shown that a well designed catalyst does not require servicing or maintenance.

The principle technology EPA anticipates will be used by sterndrive and inboard engine manufacturers to meet the requirements of this rulemaking is the recalibration of current engines. EPA does not expect recalibration will require additional maintenance beyond current production sterndrive and inboard engines.

1.4 Impacts on Vessel Design

EPA anticipates minimal impacts on marine vessel design due to this rule. Currently marketed four-stroke outboard engines have essentially identical packaging to currently marketed crankcase charge scavenged two-stroke outboard engines. The only significant impact on vessel design resulting from the use of four-stroke outboard engines is the lower power to weight ratio. As discussed in Section 1.3.2, Weight and Performance, EPA expects a 23 to 35 percent increase in engine weight for a given horsepower with the conversion to four-stroke outboards. This increase in weight will need to be taken into account when designing a vessel/engine package. This will be particularly true for personnel watercraft vessels which utilize four-stroke engines due to the very small size of the personnel watercraft hull.

EPA anticipates little or no impact to vessel design resulting from the use of direct-injection two-stroke engines in either outboard engines or as power units for personnel watercraft. EPA also anticipates the application of catalytic convertors to crankcase charge scavenged two-stroke engines will have minimal impacts on vessel design. EPA believes catalytic convertors would be built into the engine package, and would not be designed as part of the vessel structure.

EPA believes the recalibration of sterndrive and inboard engines to meet the emission requirements of this rule will have no impact on vessel design.

Chapter 1: References

1. International Bodensee Shipping Commission (IKSB), *Article 13.11 of the Bodensee Shipping Regulations (BSO): Exhaust Gas Regulations for Marine Engines*, June 4, 1991.

2. Morgan, E., Lincoln, R., *Duty Cycle for Recreational Marine Engines*, SAE Paper Number 901596.

3. 40 CFR Part 86, Subpart I.

4. Michigan Automotive Research Corporation, *A Comparison of Exhaust Emissions on a Marine Engine Run on Steady State and Simulated Transient Cycles*, October 8, 1992, Prepared for National Marine Manufacturers Association.

5. Samulski, M., *Sensitivity of Test Cycle and Fuel Type on a Crusader 350 Inboard Marine Engine; Test Results - 1992*, NTIS Order Number PB 94-128105, May 26, 1993.

Chapter 2: Aggregate Cost Analysis and Economic Impacts

This chapter describes the industry, presents aggregate costs, consumer costs, and describes potential economic impacts.

2.1. Industry Description and Market Analysis

The spark-ignition marine industry is comprised of a small number of engine manufacturers. The engine manufacturers noted in Table 2-01 make up over 90% of the market. Table 2-01 also lists the major types of propulsion systems: outboards, personal watercraft, and sterndrives & inboards.

Table 2-01
Engine Manufacturers

OUTBOARD	PERSONAL WATERCRAFT	STERNDRIVES & INBOARDS
OUTBOARD MARINE CORP.	YAMAHA	MERCURY MARINE
MERCURY MARINE	KAWASAKI	INDMAR
YAMAHA	ART CO.	VOLVO PENTA/OMC
SUZUKI	BOMBARDIER	CRUSADER
TOHATSU	SUZUKI	VARIOUS MARINIZERS
HONDA		
NISSAN		

The engine industry exhibits characteristics of an oligopolistic market structure: a few engine manufacturers dominate market share with a high degree of product differentiation.

EPA contracted for two market studies to gather information on the marine engine and vessel markets. The first study was performed by ICF Incorporated and the second study was performed by Specialists in Business Information. The following excerpts contain the points EPA thinks are most relevant to the regulation of emissions from spark-ignition marine engines.

"Demographics of Boat Ownership: There are numerous ways to report boating activity ownership patterns, including ownership registration, and total and mean passenger hours of use. These measures are further described according to such characteristics as geographic distribution, as well as various socio-economic characteristics including age, household size, income, gender, and race. National estimates of boat ownership vary depending upon the data source. For example, although the [National Marine Manufacturers Association] NMMA estimates that there are approximately 16 million recreational boats owned in the U.S., estimates of number of boats registered is closer to 11 million (in part because of the differences among states in registration requirements as well as compliance by boat owners with registration requirements). Five states (Michigan, California, Minnesota, Florida, and Texas) account for 33.1 percent of U.S. boat registration. When states are ranked according to boaters as a percentage of all U.S. boaters, the five top states are California, Michigan, Texas, New York, and Illinois. Boaters tend to fall into the 20-30 and 31-40 age groups, but analysis of data related to intensity of use indicates that boating use is relatively constant among population groups when adjusted for the number of individuals in each age category. Also, at upper income levels, the percentage of total boaters tends to be larger than the U.S. population for that income range. For all age groups, the percentage of male boaters exceeds the corresponding U.S. census percentage, as does the percentage of white boaters. With respect to the characteristics of the boats, the average age of the fleet is increasing. In particular, between 1976 and 1989 the average age for speedboats, cabin sailboats, and cabin cruisers increased from 8.6 years to 10.5 years, 8.5 years to 11.9 years, and 9.7 years to 11 years, respectively.

Overall Size of the Marine Industry: Trends for marine industry retail expenditures reflect those for the economy as a whole, showing prosperity during the mid-1980s, peaking in 1988, and decreasing since 1988. As a percentage of the GDP, marine industry retail expenditures exhibit the same pattern over the period. Although there is no conclusive explanation for these trends, it appears likely that the economy as a whole and the January 1991 luxury tax exacerbated trends for the marine industry. Both the tax and the uncertainty associated with speculation that it would be repealed may have caused consumers to delay purchases. Not surprisingly, the top ten states include those states with extensive coastal area, large populations, and relatively high per capita income. These data correspond to boat registration by state data presented elsewhere in this report.

The total number of people employed in boat building and repairing increased steadily from 1982 to 1987 (except for 1985). The number of people employed in engine manufacturing and in ship building have generally decreased since 1981.

The marine industry is concentrated in relatively few states: four states account for 56 percent of marinas, eight states account for nearly half of all boat dealers, and 10 states account for almost two-thirds of all boat manufacturers.

The value added by manufacturing in the marine industry was more than $12 billion in 1987, a 30 percent increase form the approximately $8 billion in 1982. Value added in boat building nearly doubled, while value added in ship building and engine manufacturing increased less rapidly and uniformly.

Structure of the Pleasure Boating Industry: The pleasure craft industry is extremely complicated, with numerous distribution channels, large numbers of highly specialized manufacturers, and a smaller number of well-diversified manufacturers. For example, even though a small number of engine manufacturers dominate the industry in terms of overall market share, there are relatively large numbers of manufacturers willing to compete in the industry, and overall levels of competition are high. As discussed in Chapter 6, this study identified more than 40 engine manufacturers producing more than 1,200 distinct engines. The vessel industry has a large number of distinct product categories that cater to very specific boating needs. Although a few major manufacturers have a significant overall market share, the specialization has supported a large number of individual manufacturers of all sizes. The major manufacturers themselves are internally organized to produce boats under numerous distinct, often competing brand names.

Similarly, distribution channels are complicated. As relatively high dollar value consumer items, much like automobiles, manufacturers of individual engines and vessels (and especially smaller vessel manufacturers) frequently deal directly with their customers, rather than through chains of intermediaries. Even so, some lines of boats and engines are marketed to dealers through distributorships; distributorships and dealers can be either independent or owned by manufacturers.

Boat construction is geographically dispersed. Although only four states account for half of all establishments, 29 other states have some level of boat building and repairing. Similarly, 24 states have active shipyards.

One measure of the complexity of the industry is the number of distinct product classes and classification schemes. Sources that are primarily directed towards establishing the value of specific boats (e.g., the new and used boat guides published by BUC Research, Inc.) use very narrow categories to allow analysis within very discrete subsets of vessel types. Sources that focus on major industry market segments (e.g., Boating Industry magazine) rely on relatively broad categories of engine type and material of construction. The American Red Cross, which is primarily interested in safety concerns, categorizes boats in terms of factors that affect operation of the craft. The Bureau of the Census uses categories that appear to relate to differences in overall design factors that may affect methods of production. Because of the wide differences in the classification schemes used, it is virtually impossible to correlate the data from these different sources.

Industry Trends in 1992: The marine industry has experienced several changes over the last decade. First, there has been an increasing level of vertical integration between the engine and vessel manufacturing sectors, as reflected primarily in the efforts of Mercury Marine (Brunswick Corporation) and OMC to purchase boat manufacturers as captive companies to guarantee outlets for their products, build brand loyalty, and capture potential economies of scale in design, production and distribution. Although this trend may have been abated somewhat by the recession, during which both Brunswick and OMC have suffered from reduced flexibility, the prospects that integration offers for high volume, standardized designs should continue to be enticing in the long run.

Second, foreign manufacturers have played an increasing role in the engine sector of the industry. Such innovations as Yamaha's counter-rotating engines (to smooth the ride of twin engine boats) and Kawasaki's personal watercraft have opened market niches and increased consumer acceptance of foreign engine manufacturers that did not exist in the early 1980s. Foreign manufacturers that have developed reputations for quality in other engine markets (e.g., Honda) may be able to use those reputations to compete in the marine industry as well, further crowding the market. This effect may be mitigated by the increasing development of foreign markets for pleasure craft. U.S.-made boats are highly regarded in world markets, and the overall size of foreign markets appears likely to increase as levels of awareness of boating-as-recreation increase and as disposable income increases. To the extent that competition in foreign markets requires more sophistication, however, the increasing levels of imports and exports may further encourage the trend towards consolidation and integration.

Third, the significance of product innovations appears to have slowed recently. The enhancements to the reliability and durability of both engines and vessels made from the early 1970s through the mid-1980s may have encouraged boat buyers to purchase the newer, better boats rather than older vessels. Many of the recent innovations, such as improved navigation and communication, may not require the purchase of new vessels. Consequently, consumers may be more willing than before to purchase used boats rather than new boats, leading to a relatively softer market for new boats and continued intense competition.

