State of California
AIR RESOURCES BOARD

STAFF REPORT

PUBLIC HEARING TO CONSIDER ADOPTION OF EMISSION STANDARDS AND TEST PROCEDURES FOR NEW 2003 AND LATER SPARK-IGNITION INBOARD AND STERNDRIVE MARINE ENGINES

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EXECUTIVE SUMMARY

In 1994, the Air Resources Board (ARB) approved a revision to the State Implementation Plan (SIP) which contains clean-air strategies needed to meet the health-based, 1-hour, federal ozone air quality standard (ARB 1994b). The ozone SIP includes measures to reduce emissions from mobile sources under state control (including passenger cars, heavy-duty trucks, and off-road equipment) as well as federal assignments to control emissions from sources under exclusive or practical federal control (such as aircraft, marine vessels and locomotives). The responsibility to adopt emission standards for marine pleasure craft (measure M16) was assigned to the U.S. Environmental Protection Agency (U.S. EPA). The SIP's M16 emission reduction obligation was 12 tons per day hydrocarbon (HC) reductions in 2010 in the South Coast Air Basin (approximately 10 tons per day from two-stroke outboards and 2 tons per day from four-stroke inboard and sterndrive engines). The U.S. EPA rulemaking, starting with the 1998 model-year for outboards, combined with a subsequent California rulemaking for outboards starting with the 2001 model-year, accounted for the reductions expected from outboard engines. The proposed U.S. EPA rulemaking for spark-ignition (gasoline) inboard and sterndrive engines has not yet been adopted.

ARB staff proposes regulations to reduce HC emissions and oxides of nitrogen (NOx) emissions from new gasoline inboard and sterndrive marine engines sold in California. Development of this proposal was undertaken to address California's SIP commitment and the overall significant emissions impact from this category of engines.

Central to the proposal are exhaust emission standards that start in 2003 and become more stringent in 2007. Specifically, staff is proposing an HC+NOx emission standard capped at present-day levels beginning with the 2003 models. More significantly, the proposal includes a more stringent hydrocarbon plus nitrogen oxides (HC+NOx) standard of 5 g/kW-hr, a reduction of about 67% from today's engines, phased-in in 2007, with full implementation on all models in 2009. Additional features of the proposal include provisions for installation of on-board diagnostics, broadening of the existing consumer-labeling program for outboards to include a 4-star super ultra-low emissions label, establishment of emission warranty requirements and new and in-use engine compliance provisions.

If adopted, the regulation will reduce statewide HC+NOx emissions by 10 tons per day on a typical summer weekend in 2010. By 2020, when many inboard and sterndrive engines will be emission-controlled, the HC+NOx emission reduction will be 56 tons per day. Using assumptions consistent with the 1994 SIP for the South Coast Air Basin, the HC reduction on an annual average day will be 1 ton, which achieves one half of the SIP commitment. The staff was unable to identify a viable option which would achieve the full 2 tons per day HC commitment.

The cost-effectiveness of this proposal is $2.08 to $3.39 per pound of HC+NOx emissions reduced for the 2007 standards. This translates to average price increases for new engines of about $750 to $1200 for the 2007 standards to comply with this regulation. The range of estimates is due to differing assumptions regarding spreading of development costs for the emission control system over all U.S. sales *versus* over just California sales. For perspective, these costs represent 3 to 4 percent, respectively, of the average 2000-model year sterndrive boat price ($28,600). The cost-effectiveness of the proposal is well within the range of other adopted mobile source measure costs.

To address the limited resources available to individual marine engine manufacturers, and increase confidence in the in-use operation and durability of catalyst systems installed in boats, the ARB, U.S. EPA and the National Marine Manufacturers' Association are cooperating in a program to test catalysts on marine engines, design optimum air-fuel control programs, minimize water exposure of catalysts and oxygen sensors, and demonstrate the catalyst systems for the full boat-design life. So far this effort has demonstrated a catalyst-controlled engine in the laboratory with a compact catalyst which achieves 67% reduction of HC+NOx emissions, and that water exposure of the exhaust components can be minimized by routing warm cooling water to the exhaust manifolds. The in-boat catalyst demonstration program is scheduled to begin in summer, 2002. The results of this program will be the basis of the proposed 2003 and 2005 technology reviews.

The staff recommends that the Board adopt the staff proposal.