In addition to shifts in the structure of the industry, there have been shifts in the nature of the consuming population. First, as a consequence of improved boats and vessels, consumers may be more likely to consider used boats as viable alternatives to new boats. The increased durability of fiberglass boats relative to wooden boats means that buyers need be less concerned about upkeep costs and remaining lifetimes. Thus, builders of new boats must compete not only with other builders, but also with the increasingly large resale market. Second, the domestic industry faces increased competition from other spending alternatives. U.S. consumers may weigh boating against a wider array of alternatives. Consequently, the domestic marine industry must compete not only within itself, but also with other luxury and vacation industries.

Third, the overall demographics of the population are shifting. In the near-term, the aging of the "baby boomer" generation should extend recent trends towards larger, more luxurious new boats. ... [T]he segment which has increased most rapidly in size since 1983 has been boats with engines larger than 100 horsepower. Average boating levels, in terms of boating hours per capita, remain relatively constant from the ages of about 20 to 50. Thus, as the population continues to age, there will be continuing shifts in the proportion of older boaters, with commensurate shifts in purchasing patterns. Over the longer term, as the population ages beyond 50 (when levels of boating participation tend to decrease), actual boating levels and boating demand may decrease. The extent of the decrease will depend on the extent of boating by the generation of baby-boomers' children.

The effects of the luxury tax are not easily analyzed. The apparent influence of the surcharge in terms of reductions in the number of vessels sold appears may have been exacerbated by three factors: increases in the average vessel size and price (which may have led to disproportionate concentration on the larger boats subject to the tax), other consumer confidence issues such as the Persian Gulf War, and widely publicized efforts to repeal the tax. The long-term effects of the luxury tax are difficult to foresee."(1)

"Market Profile Highlights: The U.S. pleasure boat industry is recovering from the severe 1990-1991 recession due to stronger personal income gains, lower interest rates and the repeal of the luxury tax. However, industry growth has entered a more mature period due to changing demographic patterns and rising saturation levels. As a result, U.S. manufacturers and marketers must resort to innovative new products and boat designs to stimulate demand. Producers should also strengthen foreign distribution channels to take advantage of emerging world boat markets.

U.S. factory shipments of pleasure boats are estimated to have increased at a 9.8% annual average compound rate over the past three years. This compares to a 17% annual decline during the previous three year period. The recovery was primarily driven by a rebound in personal income, lower interest rates, and declining gasoline costs.

So far, the recovery has been led by low cost product lines such as personal watercraft and canoes. Unit sales of personal watercraft increased by some 41% between 1992 and 1994. This compares to a 20% rise in total retail boat sales over this period. The growing popularity of low cost watercraft reflects the sluggish nature of personal income gains and consumer cautiousness during the current recovery.

Boat demand, however, could shift up-market in 1994 as the August 1993 repeal of the luxury tax boosts sales of luxury boats and yachts. Stronger personal income gains in 1994 could also lead to the breakout of pent-up demand for higher end product lines.

The recovery has also resulted in improved plant profit margins. Gross plant profit margins are estimated to reach 21.8% during 1994. This compares to 17.5% in 1991. The increase in operating efficiency reflects moderating material costs, rising labor productivity, and an expanding industry capital spending effort. The industry's desire to maximize plant efficiency is imperative in the face of rising foreign competition. Imports could capture 14% of the total U.S. market sales during 1994, versus 7% in 1990.

Domestic manufacturers and marketers must also increase spending on new products in order to remain competitive in a rapidly maturing market structure. Future industry growth is forecast to remain below long term trends over the next decade due to the aging of the baby boom population and the decline in the potential number of first-time boat purchasers.

Boat producers will be marketing increasingly to an aging boating population, who generally cut back on boating spending as they enter the 45 to 54 year old age group. The leading edge of the huge baby boom population, which helped boost boat demand dramatically during the 1980's, is now entering this age cohort. The boating industry must target new boat designs and amenities to this important boating population. At the same time, the number of potential first time buyers is drying up as the population of 25 to 44 year olds declines.

New designs and innovations must also be used as a marketing tool to entice the relatively large base of existing owners to trade in existing watercraft. This reflects the doubling of existing boat-owning families over the past twenty-five years.

In order to offset maturing domestic demand, manufacturers must seek out growth opportunities in foreign markets. Producers should seek out growing marketing opportunities in relatively untapped markets, such as Eastern Europe, Mexico and the emerging Asian economies. U.S. manufacturers should exploit their competitive advantage of developed distribution channels and other economies of scale that come from supplying the world's largest domestic market. As a result, export shipments are seen leading the recovery for the remainder of the 1990's.

Market Sector Analysis, Summary of Major Findings:

1. U.S. factory shipments of outboard motorboats could reach $1 billion during 1994, a 12.3% annual average gain over the past two years. This reverses most of the decline in shipments that occurred between 1987 and 1992. Runabouts and bass boats dominate this sector of the pleasure boat industry, however, cabin cruisers have made inroads since the late 1970's.
2. Inboard motor sales also experienced a rebound in shipments over the past two years. This is important to this industry, since inboard boats is the largest sector of the U.S. pleasure boat industry on a dollar basis. Cabin cruisers account for over 60% of inboard motorboat sales, however, runabouts have outpaced sector shipment trends since the late 1960s.
3. Inboard-outdrive boats have been the most adversely affected by the past recessionary period and the relatively sluggish recovery. Dollar factory shipments could reach $975 million during 1994, however, this remains 34% below 1987 levels.
4. Sailboat shipments also remain weak. Dollar factory sales are estimated to reach $125 million during 1994 or 2.9% of total U.S. pleasure boat shipments. This compares to 4.2% of total shipments during 1987, and 11.8% in 1982.
5. On the other hand, a relatively strong growing nonpowered line on a unit basis is canoes and kayaks. The popularity of these watercraft reflects their inexpensive price and portability, and that they are seen as environmentally friendly. There is also growing interest in battery powered boats since internal combustion engines are prohibited from a growing number of lakes.
6. However, the strongest growing market sector is personal watercraft. ... Kawasaki, Yamaha, and Bombardier are the largest manufacturers. However, in 1993, a number of traditional boat manufacturers such as Sea Ray and Boston Whaler began producing personal watercraft.
7. Over the past five years, prices have been strongest for inboard motorboats and rubber boats.

Economic Structure of Domestic Boat Builders and Repair Services, Highlights:

1. The U.S. pleasure boat industry continues to be dominated by relatively small boat builders despite a consolidation in the number of players since the mid-1980s. However, industry sales are increasingly

concentrated among the top U.S. boat producers who manufacture pleasure boats in larger and integrated operations that benefit from economies of scale. During 1992, the top four companies captured 39% of total U.S. factory sales. This compares to only 14% in 1982.

2. The industry also experienced an improvement in plant profit margins as U.S. pleasure boat demand began to recover from the past recession. Gross plant profit margins are estimated to reach 21.8% during 1994. This compares to 17.5% in 1991. The increase in operating plant efficiency reflects moderating material costs and a surge labor productivity.
3. The major competitors, Brunswick and OMC, are also increasing their capital expenditures to boost plant efficiency.
4. Key producing states include Florida, California, Tennessee, Louisiana, Michigan, Washington, Texas, and Indiana."(2)

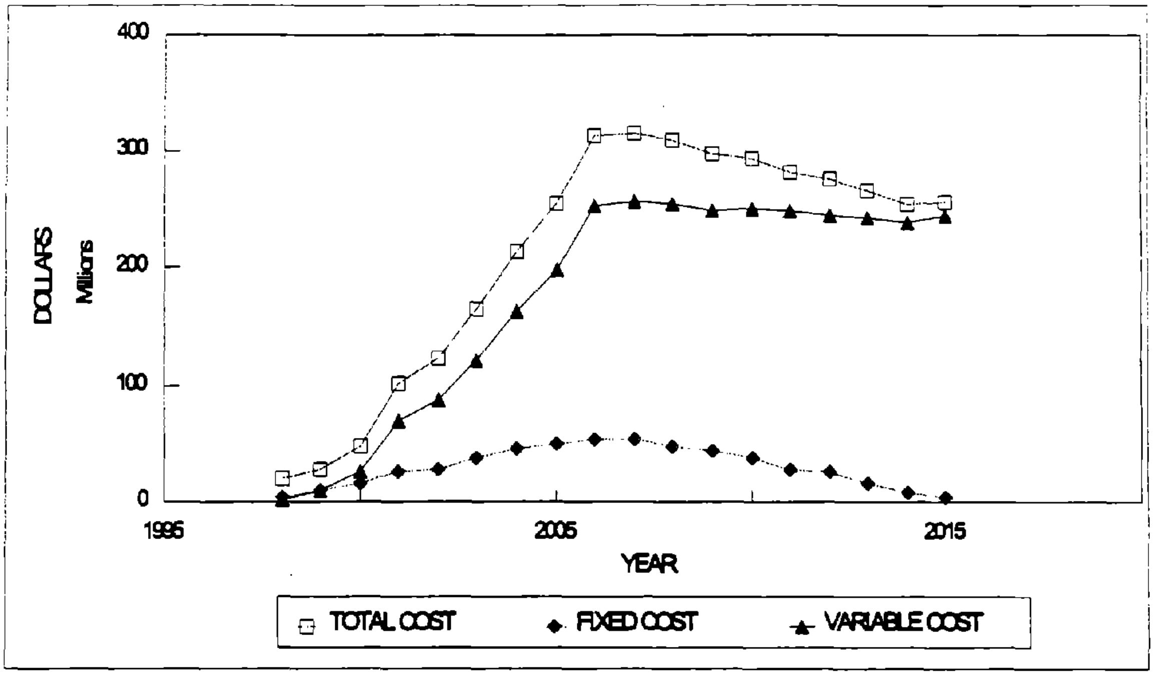

Figure 2-01
Aggregate Cost Estimate

2.2. Aggregate Cost Estimate

EPA's aggregate cost estimate to meet proposed standards is presented in Figure 2-01 and Table 2-01. The annualized costs of this rulemaking exceed $300 million in 2006. Variable hardware costs required to reduce emissions from the controlled engine families contribute the largest portion of total costs.

It should be noted that the magnitude of these costs can be put in perspective by comparing them to the total retail expenditures on outboards and personal watercraft for 1993 as given in Table 2-02. In 2006, total annualized costs due to this regulation are roughly 7% of projected retail expenditures in that year. Additionally, it should be recognized that the increased costs for these engines are typically financed by consumers.

Table 2-01
Total Annualized Cost Estimate

YEAR	TOTAL COST
1998	$13,569,031
1999	$26,604,903
2000	$46,366,647
2001	$99,408,847
2002	$120,445,320
2003	$161,116,451
2004	$210,386,008
2005	$252,179,474
2006	$312,019,471
2007	$314,174,299
2008	$307,005,227
2009	$295,299,615
2010	$291,878,517
2011	$280,974,958
2012	$275,161,349
2013	$264,846,545
2014	$252,522,690
2015	$253,902,306
2016	$257,251,826
2017	$264,262,031
2018	$271,863,912
2019	$280,199,621
2020	$287,199,617
2021	$294,322,422
2022	$301,166,993
2023	$306,885,911
2024	$282,224,916
2025	$285,576,662
2026	$286,562,440
2027	$288,456,757
2028	$289,259,155
2029	$290,863,455
2030	$291,986,910
2031	$292,935,130
2032	$293,925,822
2033	$294,948,785
2034	$295,517,324
2035	$296,885,139
2036	$297,829,470
2037	$298,842,772
2038	$299,209,900
2039	$300,392,654
2040	$301,242,063
2041	$302,156,302
2042	$302,867,541
2043	$304,590,964
2044	$305,745,835
2045	$306,320,636
2046	$307,406,089
2047	$308,925,983
2048	$309,654,001
2049	$310,810,772
2050	$311,854,920
2051	$313,126,017

Table 2-02
1993 Retail Expenditures

	1993
OUTBOARDS	$1,364,000,000
PERSONAL WATERCRAFT	$618,000,000

2.3. Consumer Cost Summary

EPA cannot present specific consumer costs with respect to different control technologies due to concerns over confidentiality of manufacturer data. However, it seems clear that no confidential information could be gleaned by presenting the overall sales-weighted average per-engine cost increase for outboards and personal watercraft.

The following average per-engine cost estimates reflect costs averaged across all engine families for outboards and personal watercraft. It should be noted that actual prices and costs in the market will differ from the information presented here for a number of potential reasons. First, not all costs of control will average across all engine families if the market for emission reduction credits does not work well. Second, prices of engines are set by the market forces of supply and demand. Even if the market for emission reduction credits worked well, prices could be different than expected if people were willing to pay more or less than the changes in the cost to supply engines. For example, if people value most highly the engines with the lowest emissions and those people are willing to pay a lot more than the engines cost to produce, one would expect the engine price to reflect consumer willingness to pay. On the other hand, if people demand more of the clean engines than predicted, the price may fall due to economies of scale or increased competition in the market from entry of competing engine families. Third, consumer willingness to pay is most likely linked to engine output. Therefore, a $100 increase in price for a 10 kW engine will likely have a different effect on sales than a $100 increase in price for a 100 kW engine. These effects will be played out in the market and the market price may be different than expected.

Table 2-04
Estimated Per Engine Consumer Cost Increase

Year	Variable Cost	Fixed Cost	Dealer Cost	Fuel Savings	Maintenance Cost	Admin. Cost	Total Cost
1998	$12	$21	$5	($76)	$57	$13	$32
1999	$24	$42	$10	($152)	$129	$8	$62
2000	$35	$98	$23	($186)	$159	$8	$137
2001	$56	$178	$41	($241)	$214	$8	$257
2002	$64	$231	$53	($280)	$228	$8	$305
2003	$83	$279	$64	($343)	$297	$8	$389
2004	$102	$350	$81	($400)	$354	$8	$495
2005	$115	$410	$94	($442)	$389	$8	$575
2006	$126	$495	$114	($499)	$453	$8	$698

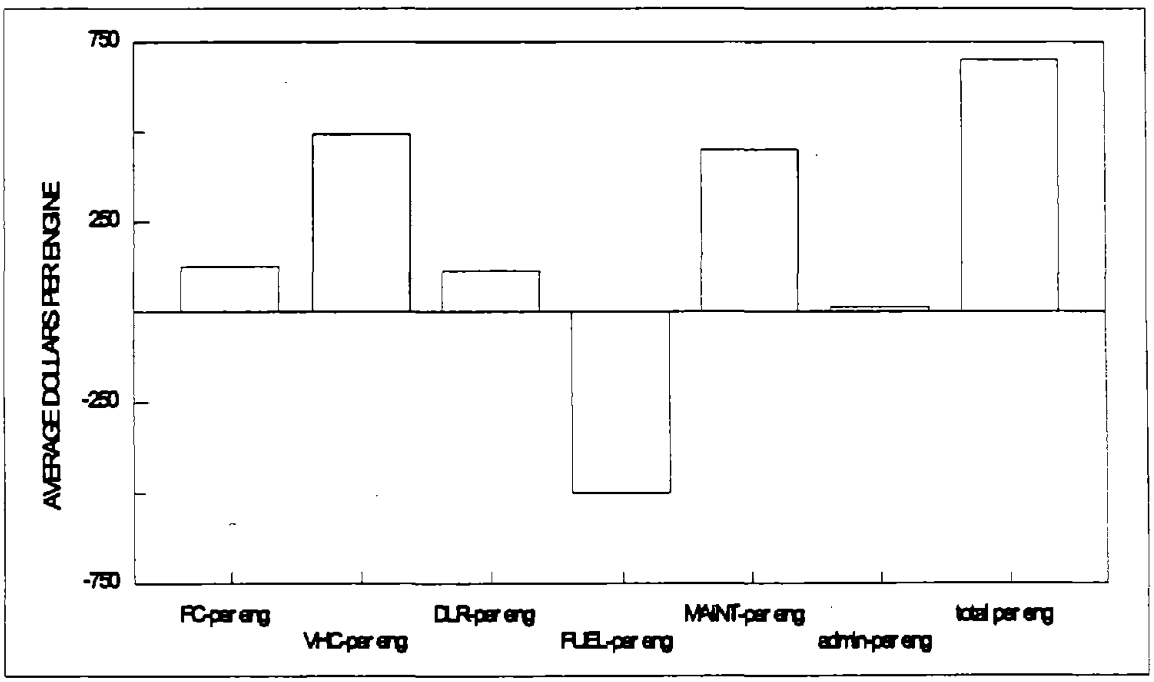

Figure 2-04
Average Consumer Cost Components Per Engine

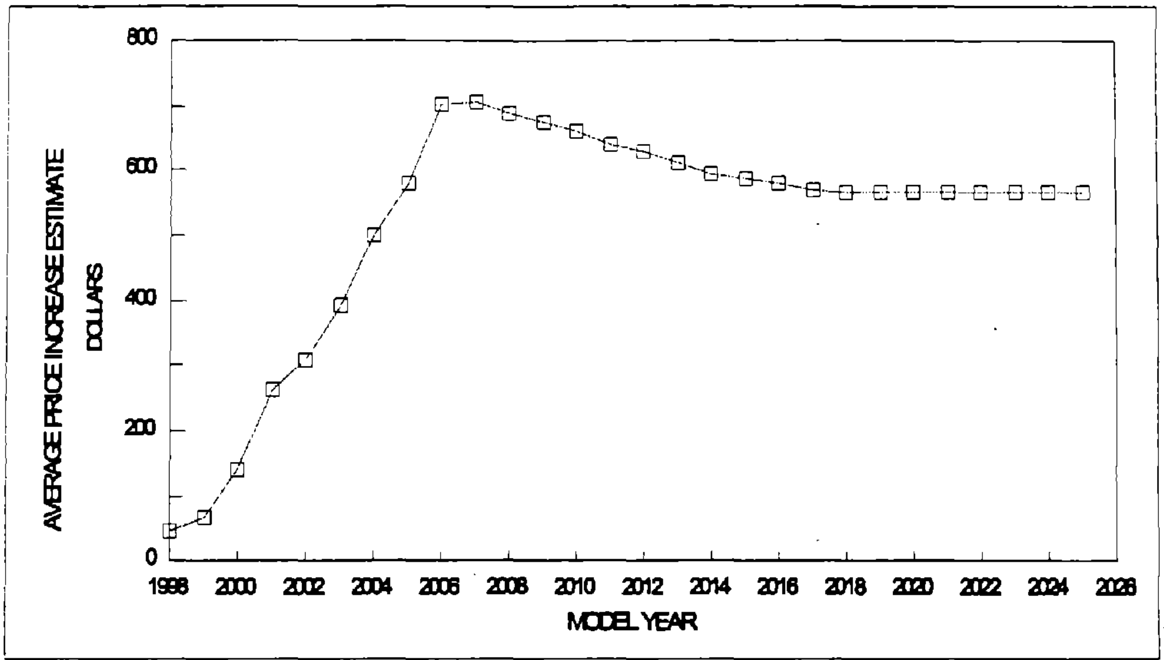

Figure 2-04
Estimated Average Price Increase

With these qualifications in mind, the estimated per engine cost estimate is presented in Table 2-03. Figures 2-02 and 2-03 graphically present the relative cost components and cost estimates over time.

2.3. Incremental Economic Impacts

2.3.1. Capital–Impacts on capital as a result of this rule are the result of increased investment by manufacturers in order to make their engines comply with the average emission standards proposed. These costs become part of the cost of manufacturing and are recaptured in price increases. As a result, private capital investment is unlikely to be displaced. All expenditures related to this rule can be expected to be borne from consumer savings or consumer credit markets, not from private capital markets. As shown in the aggregate cost section, the capital costs are the lesser costs of this rulemaking. In the year 2006, the peak year for costs, the capital costs are approximately $55 million.

2.3.2. Sales and Employment--Impacts on sales and employment are difficult to assess for this rulemaking. EPA considered impacts on engine manufacturers, boat manufacturers, boat dealerships, and manufacturers of other recreational marine products such as accessories.