I. INTRODUCTION

The California Clean Air Act, as codified in Health and Safety Code section 43013, directs the Air Resources Board (ARB) to regulate off-road mobile sources of emissions. Health and Safety Code section 43018 further mandates ARB “to achieve the maximum degree of emission reduction possible” from mobile sources of pollution in order to attain California’s ambient air quality standards. These off-road mobile sources include, but are not limited to, marine vessels, locomotives, utility engines, off-road motorcycles, and off-highway vehicles. This regulation focuses on spark-ignition (gasoline) inboard and sterndrive marine engines, typically found in recreational boats such as ski boats or family fishing boats.

In 1998, ARB adopted emission control regulations for gasoline marine engines used in personal watercraft and outboard-engine boats. Inboard and sterndrive engines were not addressed in the rulemaking. At this juncture, staff proposes amending the gasoline marine regulations (Title 13, California Code of Regulations, section 2440 *et seq*.) to include inboard and sterndrive engines. Because these engines are automotive-derived, staff believes that emissions from these engines can be reduced significantly through the use of common automotive emission control technologies such as closed-loop fuel-control systems and three-way catalytic converters. The proposal described herein establishes exhaust emission standards and accompanying compliance procedures for new marine inboard and sterndrive engines.

II. BACKGROUND

In November 1994, ARB approved the State Implementation Plan (SIP) for ozone, which outlined the measures to be taken to bring the State’s air quality into attainment with federal ambient air quality standards for ozone (ARB 1994b). During the SIP’s development, it became clear that reducing emissions of hydrocarbons (HC) and oxides of nitrogen (NOx) from off-road engines and equipment operating within the state is imperative for cleaning California's air. The SIP identified several categories of off-road mobile sources in which significant emission reduction opportunities exist, including outboard marine engines, inboard marine engines, and commercial diesel marine engines.

The SIP includes various control measures to reduce ozone; the responsibilities for which were divided between ARB and U.S. EPA. SIP measures M9 and M13 focused on off-road compression-ignition (diesel) engines and large ocean-going marine vessels, respectively. Measure M16, entitled “Pleasure Craft,” focused on recreational gasoline marine engines. At that time, implementation of measure M16 was determined to be the responsibility of U.S. EPA.

The U.S. EPA adopted regulations for outboard and personal watercraft marine engines in 1996 (40 CFR 91) and for commercial marine diesel engines in 1999 (40 CFR 94). However, when updated emission inventory assessments showed a significant increase in recreational marine emissions, the ARB adopted more stringent regulations for outboard and personal watercraft marine engines in 1998. No regulations have yet been adopted for gasoline inboard and sterndrive marine engines.

A. Description of Inboard and Sterndrive Engines

Before describing inboard and sterndrive engine types, a distinction between propulsion and auxiliary engines should be made. Marine propulsion engines act to move the boat by impeller (in the case of jet-drives) or propeller. Marine auxiliary engines are those used for power generation or deck winch operation. For sailboats, the term “auxiliary engine” also refers to a small propulsion engine, either inboard/propeller or sterndrive/propeller, which is meant for use in times of low wind. The greatest number of marine auxiliary engines are small diesels used on sailboats. Under California’s land-based off-road engine regulations, the emissions of auxiliary and propulsion diesel marine engines below 50 horsepower (hp) are controlled. Likewise, non-propulsion gasoline marine engines are regulated under California’s small (below 25 hp) off-road engine regulations, and large (25 hp and greater) off-road engine regulations. Thus auxiliary engines are subject to existing emission requirements, and are not addressed in this proposed regulation.

Propulsion engines can be mounted outboard, on the boat’s rear transom wall, or inboard. Outboard engines are specially designed to be self-contained, and to have a high power-to-weight ratio. This means they are traditionally two-stroke combustion-cycle gasoline engines (although four-stroke outboards are becoming increasingly available). Inboard and sterndrive engines, on the other hand, are most commonly derived from V-8 or V-6 automotive gasoline engines. In the simplest inboard design, the engine drives a long, straight propeller shaft. This is the oldest historical design and it remains popular today. With sterndrive boats, the engine is situated inboard in the extreme rear-end of the boat, with the S-shaped transmission external to the boat. They are sometimes referred to as “inboard-outboards” for this reason.

The mode of propulsion of motor boats is mostly by propeller, although the use of water jet drive is also common. Personal watercraft use two-stroke modified outboard engines or marinized snowmobile engines to drive water jet-drive pumps. These are available up to 155 hp. Increasingly they are used in small boats, some with two such engines installed. Automotive-derived engines used in inboard boats can also drive jet-pumps.