EPA does expect sales to be affected by the price increases which will result from this rulemaking. See the benefits chapter for the specific sales estimates EPA has projected. Although sales will decline from projected baseline levels, overall sales of outboard engines under the controlled scenario are expected to return to 1997 levels by the year 2011 while sales of personal watercraft and sterndrive & inboard boats are expected to continue to increase past 1997.

Engine manufacturers have indicated to EPA that any sales decrease due to this regulation may be made up by exports. If this is the case, employment may not be affected by a sales decrease. Several manufacturers have indicated that employment may increase for engine and boat manufacturers due to the broadening of product lines expected as a result of this regulation. Manufacturers of engines will carry controlled engines for sale to the U.S. market and uncontrolled engines for sale to the world market. However, it is difficult to assess exactly what might be the increased employment. Employment increases will depend on individual manufacturers specific types of production lines.

EPA expects that if any decreases in employment do occur, it is most likely that they will occur in boat dealerships and in companies who make accessory products. These effects would be due to decreased sales of outboard engines and to reduced consumer budgets for consumers who purchase new outboard or personal watercraft engines.

Boat dealerships have been in poor financial shape in the past 5 years. The number of boat dealers has fallen as demand for pleasure craft has decreased and the competitive market has greatly intensified. Boat dealers, boat builders, and industry service sectors, such as marinas, have all experienced decreased demand. ...50 percent of the boat dealers in the U.S. are behind in interest payments, and at least 30 percent of all retailers have failed since 1989.(3) Although sales of pleasure boats are dramatically increased this year[3] making up for recent downturns, any potential sales decrease in the future may adversely affect the boat dealership sector which is very sensitive to changes in the economy. Further, sales decreases may affect boat dealers' employment more than engine or boat manufacturers since boat dealers do not participate in the expanding world markets. However, EPA is only in a position to recognize this potential effect and does not have any certainty over the potential extent of the effect.

Reduced outboard and personal watercraft sales and increased prices of remaining sales might mean that consumers have less money to purchase other marine accessory products. If this is the case, then employment may be affected for those manufacturers who produce accessory marine products, assuming that consumers total budgets for all marine products do not change. Quantification of these kinds of potential effects was not performed and would be uncertain at best.

In summary, EPA is uncertain as to the exact employment effects due to this rulemaking. EPA requests comment on what those effects may be.

2.3.3. Energy--Reduced energy consumption will be the result of the proposed emission standards. Resultant increases in fuel economy of these engines mean demand for energy will decrease marginally in the U.S. The resultant impact on the U.S. balance of trade is approximately $250 million per year. The estimate of gasoline savings is presented in Figure 2-04.

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[3] The Wall Street Journal reported on September 15, 1994, page A1, that sales of new pleasure boats were up 22% from 1993 to the highest level since 1989 as reported by the Boat Owners Association of the U.S. The group sees double-digit gains for '95, too.

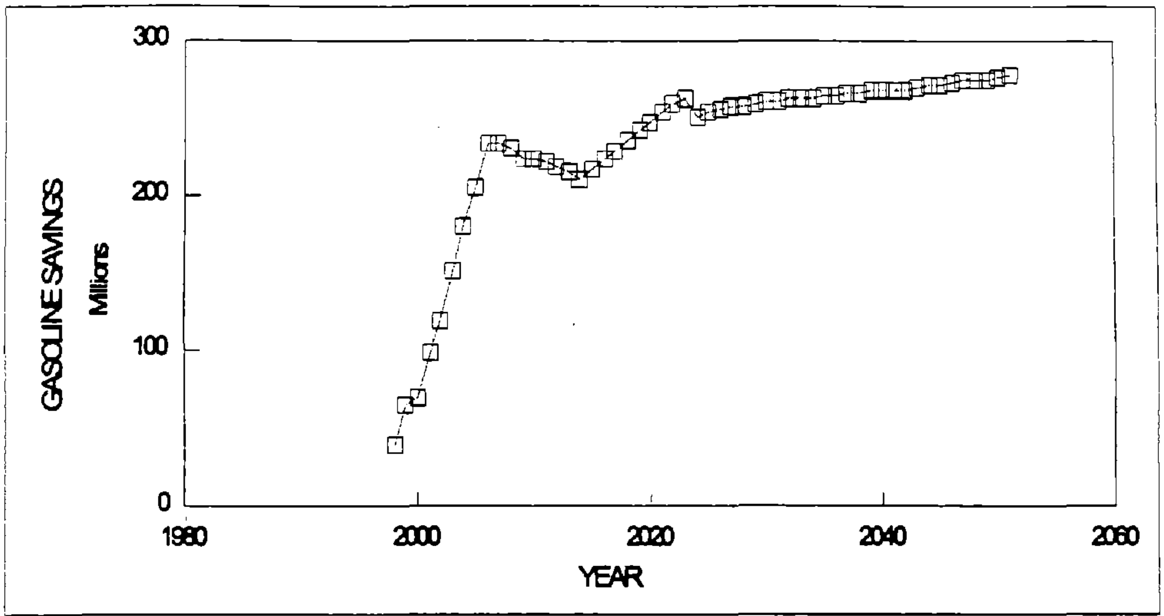

Figure 2-04
Expected Gasoline Savings

Chapter 2: References

1. ICF Incorporated, "Marine Industry Characterization Report," March 25, 1993, pages ES-1..ES-5.

2. Specialists in Business Information, Incorporated, "The SBI Market Profile on Pleasure Boats, Profile No. R-716," May 1994.

3. ICF Incorporated, "Marine Industry Characterization Report," March 25, 1993, page 4-6.

Chapter 3: Environmental Benefit

This chapter presents the methodology used by EPA to quantify the emission benefits that would be realized through the proposed HC and NOx emission standards for SI marine engines. Since the standards are based both on technology and the power rating of the specific engine, for purposes of calculating aggregate emissions , the technologies relevant to an application are grouped together. In all, 16 technology types distributed over 9 kilowatt-based niche categories have been considered for the analysis.

Benefits, in terms of HC emission reductions and NOx increments , are presented in two forms: per-engine benefits and aggregate source benefits. "Per-engine" benefits are the emission reductions expected to occur during the life of an engine whose emissions are controlled in response to the proposed standard. "Aggregate Source" benefits are the estimated, future nationwide application-specific emission reductions from affected engines. Estimated "aggregate source" benefits illustrate the potential future effect of the proposed standard on the emission inventory of the source. Air quality benefits are discussed qualitatively for HC standards.

Many of the detailed results discussed below are presented in separate tables included in Appendix A - Supplementary Tables.

3.1. Estimated HC Emissions Reduction

To estimate the average annual emissions per current nonroad SI marine engine, EPA used data provided by NMMA (National Marine Manufacturers Association) and confidential data provided by individual manufacturers on sales, kW ratings, and average load factor. Data from the Price Waterhouse study(1) was used in arriving at average annual hours of application-specific engine usage. Table A-01 of the Appendix presents average Kw-ratings for each of nine niche categories as they apply to technology types.

Average annual emissions calculated for each valid niche category are based on in-service population of engines, an activity factor and a technology -based sales-weighted emission factor . The technology types include current and manufacturer-proposed future cleaner technologies that are expected to replace current ones in order to meet the proposed standards. Each of the technology types, by definition, is mutually exclusive in the sense that each one is associated with one and only one of the three source types - outboard (OB) , personal watercraft (PWC) and inboard/sterndrive (IB/SD). For each of these sources, the emission inventory is calculated separately using the following equation:

$$INV_{ij} = N_{ij} \times HP_{ij} \times LOAD_j \times HOURS_j \times EF_{ij}$$

where

$N_{i,j}$	-	nationwide in-use population of engines that belong to niche category i and application type j.
$kW_{i,j}$	-	average rated power in kilowatts, for category i and application j.
$LOAD_j$	-	rated ratio (%) between average operational power output and rated power for application j
$HOURS_j$	-	average annual hours of engine usage for application j
$EF_{i,j}$	-	brake specific emission rate (grams/kilowatt-hr) for category i and application j
$INV_{i,j}$	-	annual nationwide emissions inventory in tons per year (tpy) for engines that belong to niche category i and application type j

In-service population and activity information used to construct the inventory relied predominantly on data provided by NMMA and the individual manufacturers. Table 3-01 presents data used in calculating the activity rate per niche for the three application types. The Average Load Factor is assumed to be 0.207 for every engine irrespective of Kw rating and technology class.

Table 3-01
Average Annual Hours of Use by
Niche Category and Technology Class

		Technology Class* Outboard (OB)	Personal Watercraft (PWC)	Inboard/Sterndrive (IB/SD)
Niche Category	Power Interval	T1,T4-T9,T15	T2,T13,T14	T3,T10-T12,T16
1	0-2.91	34.8		
2	2.98-7.38	34.8		
3	7.46-22.29	34.8		
4	22.37-37.21	34.8	77.3	
5	37.28-55.85	34.8	77.3	
6	55.92-74.49	34.8		
7	74.56-111.77	34.8		47.6
8	111.84-149.05	34.8		47.6
9	149.12+	34.8		47.6

* The Technology Classes are referenced by the letter T.

3.1.1. Per-Engine HC Emissions Reduction

This section describes the calculation of the per-engine emission reductions which are expected to occur during the life of an engine whose emissions are controlled in response to the proposed standards. EPA calculated average annual per-engine
emissions from source *i* using the equation

$$INV_{avg,HC}\text{-}\sum INV_{i,HC}+\sum N_i$$

where the summations are taken over all engines specific to a source/ application. The average annual per-engine HC emissions per source is then given by $INV_{avg,HC}$, which is calculated both for the baseline and control scenarios. The results of the calculation are summarized in Table 3-02 below for Outboard engines by niche category.

3.1.2. Aggregate Estimated Annual HC Reduction

The calculation of aggregate HC reductions is described in this section. The calculation takes into account U.S sales by model year, engine survival rates and average annual rates of usage. Estimates of technology-based sales-weighted average emission rate for each niche is calculated , using which EPA derived projected nationwide aggregate annual HC emissions through 2051, the year of complete fleet turnover . Here the "fleet" refers to fleet of all engines independent of application. It should be noted that the outboards have the longest useful life and therefore contributes to the long fleet turnover time.