Provided below are illustrations showing the different inboard boat drive types, that are subject to this regulation. Figure 1 shows the profile of an inboard propeller-drive ski boat. Figure 2 provides a “bird’s-eye” view of engine compartment location at the center of the boat. The propeller is under the boat, so with the boat in the water no propeller would be visible. The engine is typically placed about half way between the bow and stern of the boat, near the balance point.

Figure 1
Profile of an Inboard-engine Propeller Boat

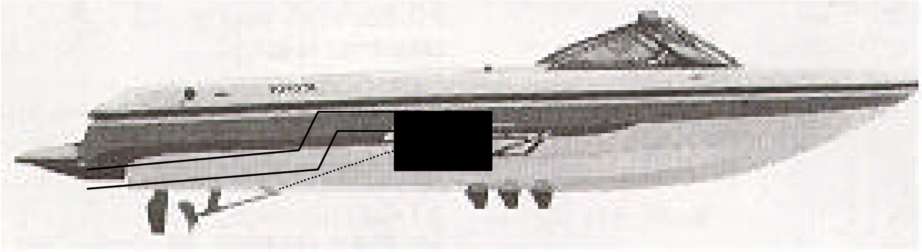


Figure 2
View of Inboard Engine Compartment

The left- and right-bank exhaust pipes are routed below the floor to the rear (transom), exiting just above water level. With this design, the propeller, shaft, gear box, and exhaust system are fitted by the boat builder. In contrast, for the sterndrive package, the entire assembly comes with the engine.

Figure 3 shows an x-ray view of an inboard vee-drive. It is referred to as a vee-drive because the engine is placed at the extreme rear end of the boat but faces backward with the shaft-end toward the front, forming the shape of a “vee.” This placement allows more room in the boat unobstructed by an engine compartment. The exhaust in this configuration is also routed through the transom.

Figure 3
Schematic of an Inboard Vee-drive

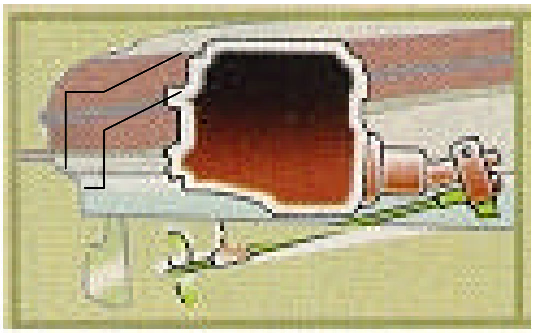


Figure 4 shows the side view of a sterndrive engine with drive attached. The engine is located at the extreme rear end of the boat. The slanted wall to the right of the black engine is the transom of the boat. The drive protrudes well below the bottom of the boat. The engine exhaust for most size engines flows out of the two manifolds (one on each side) through the exhaust riser, into the drive, and out through the propeller center hub. With this design, the engine and drive come as a package; the boat builder is not responsible for the design and fabrication of the exhaust system.

Figure 5 shows a jet-drive (without the engine attached). It would be installed at the rear of the boat where the shaft of a sterndrive would protrude. The drive is basically a water pump. The water inlet is at the bottom (lower left of figure) and is open through the bottom of the boat. The water jet comes out of the external end of the pump (right center in figure). In the figure, the nozzle is covered by a gate valve (lettered “Legend”). The valve is in the closed (covered) position, which provides reverse thrust. When it is open, the water jet moves the boat forward. The engine would be located in the extreme rear end of the boat, like a sterndrive, but the exhaust pipes would exit through (or above) the transom wall.

Figure 4
Side View of Sterndrive engine with Drive

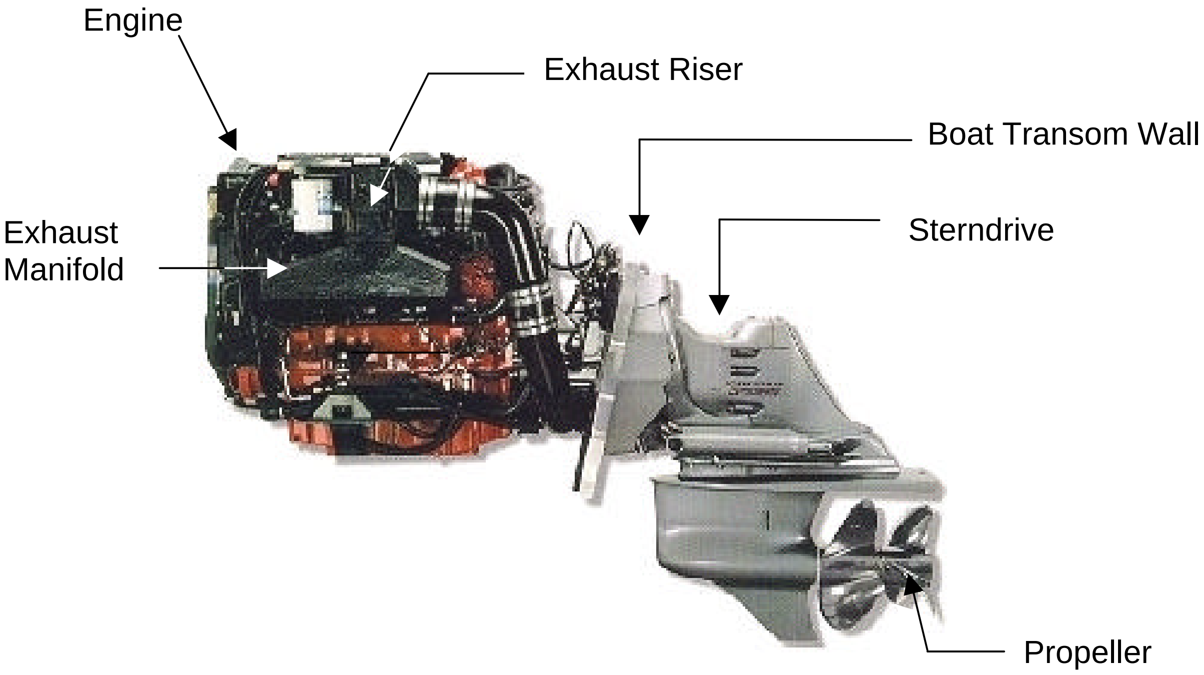
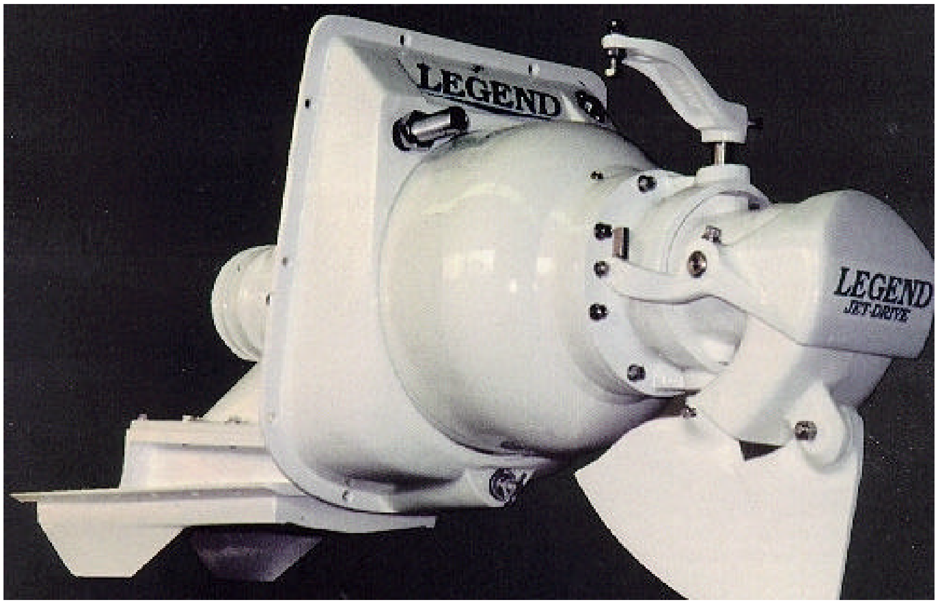


Figure 5
Jet-drive



B. Marinization

Gasoline inboard and sterndrive marine engines are automobile (or truck) engines adapted for use in boats. They are typically cast-iron four-stroke engines. The engine-out emissions characteristics of inboard and sterndrive marine engines are essentially the same as automobile engines (non-catalytic converter equipped). They have relatively high emissions.