3.1.2.1. Sales Projections--To estimate future emission levels, some projection of the future population of uncontrolled and controlled engines is needed. Because engines are introduced into the field through sales, estimates are needed not only of sales prior to the standard, but also of sales after the standard goes into effect. The proposed standard would begin to take effect starting 1998 and would involve a 9-year phase-in period ending in year 2006. Beginning in 1998, an appropriate fraction of engines sold are assumed to comply with the proposed standards based on EPA's calculation of marginal cost-effectiveness.

Projection of future outboard engine sales was done in two steps. In the first step a regression curve was fitted to historical sales data, available for the period 1961 through 1993. The functional form assumed is:

$$S_y = CI^aR^bP^c[\exp kB_{y-1}]^d$$

where S_y = Per capita Outboard sales in year y

I = Per capita income adjusted for CPI

R = Real interest rate

P = Outboard price adjusted for CPI

B_{y-1} = Total boat population in the previous year

C,a,b,c and d are constants determined from the regression.

The sales projection for 1994 through 2051 assumes that all economic variables remain constant except for a steady 1.25% growth per year in human population and a steady increase in price of outboards over the nine-year phase-in period ending in year 2006. As for inboards , the same equation is used to project sales, except that engine price remains constant over the phase-in years and beyond. For PWCs, sales projections S_y for the phase-in years and beyond -upto year 2015, are made using the equation :

$$S_y = (1+.04*(y-1997))* S_{y-1}* (P_y/P_{93})^{-2.0}$$ where

y = calendar year

S_{y-1} = sales in previous year

P_y / P_{93} = current year sales compared to base year(1993) sales

For years 2016-2051, the projections are based on the equation:

$$S_y = (1+.005*(y-2015))* S_{y-1}* (P_y/P_{93})^{-2.0}$$

where y = calendar year

S_{y-1} = sales in previous year

P_y / P_{93} = current year sales compared to base year (1993) sales

(The above is based on what **EPA thinks** the future growth rate of PWCs will be, and hence is open to comments.)

However, it should be recognized that, while national growth is measured at the level of the economy as a whole, growth in specific areas of the country is likely to vary from area to area in response to the specific demographic and commercial trends in those areas. These effects should be taken into account in estimating growth at the local level.

EPA distinguished between sales of controlled and uncontrolled engines in each future year starting in 1998, when an appropriate proportion of engines manufactured and sold are assumed to comply with the proposed standards. Although the proposed averaging and trading provisions allow for engines to emit at rates above the standard, they must be balanced by cleaner (i.e., below the standard) engines. Consequently, starting in year 2007, every new engine sold should emit at or below the proposed standard . Tables A-02 and A-03 present estimated sales of pre- and post-control engines by niche category for model years 1994-2051.

3.1.1.2. Survival Probabilities–In calculating the emission reductions that are expected to occur during the life of an engine, whose emissions are controlled in response to the proposed standard, EPA relied on estimates of average useful life provided by manufacturers. For outboard engines the average useful life (μ) is determined to be a function of the kilowatt rating and is of the form:

$\mu = 41.27*(1/.075kW)^{-0.204}$, where kW is the kilowatt rating of the engine.

Also the life distribution of marine engines in the field is assumed to be a 2-parameter Weibull distribution function of the form:

$$F = 1\text{-}\exp -(t/\theta)^b$$

where

F	=	cumulative fraction of engines failed
t	=	age of the engine or time to failure
θ	=	scale parameter or characteristic life
b	=	shape parameter or slope

The characteristic life θ is related to the mean life μ and slope b through the equation

$$\mu \quad = \quad b\Gamma(\theta + 1/\theta)$$

Based on information obtained from reliable source, EPA assumed the shape parameter for the Weibull-based life distribution of marine engines to be 4.0. Hence θ for each outboard niche category is computed as displayed in Table A-04. As for personal watercraft and inboard/sterndrive engines the average usefule life was assumed to be 10 and 20 years respectively and are independent of kilowatt ratings.

3.1.1.3. In-Service Population—By coupling the estimated sales projections given in Table A-02 with the engine survival function described above, EPA calculated the estimated in-service populations for calendar years 1990 to 2051 for engines in each niche category of an application. In doing so, EPA distinguished between controlled and uncontrolled engines, so that the effect of the standards could be ascertained. Table A-05 shows the resulting population projections for 1990-2051 for un-controlled and controlled engines used in all three application types. These projections are represented graphically in Figure 3-01.

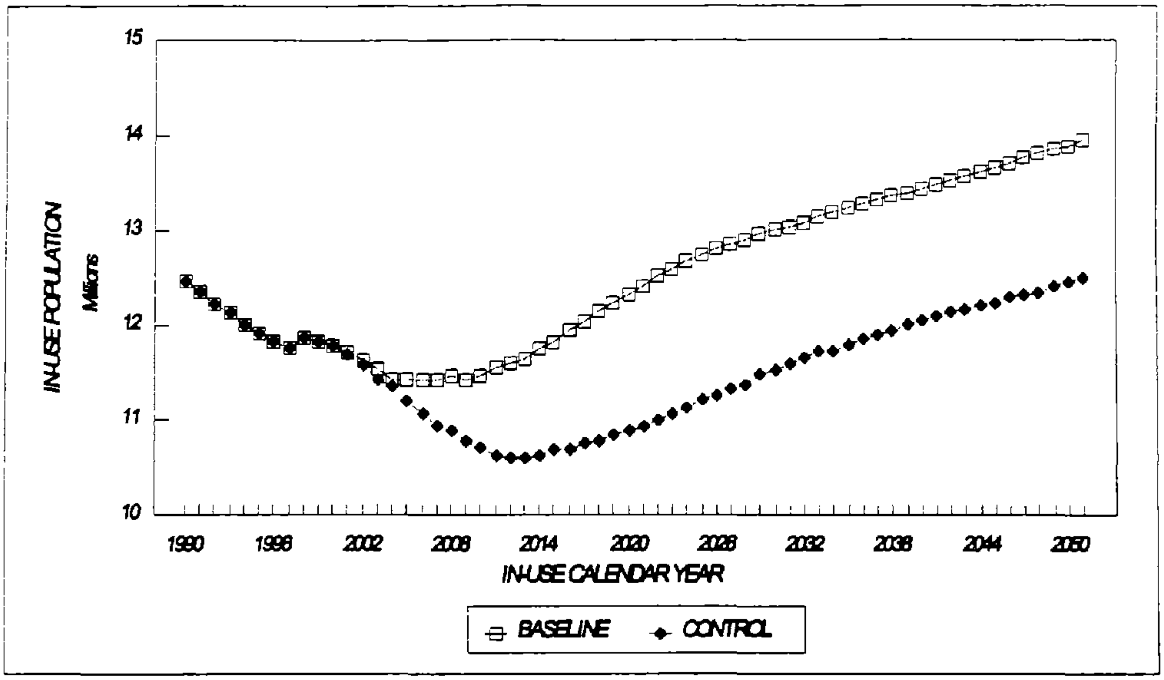

Figure 3-01
In-Use Engine Population by Calendar Year

3.1.1.4. Aggregate Source Emissions Inventory--EPA projected future annual nationwide HC and NOx emissions from engines addressed in this proposal under the baseline (no controls applied) and controlled scenarios. This was accomplished using the equation:

$$INV_{HC,y} = \sum_{j=y-44}^{y} (SALES_j \times S_{y-j} \times INV_{avg,HC,j})$$

In this equation,

y	-	inventory year (same as calendar year)
j	-	model year of engine (new model year is assumed to begin on October 1 of the calendar year)
SALESj	-	engine sales in year *j*
S_{y-j}	-	fraction of engines sold in year j that survive through yr. *y*
$INV_{avg,HC,j}$	-	*average annual per-engine HC emissions of engines sold in year j*

For each inventory year between 1990-2051, the calculation is carried out for all niches within an application type. The grand total over all niches and application types yields the total inventory of emissions from sources addressed by the current proposal. The controlled and uncontrolled scenario differences were accounted for by $INV_{avg,HC,j.,}$ while all other parameters remained tha same in both scenarios. NOx emissions inventory is calculated in a similar fashion.

Table A-07 presents total annual nationwide HC and NOx emissions from engines addressed in this proposal under the baseline scenario , and Table A-08 presents results for the controlled scenario. These are shown graphically in Figure 3-02.

In Figure 3-02, the annual benefit of the proposed regulation is indicated by the difference between the upper and lower curves. The area between the curves represents the net benefit of the proposed regulation during the time required for the marine SI fleet to completely turn over. The stream of benefits projected for year 2051 yields a reduction of 642,211 tons in HC emissions which translates to 74.2 % reduction.