In this report we refer to the engine marinizers as "engine manufacturers" because they are responsible for the final engine configuration which is installed in the boat. The marinizers receive the engines from a supplier, such as General Motors, and modify them for use in boats. A list of the major players in the different facets of the boat-building process is given in Table 1. The marinization process typically involves adding a raw-water cooling system, water-cooled and wetted exhaust system, leak-resistant fuel lines, corrosion-resistant and spark-resistant starter, alternator, and fuel pump. For carbureted and throttle-body fuel-injected engines, the engine manufacturers add an intake manifold and a carburetor or throttle-body. The engine manufacturers add an engine control module (on-board computer) to accommodate a marine air-fuel calibration. The marine versions of the automotive engines can also have a different camshaft and more corrosion-resistant head gaskets. A further description of the two main unique characteristics of a marinized engine, its exhaust system and its calibration/operating conditions, is provided below.

Table 1

Inboard/Sterndrive Powerboat Industry

Engine Suppliers	Engine Manufacturers or marinizers	Boat builders
General Motors	MerCruiser	Bayliner Yachts
Ford Motor Co	Volvo Penta	Chris-Craft
Toyota	Indmar	Larson
	Marine Power	Malibu Boats
	Pleasure Craft Marine	Sea-ray

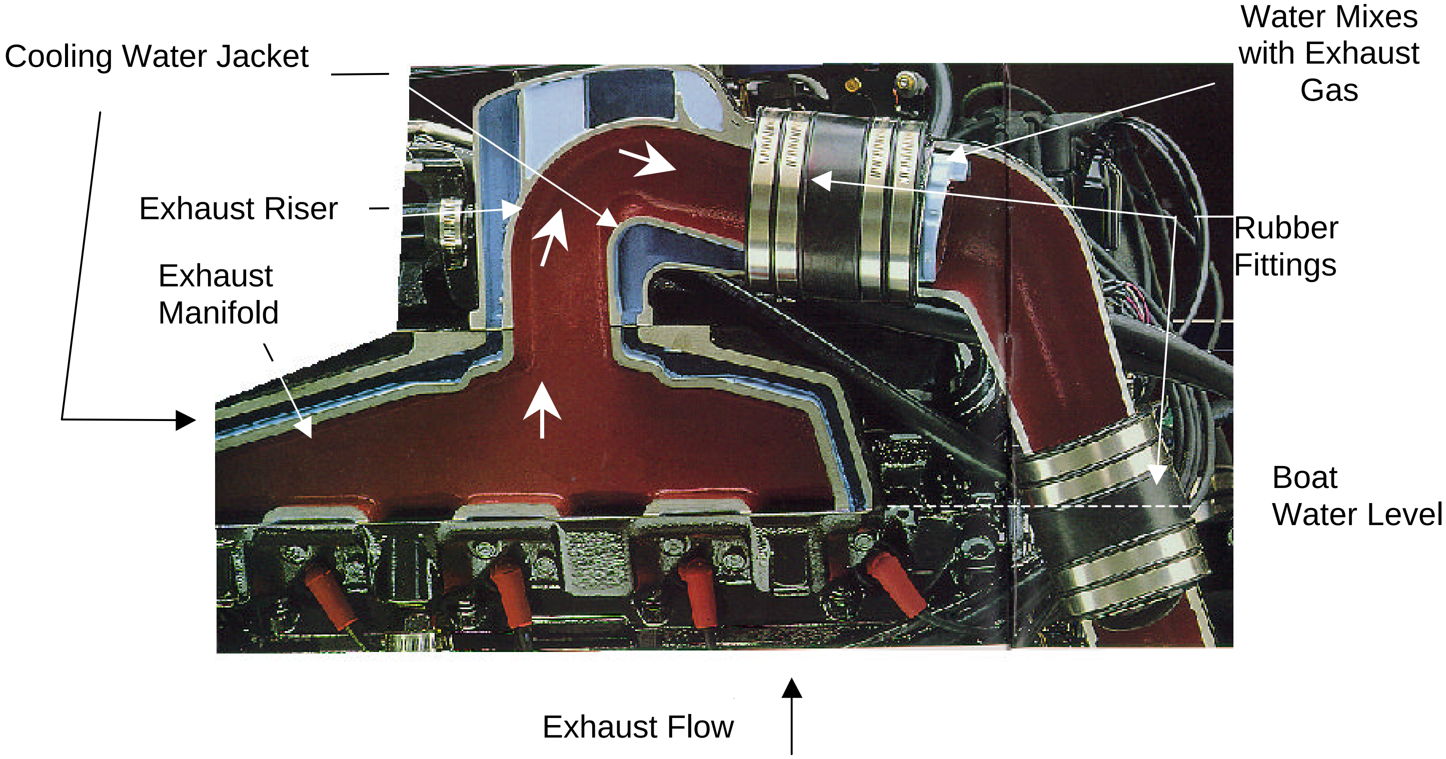
These lists are not all-inclusive.

1. Exhaust System

The engine exhaust in boats is treated differently than land-based engines. For the majority of inboards, the engine exhaust is ducted horizontally to the rear of the boat and passes through the transom, exiting just above the water line. In sterndrive and outboard engines, the engine exhaust is ducted through the lower propeller shaft and exits below water through the propeller hub. In all these drive-systems "used" cooling water is added to the exhaust gases inside the exhaust pipes, and exits with the exhaust gases as a spray. This is done primarily for safety reasons, to minimize heat generation from otherwise hot exhaust pipes within a confined engine compartment.

Figure 6 shows a cut-away view of a typical sterndrive exhaust system configuration. After exiting the exhaust manifold the exhaust gases are ducted up for a short distance through the exhaust riser before reversing direction and being ducted downward. The static water level in the boat is approximately even with the bottom of the exhaust manifold in the photo. This means that lake or sea water will fill the exhaust pipe when the engine is off up to approximately the middle of the rubber coupling on the right lower corner of the photo. Thus, the riser provides a labyrinth or seal which protects against the outside water traveling back up the exhaust pipe into the engine cylinders. The riser is typically water-jacketed. It is in the down leg or elbow that the water is directly mixed with the exhaust gases. After this point the exhaust gases are cool enough so that rubber pipes and joints can be used for the exhaust pipes.

Figure 6
Cut-away view of marine exhaust manifold



2 Calibration/Operating Conditions

Marine versions of automobile engines are usually operated at high speeds (wide-open throttle) for sustained periods of time. The basic automotive engine is designed for more low and medium-speed operation than for sustained, very high speeds. As an example of how an engine can differ depending on its application, a 350 cubic inch displacement engine used in a Chevrolet truck is rated at 255 hp at 4600 rpm. The industrial version of this engine used in forklifts is governed to 3000 rpm where it develops 201 hp. But the marine version is rated at 307 hp at 5000 rpm. Thus, marine engines are uniquely adapted and rated for the marine environment. In addition to unique camshaft designs, adequate cooling is critical. The air-fuel mixture is purposefully richened (using more fuel for the given rate of air) to limit oxidation of the carbon in the fuel, resulting in lower heat release and combustion temperatures, and large amounts of carbon monoxide (CO).

C. Emissions Inventory

Since the adoption of the 1994 SIP, the emissions inventory for marine engines has been updated. Table 2 below identifies the marine engine contribution to HC, CO, and NOx in California based on a typical summer weekend. Summer weekend values are shown because recreational boat usage is highly concentrated during these times, contemporaneous with the height of photochemical ozone production.

Table 2

Aggregate Marine Vessel Emissions

	Population, 2010	HC, TPD	NOx, TPD
Outboards	371,200	116	7
PWC	293,485	84	29
Inboards	124,200	30	40
Sterndrives	262,300	37	46
Recreational Diesels	12,200	4	11
Sail Auxiliary	11,400		
Commercial Diesels	*	10	109

Sources: (ARB 1998c), ARB OFFROAD model, ARB emission inventory website, this work. Summer weekend averages shown. The inboard and sterndrive entries do not include the effect of this proposal.

*7,200 berthed boats plus19,000 port visits per year (Booz Allen Hamilton, 1992).

As shown, the gasoline engines are much more numerous than the large commercial diesel engines (however they are not used nearly to the extent that the commercial diesel engines are). Also note that the two-stroke outboards and personal watercraft are the largest hydrocarbon sources. This is why they were targeted for control measures from U.S. EPA starting in 1998, and ARB starting in 2001. Additional reductions, beyond 2010, will occur when the regulations are fully implemented. The table also shows that the commercial diesels are the primary source of NOx emissions among the marine engines. This is why U.S. EPA targeted them for control starting in 2004. This leaves the recreational gasoline and diesel inboard and sterndrive categories as the next significant source of emissions. In particular, inboard and sterndrive engines, collectively, account for about 25% of the marine vessel HC inventory.