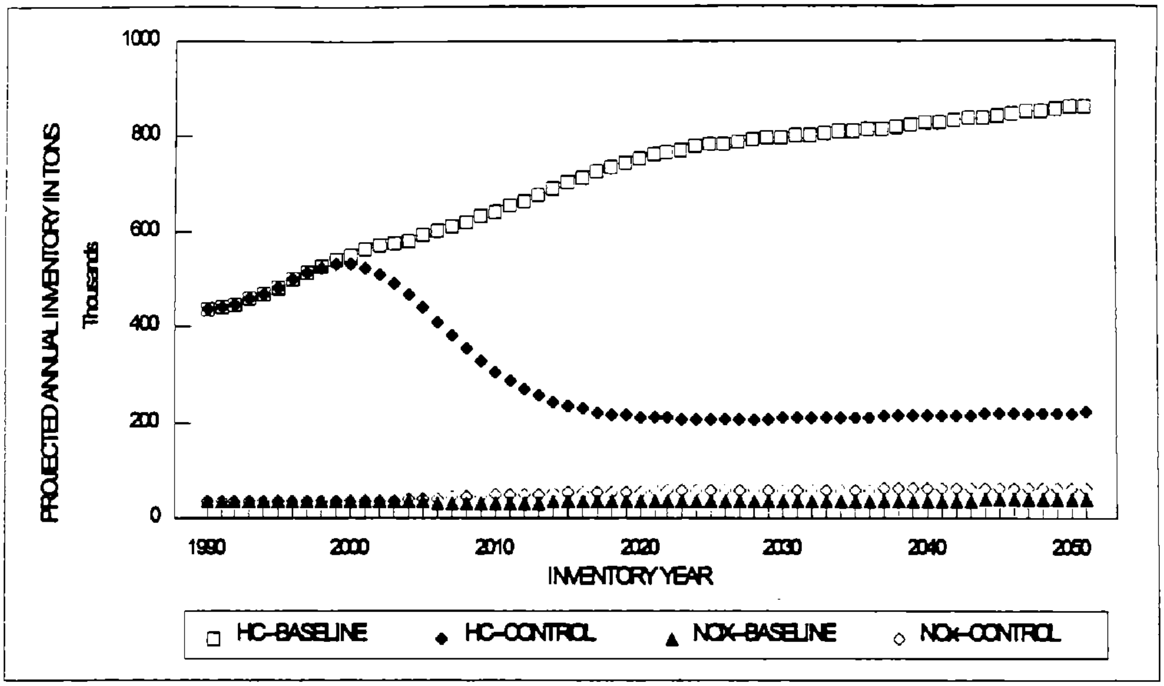

Figure 3-02
Marine Spark-Ignition Projected Inventories

3.1.2. Cost-Effectiveness

EPA has calculated the program cost-effectiveness for this rule as the ratio of the net present value of the projected stream of costs given in Table 2-01 divided by the net present value of the projected stream of emission reductions from projected baseline levels. The ratio is $718 per ton of HC emissions reduced. According to EPA guidance, the discount rate used for purposes of calculating net present value was 3%. Alternatively, the Office of Management and Budget recommends a default discount rate of 7% for the purposes of calculating net present value. Using 7%, the cost-effectiveness for the program would be $994 per ton of HC emission reduced. EPA has decided to use the ratio $718 per ton of HC reduced as the official program cost-effectiveness for this NPRM as it applies to gasoline marine engines.

3.2 Air Quality Benefits

Air quality benefits associated with reduction in VOC emissions are discussed in this section. Health and welfare effects of the pollutants as they impact on ozone formation are also described.

3.2.1. Volatile Organic Compounds (VOC)

EPA expects that reducing VOC emissions from spark ignition marine engines will help to mitigate the health and welfare impacts of ambient VOC's as well as urban and regional tropospheric ozone formation and transport.

3.2.1.1. Health and Welfare Effects of VOC Emissions--VOC is the general term used to denote volatile organic compounds, a broad class of pollutants encompassing hundreds of specific toxic compounds, including benzene, 1,3 butadiene, formaldehyde, acetaldehyde, and gasoline vapors. As stated previously, VOC is a criteria pollutant for which the EPA has established a NAAQS. Measures to control VOC emissions should reduce emissions of air toxics. However, the magnitude of reduction will depend on whether the control technology reduces the individual toxics in the same proportion that total VOC are reduced. Spark ignition marine engines do have significant VOC impacts, and it is suspected they may have significant air toxics impacts as well.

At elevated concentrations, VOC, a precursor to ozone, can adversely affect human health, agricultural production and environmental welfare.

Nonroad sources contribute substantially to summertime VOC emissions. The median contribution of total nonroad emissions to nonattainment VOC inventories in summer ranges from 7.4-12.6 percent, depending on the area(2). In EPA's 1991 Nonroad Engine and Vehicle Emission Study (NEVES), the recreational marine category, made up primarily of spark-ignition marine engines, was estimated to be a major contributor to summertime VOC emissions, accounting for a median ranging from 3.4 percent to 4.0 percent of the total VOC inventory in tons per summer day , depending on the area.

3.2.2. Benzene

Benzene is a clear, colorless, aromatic hydrocarbon which has a characteristic odor. It is both volatile and flammable. Benzene is present in both gasoline fuel and it is formed during the incomplete combustion of gasoline. The benzene level of typical unleaded gasoline sold today is approximately 1.5 percent. The fraction of benzene in the exhaust varies depending on cycle type, control technology and fuel composition. For on-highway motor vehicles, benzene is typically 3 to 5 percent of the exhaust tailpipe total organic gases emitted. It has been found for on-highway motor vehicles that benzene generally represents 1 percent of evaporative emissions, depending on the control technology and fuel composition.

Mobile sources account for approximately 85 percent of the total benzene emissions, of which approximately 30 percent can be attributed to nonroad mobile sources. These estimates were obtained from EPA's NEVES report. In the NEVES report, benzene was estimated to be about 3.0 percent of VOC emissions and 1.7 percent of evaporative VOC emissions for nonroad equipment. The split between exhaust and evaporative benzene emissions was assumed to be 80 percent exhaust to 20 percent evaporative. Thus, the overall benzene fraction of nonroad VOC emissions was estimated to be 2.74 percent.

However, the NEVES study did not distinguish between crankcase fuel/air scavenged (CS) two-stroke and four-stroke engines. An examination of the air toxic data used in support of the NEVES study(3), along with two additional reports from SouthWest Research Institute(4)(5) indicates a significant difference in air toxics as a percentage of total VOC emissions between crankcase scavenged two-stroke and four-stroke spark ignition gasoline engines. The data set consisted of nine unregulated, spark-ignition engines. The data set includes two new CS two-stroke engines, two used CS two-stroke engines, two new four-stroke engines, and three used four-stroke engines, all engines were used in equipment for the lawn and garden industry. A summary of air toxics as a percentage of total hydrocarbons from this data set is given below in Table 4-01

Table 3-02
Air Toxics as a Percentage of Total Hydrocarbons:
Mean Values for Small Nonroad Spark-Ignited Engines

Engine Cycle Type	benzene	1,3 butadiene	formaldehyde	acetaldehyde
CS Two-Strokes (four engines)	1.2%	0.16%	0.36%	0.08%
Four-Strokes (five engines)	4.0%	0.55%	0.62%	0.11%

The primary difference in air toxics as a percentage of total hydrocarbons between CS two-strokes and four-stroke engines are the high scavenging losses inherent in the CS two-stroke engine. Typically 80 to 95 percent of the exhaust hydrocarbons emitted from a CS two-stroke engine are from the unburnt fuel which escapes during the scavenging of the exhaust products with fresh charge. Though unburnt fuel does contain benzene, incomplete combustion of non-benzene aromatics can contribute significantly to an engines benzene emission rate. Therefore, when presented in terms of a percentage of total hydrocarbons emitted, a four-stroke engine has a higher percentage than a CS two-stroke because the CS two-stroke's mass emission rate of benzene is being diluted by unburnt fuel which contains a small amount of benzene. Fuel analysis done by SouthWest Research for the engine tests results shown in Table 3-02. above indicated a fuel benzene content of approximately 1.0 percent by volume.

3.2.2.1 Projected Benzene Emission Reductions—The data set summarized in Table 3-02. above is the only publicly available air toxics data on nonroad spark-ignition engines. EPA is not aware of any data which is available on air toxic emissions from spark-ignition marine engines. EPA has estimated this marine rule will result in a 74 percent (642,211 tons/year) reduction in VOC's from spark-ignition marine engines. It would be inappropriate to assume that this rule would result in a 74 percent reduction in benzene emissions. As stated earlier, there is a very small data set available on air toxic emissions from nonroad engines, and no data exists on marine engines or direct-injection (DI) two-strokes. EPA expects manufacturers to meet the proposed emission standards through a mix of technologies, primarily the conversion of CS two-strokes to either four-strokes or DI two-strokes engines. EPA is unaware of any air toxics data on DI two-strokes. If the assumption is made that as a percentage of total hydrocarbons, DI two-strokes will be similar to four-stroke engines with respect to air toxics, and that marine CS two-strokes and future marine four-strokes will emit air toxics as percentage of total hydrocarbons similar to the nonroad engines tested by SouthWest Research Institute, the following estimate can be made. Using a benzene emission factor for CS two-strokes of 1.2 percent of total VOC's, and a value of 4.0 percent for both four-stroke and DI two-stroke engines, this rule making will result in approximately a 20 percent (2,300 tons/year) annual decrease in benzene emissions from spark-ignition marine engines. This assumes evaporative VOC emissions, and therefore evaporative benzene emissions, remain unchanged. It should be stressed that this estimate is based on a very limited data set of nonroad spark-ignition small engines, not on actual marine engine data, and that no data is available on direct-injection two-stroke engines. In order to produce an accurate estimate of benzene, and other air toxins, reduction from marine engines, additional testing would need to be performed both on baseline and controlled engines.

3.2.2.2 Health and Welfare Effects of Benzene Emissions--Health effects caused by benzene emission differ based on concentration and duration of exposure. EPA's Total Exposure Assessment Methodology (TEAM) Study identified the major sources of exposure to benzene for much of the U.S. population. These sources turn out to be quite different from what had previously been considered the important sources. The study results indicate that the main sources of human exposure are associated with personal activities, not with the so-called "major point sources" . The results imply that personal activities or sources in the home far outweigh the contribution of outdoor air to human exposure to benzene. Since most of the traditional sources exert their effect through outdoor air, some of the nonroad small SI engine sources could explain the increased personal exposures observed. The TEAM Study is described in detail in a four-volume EPA publication (6).

The International Agency for Research on Cancer (IARC), classified benzene as a Group I carcinogen . A Group I carcinogen is defined as an agent that is carcinogenic to humans. IARC (1987) based this conclusion on the fact that numerous case reports and follow-up studies have suggested a relationship between exposure to benzene and the occurrence of various types of leukemia. The leukemogenic (i.e., the ability to induce leukemia) effects of benzene exposure were studied in 748 white males employed from 1940-1949 in the manufacturing of rubber products in a retrospective cohort mortality study (Infante et al. 1977a,b). Statistics were obtained through 1975. A statistically significant increase in the incidence of leukemia was found by comparison to the general U.S. population. The worker exposures to benzene were between 100 ppm and 10 ppm during the years 1941-1945. There was no evidence of solvent exposure other than benzene. In addition, numerous investigators have found significant increases in chromosomal aberrations of bone marrow cells and peripheral lymphocytes from workers with exposure to benzene (IARC 1982).