D. Outboard Engine Regulation

The 1994 SIP counted on U.S. EPA to adopt exhaust emission standards for outboards and personal watercraft (SIP measure M16). The standards, which phase-in between 1998 and 2006, ultimately require a 75% HC reduction for new engines. In 1998, ARB adopted regulations requiring outboard and personal watercraft engine manufacturers to meet the 2006 U.S. EPA standards five years earlier (*i.e.*, in 2001) and more stringent standards in 2008. Table 3 below compares the Federal and California phased-in exhaust emission standards for a 75-kilowatt (100 horsepower) outboard marine engine, the size of the typical personal watercraft engine.

Table 3

New Outboard Engine Emission Standards

	Federal $HC+NO_x$ g/kW-hr*	California $HC+NO_x$ g/kW-hr
1998	151	—
1999	138	—
2000	125	—
2001	113	47
2002	99	47
2003	86	47
2004	72	36
2005	60	36
2006	47	36
2007	47	36
2008	47	16

*grams per kilowatt-hour

E. Federal and International Regulations

1. Federal Standards

The U.S. EPA recently issued an Advanced Notice of Proposed Rulemaking for recreational marine diesel and inboard and sterndrive gasoline engine emissions (65 FR 76797). The recreational diesel requirements are similar to the commercial diesel requirements[1]. The proposed U.S. EPA inboard and sterndrive gasoline engine emission requirements are in the range of 9-10 g/kW-hr HC+NOx for engines near-term, and 5-7 g/kW-hr HC+NOx for engines with catalysts long-term. ARB and U.S. EPA are working together to set harmonized national emission requirements. It is anticipated that the U.S. EPA will promulgate standards similar to those proposed by staff. However, the U.S. EPA standards will probably lag the ARB-proposed implementation dates.

2. Swiss (BSO) Standards

A multi-country group (Switzerland, Germany, and Austria) regulates boat traffic on Lake Constance. The group is called the International Shipping Commission. They originally passed the *Bodensee Schiffahrts Ordnung* (BSO) in 1976. It dealt originally with traffic rules and boat equipment on Lake Constance. In 1992, boat-engine emission standards were added to the BSO.

Beginning in 1993, boat usage on the lake was contingent on the boat owner possessing certification from the boat/engine manufacturer stating that the engine(s) emit less than the “Stage 1” standards. Pre-1993 boats were exempted. The test cycle used to demonstrate compliance is the BSO steady-state 9-mode test cycle. The BSO test cycle is similar to ARB’s proposed E4 test cycle (ISO 8178 E-4), to be discussed later in this report. The average power (weighted) on the BSO test cycle is 32%, as contrasted to 21% on the E4 test cycle. The E4 HC results are expected to be 8 to 10% higher than BSO hydrocarbon results.

The standards for 1993 (Stage 1) range from 4 to 5 g/kW-hr for HC (depending on engine power) and 15 g/kW-hr for NO_x. These apply to outboards and inboards, diesel or gasoline, commercial or recreational boats. In addition, all gasoline boats (and recreational diesels) have absolute mass emission rates (in grams per hour), which may not be exceeded. Diesel engines have a “smoke number” standard, whereby a white filter paper is measured for discoloration due to exposure to the exhaust.

Effective January 1996 on Lake Constance, the standards became so low as to preclude two-stroke outboards, and to require the use of catalysts on four-stroke

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[1] The U.S. EPA-promulgated emission requirements for commercial diesel marine engines begin in 2004 (40 CFR Part 94). The regulations apply only to captive U.S.-flagged vessels with engines less than 30 liters per cylinder in displacement.

gasoline inboard and sterndrive engines. The standards vary according to the engine power rating, but a typical 120-kilowatt (165-horsepower) inboard or sterndrive engine is required to meet a 1.3 g/kW-hr standard for HC and a 3.7 g/kW-hr standard for NO_x. The standards for a very high-output inboard or sterndrive engine (300 kilowatts/400 horsepower) are 1.0 g/kW-hr for HC and 3.8 g/kW-hr for NO_x. No gasoline engines are available to meet these standards at this time, and the only boats operating on that lake are “grandfathered” pre-1993 boats.