Exposure to benzene has also been linked with genetic changes in humans and animals. EPA has concluded that benzene is a Group A, known human carcinogen based on sufficient human epidemiologic evidence (Rinsky et al. 1981; Ott et al. 1978; Wong et al. 1983) demonstrating an increased incidence of nonlymphocytic leukemia from occupational inhalation exposure. The supporting animal evidence (Goldstein 1980; NTP 1986; Maltoni et al., 1983) showed an increased incidence of neoplasia in rats and mice exposed by inhalation and gavage. EPA calculated a cancer unit risk factor for benzene of 8.3×10^{-6} $(\mu g/m^3)^{-1}$ based on the results of the above human epidemiological studies in benzene-exposed workers in which an increase of death due to nonlymphocytic leukemia was observed. EPA's office of Research and Development (ORD) has recently started the process to review and update the benzene risk assessment.

The California Department of Health Services (DHS, 1984), which provides technical support to CARB, has also determined that there is sufficient evidence to consider benzene a human carcinogen. CARB performed a risk assessment of benzene that was very similar to EPA's risk assessment. The CARB risk estimate is actually a range, with the number calculated by

EPA serving as the lower bound of cancer risk and a more conservative (ie., higher) number, based on animal data , serving as the upper bound of cancer risk. The CARB potency estimate for benzene ranges from $8.3x10^{-6}$ to $5.2x10^{-5}$ $(\mu g/m^3)^{-1}$.

A number of adverse noncancer health effects have also been associated with exposure to benzene. People with long-term exposure to benzene at levels that generally exceed 50 ppm (162,500 $\mu g/m^3$) 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 and a reduced ability to clot. Exposure to benzene at comparable or even lower levels can be harmful to the immune system, increasing the chance for infection and perhaps lowering the body's defense against tumors by altering the number and function of the body's white blood cells. In studies using pregnant animals, inhalation exposure to benzene in the range of 10-300 ppm (32,500-975,000 $\mu g/m^3$) indicates adverse effects on the developing fetus, including low birth weight, delayed bone formation, and bone marrow damage.

3.2.3. 1,3- Butadiene

1,3-Butadiene is a colorless, flammable gas at room temperature with a pungent, aromatic odor, and a chemical formula C_4H_3. 1,3-Butadiene is insoluble in water and because of its reactivity, is estimated to have a short atmospheric lifetime. The actual lifetime depends upon the conditions a t the time of release, such as the time of day, intensity of sunlight, temperature etc. 1,3 Butadiene is formed in vehicle exhaust by the incomplete combustion of the fuel and is assumed not to be present in vehicle evaporative and refueling emissions.

1,3- Butadiene emissions appears to increase roughly in proportion to exhaust hydrocarbon emissions for a given engine design. However, when comparing crankcase air/fuel scavenged (CS) two-stroke engines with either four-stroke or direct injection (DI) two-stroke gasoline engines, a decrease in VOC would not be directly proportional to the decrease in 1,3 butadiene. As discussed in section 4.2.2, generally 80 to 95 percent of a CS two-stroke engines exhaust VOC emissions is unburnt fuel lost during the scavenging process. This unburnt fuel does not contain 1,3 butadiene, therefore a reduction in scavenging losses will not reduce 1,3 butadiene. Table 3-02 indicates that for nonroad CS two-stroke engines, approximately 0.16 percent of exhaust VOC is 1,3 butadiene, while approximately 0.55 percent of nonroad four-stroke VOC is 1,3 butadiene.

3.2.3.1 Projected 1,3-Butadiene Emission Reductions--Current EPA estimates indicate that mobile sources account for approximately 94 percent of the total 1,3-butadiene emissions, out of which 41 percent can be attributed to nonroad mobile sources. The remaining 1,3-butadiene emissions come from stationary sources mainly related to industries producing 1,3-butadiene and those industries that use 1,3-butadiene to produce other compounds. Using the emission factors from Table 4-01, and assuming that controlled marine four-strokes and DI two-strokes will emit the same percentage of 1,3 butadiene with respect to total VOC, the proposed EPA marine rule will result approximately a 20 percent (280 tons/year) reduction in 1,3 butadiene emissions.

3.2.3.2 Health and Welfare Effects of 1,3 - Butadiene Exposure--The annual average ambient level of 1,3-butadiene ranges from 0.12 to 0.56 $\mu g/m^3$.

Long-term inhalation exposure to 1,3-butadiene has been shown to cause tumors in several organs in experimental animals. Epidemiologic studies of occupationally exposed workers were inconclusive with respect to the carcinogenicity of 1,3-butadiene in humans. Based on the inadequate human evidence and sufficient animal evidence, EPA has concluded that 1,3-butadiene is a Group B2, probable human carcinogen. IARC has classified 1,3-butadiene as a Group 2A, probable human carcinogen. EPA calculated a cancer unit risk factor of $2.8X10^{-4}$ $(\mu g/m^3)^{-1}$ for 1,3-butadiene based on the results of a study in mice in which an increase in the incidence of tumors in the lung and blood vessels of the heart, as well as lymphomas were observed. EPA's Office of Research and Development has recently started the process of updating the 1,3-butadiene risk assessment.

Exposure to 1,3-butadiene is also associated with adverse noncancer health effects. Exposure to high levels (on the order of hundreds of thousands ppm) of this chemical for short periods of time can cause irritation of the eyes, nose, and throat, and exposure to very high levels can cause effects on the brain leading to respiratory paralysis and death Studies of rubber industry workers who are chronically exposed to 1,3-butadiene suggest other possible harmful effects including heart disease, blood disease, and lung disease. Studies in animals indicate that 1,3-butadiene at exposure levels of greater than 1,000 ppm (2.2×10^6 $\mu g/m^3$) may adversely affect the blood-forming organs. Reproductive and developmental toxicity has also been demonstrated in experimental animals exposed to 1,3-butadiene at levels greater than 1,000 ppm.

3.2.4 Formaldehyde

Formaldehyde is formed as a result of incomplete combustion of gasoline in internal combustion engines. Formaldehyde is not a component of gasoline, and therefore it is not a component of evaporative emissions. For typical on-highway motor vehicles, 1-4 percent of tailpipe exhaust VOC is formaldehyde. The EPA NEVES study estimated that approximately 13 percent of atmospheric formaldehyde comes from nonroad mobile sources. Formaldehyde exhibits a very complex atmospheric behavior. Approximately 70 percent of the formaldehyde in the atmosphere is "secondary" formaldehyde formed from reaction of other VOC gases.

3.2.4.1. Projected Formaldehyde Emission Reductions--Using the same arguments from section 4.2.3.1, the reduction of formaldehyde from this rule will not be as great as the total VOC reduction. EPA has estimated a VOC reduction of 642,211 tons/year, 74 percent from the uncontrolled scenario. Using the emission factors from Table 3-02 for formaldehyde, 0.36 percent of VOC for crankcase fuel/air scavenged two-strokes (uncontrolled case), and 0.62 percent of VOC for both four-stroke and direct injection two-stroke marine engines (controlled case), EPA estimates approximately a 55 percent reduction (1760 tons/year) in formaldehyde emissions. It should be stressed that this estimate is based on nine engines used in the lawn and garden industry. Air toxics data from controlled and uncontrolled marine engines would need to be gathered to substantiate this reduction claim.

3.2.4.2. Health and Welfare Effects of Formaldehyde--Based on laboratory studies involving rats, EPA has classified formaldehyde as a group B1 toxic, probable human carcinogen. EPA has calculated a unit risk factor of 1.3×10^{-5} $(\mu g/m^3)^{-1}$ for formaldehyde. It should be noted that because this risk factor is based on animal data, it should be treated as an upper bound..

Formaldehyde is a known human irritant for the eyes, nose and upper respiratory system.

3.2.4 Acetaldehyde

Acetaldehyde is formed in internal combustion engines from the incomplete combustion of gasoline. Acetaldehyde is not found in evaporative emissions. For on-highway mobile sources, acetaldehyde is typically between 0.4 and 1.0 percent of exhaust tailpipe VOC. The nonroad engines and vehicle, including marine engines, contribution to the national inventory of acetaldehyde contains both primary and secondary emissions. It is estimated that approximately 39% of the national acetaldehyde inventory comes from motor vehicles. No attempts have been made to estimate the contribution of nonroad sources, including marine engines, to the national acetaldehyde inventory.

3.2.4.1. Projected Acetaldehyde Emission Reductions--Based on the data collected by SouthWest Research Institute shown in Table 4-01, acetaldehyde emissions from nonroad crankcase fuel/air scavenged small two-stroke engines is approximately 0.08 percent of total exhaust hydrocarbon emissions and a nonroad four-stroke small engines acetaldehyde emission rate is approximately 0.11 percent of total exhaust hydrocarbon emissions. As described in Section 4.2.2, the percentage emission reduction from marine engines for VOC will be greater than the reduction in acetaldehyde, primarily due to the nature of the VOC emissions coming from crankcase fuel/air scavenged two-stroke engines. Using the emission factors for acetaldehyde from Table 2-01, a very rough estimate of acetaldehyde reduction of 65 percent (450 tons/year) can be calculated for this rule. Air toxics data from controlled and uncontrolled marine engines would need to be gathered to substantiate this reduction claim.

3.2.4.2. Health and Welfare Effects of Acetaldehyde--EPA has classified acetaldehyde as a group B2 toxic, probable human carcinogen. EPA has calculated a cancer unit risk factor of 2.2×10^{-6} $(\mu g/m^3)^{-1}$. This risk factor is based on animal experiments and should be considered an upper bound. Noncancer effects include irritation of the eyes, skin, ad respitory tract. Respitory paralysis and death have occurred at extremely high concentrations.

3.2.4 Carbon Monoxide (CO)

The Clean Air Act directs the Administrator of the EPA to establish National Ambient Air Quality Standards (NAAQS) for several widespread air pollutants, based on scientific criteria and allowing for an adequate margin of safety to protect public health. The current primary and secondary NAAQS for CO are 9ppm for a 1-hour average and 35 ppm for an 8-hour average. in the EPA NEVES study, the recreational marine category's median contribution to winter time CO was 0.1 percent. Because of the very small contribution to the national CO inventory coming from marine engines, CO reductions were not a primary focus of this rulemaking. However, to meet the VOC standards in this rule, EPA does expect a modest CO reduction from marine engines. The CO emission standard set in this rule is a cap, meant to eliminate very high CO emitting engines, which generally are far above the CO emission levels of most engines sold. Most of the NAAQS nonattainment episodes for CO occur in the winter, while most boating activity in the U.S. occurs during the summer months, when CO air quality standards are rarely in nonattainment. High episodes of CO for the boat user is generally a combination of both a high CO emitting engine and boat design . High levels of CO can have severe impacts on the health of users of such engines and in these cases boat design must be taken into account. The information given below is a description of the adverse health effects of CO, however, no research has been done concerning the health effects from marine spark-ignition engine.

3.2.4.1. Health and Welfare Effects of CO--Carbon monoxide is a colorless, odorless, tasteless and nonirritating gas and gives no signs of its presence. It is readily absorbed from the lungs into the bloodstream, there forming a slowly reversible complex with hemoglobin (Hb) known as carboxyhemoglobin (COHb).

Blood COHb levels do not often exceed 0.5 to 0.7 percent in normal individuals unless exogenous CO is breathed. Some individuals with high endogenous CO production can have COHb levels of 1.0 to 1.5 percent (e.g. anemic). The presence of COHb in the blood reduces the amount of oxygen available to vital tissues, affecting primarily the cardiovascular and nervous systems. Although the formation of COHb is reversible, the elimination half-time is quite long because of the right binding between CO and Hb. This can lead to accumulation of COHb, and extended exposures to even relatively low concentrations of CO may produce substantially increased blood levels of COHb.

Health effects associated with exposure to CO include cardiovascular system, central nervous system (CNS), and developmental toxicity effects, as well as effects of combined exposure to CO and other pollutants, drugs, and environmental factors. Concerns about the potential health effects of exposure to CO have been addressed in extensive studies with various animal species as subjects. Under varied experimental protocols, considerable information has been obtained on the toxicity of CO, its direct effects on the blood and other tissues, and the manifestations of these effects in the form of changes in organ function. Many of these studies, however have been conducted at extremely high levels of CO (i.e., levels not found in ambient air). Although severe effects from exposure to these high levels of CO are not directly germane to the problems from exposure to current ambient levels of CO, they can provide valuable information about potential effects of accidental exposure to CO, particularly those exposures occurring indoors.

Carbon monoxide poisoning can cause permanent brain damage , including changes in personality and memory. Once inhaled, carbon monoxide decreases the ability of the blood to carry oxygen to the brain and other vital organs. Even low levels of carbon monoxide can set off chest pains and heart attacks in people with coronary artery disease.

Although no studies measuring the human health effects of CO emanating from marine spark-ignition gasoline engines have been conducted, ample research results are available concerning general health effects of exposure to CO. The effects of exposure to low concentrations-such as the levels found in ambient air - are far more subtle and considerably less threatening than those occurring in direct poisoning from high CO levels. Maximal exercise performance in healthy individuals has been shown to be affected at COHb levels of 2.3 percent and greater. Central nervous system effects, observed at peak COHb levels of 5 percent and greater, include reduction in visual perception, manual dexterity, learning, driving performance, and attention level. Of most concern, however, are adverse effects observed in individuals with chronic heart disease at COHb levels of 3 to 6 percent. At these levels, such individuals are likely to have reduced capacity for physical activity because they experience chest pain (angina) sooner. Exercise-related cardiac arrhythmias have also been observed in some people with chronic heart disease at COHb levels of 6 percent or higher and may result in an increased risk of sudden death from a heart attack .

The NAAQS set by EPA are intended to keep COHb levels below 2.1 percent in order to protect the most sensitive members of the general population (i.e., individuals with chronic heart disease). However, elderly people, pregnant women (due to possible fetal effects), small children, and people with anemia or with diagnosed or undiagnosed pulmonary or cardiovascular disease are also likely to be at increased risk to CO effects.

Chapter 3 : References

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3. Carroll, J., SouthWest Research Institute, *Emission tests of in-use small utility engines,* SwRI Report No. 3426-006, completed for the U.S. Environmental Protection Agency, Contract No. 68-CO-0014, Work Assignment No. 0-6, Task 3, September 1991.

4. Hare, C. and White, J., SouthWest Research Institute, *Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues,* Society of Automotive Engineers Paper No. 911222, October 1991.

5. Hare, C. and Carroll, J., SouthWest Research Institute, *Speciation of organic emissions to study fuel dependence of small engine exhaust photochemical reactivity,* SwRI Report No. 9702, July 1993.

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Appendix A: Supplementary Tables

Table A-01

Average Sales Weighted Kilowatt (Kw) Ratings

Niche Category	Power Interval	Technology Class															
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T1O	T11	T12	T13	T14	T15	T16
1	0-2.91	2.23	0	0	2.23	2.2	2.23	2.23	2.23	2.23	0	0	0	0	0	2.23	2.23
2	2.98-7.38	3.97	0	0	3.97	4	3.97	3.97	3.97	3.97	0	0	0	0	0	3.97	3.97
3	7.46-22.29	13.2	0	0	13.2	13	13.2	13.2	13.2	13.2	0	0	0	0	0	13.2	13.2
4	22.37-37.21	32.1	35.1	0	32.1	32	32.1	32.1	32.1	32.1	0	0	0	35.1	35.1	32.1	32.1
5	37.28-55.85	45.93	43.5	0	45.93	46	45.93	45.93	45.93	45.93	0	0	0	43.5	43.5	45.93	45.93
6	55.92-74.49	65.3	0	0	65.3	65	65.3	65.3	65.3	65.3	0	0	0	0	0	65.3	65.3
7	74.56 -111.77	87.3	0	89.8	87.3	87.3	87.3	87.3	87.3	87.3	89.8	89.8	89.8	0	0	87.3	87.3
8	111.84-149.05	127.9	0	122.9	128	128	128	127.9	127.9	127.9	123	123	122.9	0	0	127.9	127.9
9	149.12 +	161.3	0	195.8	161.3	161	161.3	161.3	161.3	161.3	196	196	195.8	0	0	161.3	161.3

Table A-04

Average Useful Life and Attrition Constants									
Outboard Engines				Inboard Engines			PWCs		
Niche Category	Useful Life	Theta	b	Useful Life	Theta	b	Useful Life	Theta	b
0-2.91	27.0	29.8	4.0	20.0	22.1	4.0	10.0	11.0	4.0
2.98-7.38	27.0	29.8	4.0	20.0	22.1	4.0	10.0	11.0	4.0
7.46-22.29	22.0	24.3	4.0	20.0	22.1	4.0	10.0	11.0	4.0
22.37-37.21	19.0	21.0	4.0	20.0	22.1	4.0	10.0	11.0	4.0
37.28-55.85	17.5	19.3	4.0	20.0	22.1	4.0	10.0	11.0	4.0
55.92-74.49	16.5	18.2	4.0	20.0	22.1	4.0	10.0	11.0	4.0
74.56 -111.77	15.5	17.1	4.0	20.0	22.1	4.0	10.0	11.0	4.0
111.84-149.05	14.5	16.0	4.0	20.0	22.1	4.0	10.0	11.0	4.0
149.12 +	14.0	15.5	4.0	20.0	22.1	4.0	10.0	11.0	4.0

Table A-05

Total Engine Population by Calendar Year

Year	Baseline	Control
1993	12,127,303	12,127,303
1994	12,003,980	12,003,980
1995	11,907,729	11,907,729
1996	11,832,587	11,832,587
1997	11,768,167	11,768,167
1998	11,872,627	11,870,183
1999	11,830,237	11,824,210
2000	11,778,681	11,776,501
2001	11,706,141	11,690,501
2002	11,629,131	11,582,137
2003	11,544,291	11,433,020
2004	11,439,758	11,357,253
2005	11,421,722	11,213,739
2006	11,422,809	11,062,002
2007	11,424,591	10,944,380
2008	11,471,525	10,895,324
2009	11,432,905	10,793,151
2010	11,470,180	10,711,223
2011	11,553,633	10,624,177
2012	11,601,218	10,612,829
2013	11,658,609	10,604,748
2014	11,760,265	10,626,218
2015	11,832,207	10,700,670
2016	11,949,769	10,692,492
2017	12,052,633	10,765,578
2018	12,157,258	10,777,936

Table A-05

2019	12,247,744	10,858,907
2020	12,339,222	10,887,386
2021	12,432,410	10,946,615
2022	12,536,746	11,014,314
2023	12,610,770	11,078,289
2024	12,690,183	11,139,733
2025	12,757,242	11,227,745
2026	12,818,730	11,266,014
2027	12,875,499	11,331,085
2028	12,924,804	11,390,182
2029	12,970,973	11,487,195
2030	13,018,985	11,533,361
2031	13,040,842	11,600,876
2032	13,086,792	11,662,949
2033	13,160,953	11,736,568
2034	13,202,975	11,749,464
2035	13,244,647	11,798,006
2036	13,286,235	11,878,279
2037	13,327,935	11,926,649
2038	13,369,896	11,950,652
2039	13,412,236	12,021,190
2040	13,455,049	12,064,246
2041	13,498,384	12,114,489
2042	13,540,945	12,150,855
2043	13,586,702	12,186,105
2044	13,631,549	12,234,368
2045	13,661,937	12,247,849
2046	13,703,271	12,305,310
2047	13,770,133	12,334,362

Table A-05

2048	13,816,016	12,364,420
2049	13,858,233	12,416,944
2050	13,899,730	12,475,925
2051	13,954,429	12,515,615