3. European Standards

The European Community (EC) is now developing recreational marine engine emission standards. The latest information is that standards for two-stroke gasoline engines would be phased-in in 2003. For a 50-kilowatt two-stroke engine, combining the HC and NO_x emission standards yields a total of 31 g/kW-hr. This is more stringent than California’s 2004 outboard standard of 38 g/kW-hr for a similar sized engine, but less stringent than California’s 2008 standards (16 g/kW-hr). For inboard and sterndrive engines, however, the EC standards are not as stringent as the BSO standards or the staff’s proposed standards. Again, combining EC standards for HC and NO_x, a 300-kilowatt inboard engine would be required to meet 21 g/kW-hr. Such an emission level is attainable by virtually all currently available engines.

F. Cooperative Test Program

The U.S. EPA and the ARB have been working together for the last year and half to

- demonstrate catalyst controlled emission levels on a marine engine in the laboratory and
- design and test an exhaust system on a boat which would minimize water ingestion/accumulation.

Members of the National Marine Manufacturers’ Association (NMMA) donated engines, exhaust manifolds, engine control modules and air-fuel programs, closed cooling-systems, and replacement parts in support of the laboratory engine-testing effort. Members of the Manufacturers of Emission Controls Association (MECA) donated seven sets of candidate catalysts which were specially prepared, sized and fabricated for this program. In addition, NMMA members donated a boat, spare engine, and exhaust manifolds for the boat exhaust-testing project. This testing was performed at Southwest Research Institute in San Antonio, Texas.

The catalyst-testing program found that catalysts can achieve the approximately 70% reduction of HC+NOx proposed in these regulations with no or minimal engine performance degradation, and with no overheating or safety concerns.

The in-boat water ingestion project showed that condensation on cold exhaust manifolds was the main source of water accumulation, and that incorporating a thermostat on the cooling water to the exhaust manifolds eliminated the water accumulation.

As part of the industry meeting on March 15, 2001, ARB, U.S. EPA, NMMA and MECA agreed to participate in an in-boat catalyst-controlled engine test program. The NMMA members agreed to donate 6 boats. General Motors will donate the engines for the boats. MECA members agreed to donate candidate catalyst designs. The boats will be run through various typical and demanding procedures on both fresh water and salt water, will accumulate 480 hours of service, and will undergo emission tests at various time intervals. The goal of the project is to address issues of durability, operability, and safety.

III. NEED FOR CONTROL

ARB's efforts to control emissions from engines are, in large measure, in response to the need to control ground-level ozone exceedances in urban areas.

Ozone, created by the photochemical reaction of HC and NO_x, causes harmful respiratory effects, including chest pain, coughing, and shortness of breath, affecting people with compromised respiratory systems and children most severely. In addition, NO_x itself (specifically nitrogen dioxide) can directly harm human health. Beyond their human health effects, other negative environmental effects are also associated with NO_x and ozone. For example, ozone injures plants and building materials. NO_x contributes to the secondary formation of particulate matter (PM) in the form of aerosol nitrates, contributing to acid deposition, and exacerbating excessive growth of algae in coastal estuaries.

California has made significant progress in controlling ozone. Statewide exposure to unhealthful ozone concentrations has been cut in half since 1980. The frequency and severity of pollution episodes is declining, and emissions are on a downward trend. More needs to be done, however, to reach state and federal health-based air quality standards for ozone and particulate matter. Nearly all Californians breathe air with concentrations exceeding one or more of these standards.

The 1994 Ozone SIP is California's plan for attaining the federal one-hour ozone standard. The SIP calls for new measures to reduce emissions of ozone precursors from mobile sources to about half of the rate allowed under regulations existing in 1994. Staff is developing a new "Clean Air Plan" to address all the State and federal air quality requirements including air toxics. Further emission reductions will likely be necessary to attain the goals of the new plan.

The SIP commitment to reduce emissions from gasoline inboard and sterndrive engines is 2 tons per day of ROG reductions in the South Coast Air Basin by 2010, to have been brought about by U.S. EPA adopting an emission regulation requiring 35% reduction of inboard and sterndrive engine emissions starting in 1996. U.S. EPA has not yet adopted this rule, concentrating first on the two-stroke outboard engines instead.

The ARB has been threatened with litigation over shortfalls of emission reductions promised in the SIP. ARB has entered into a settlement agreement as a result of the threatened suit. It calls for this proposed measure to be adopted in 2001 to result in 3 tons per day of HC reduction (in SIP currency, *i.e.* consistent with the inventory in place in 1994) in the South Coast Air Basin by 2010. Actual reductions will be larger as discussed later in this report, because emissions from inboard and sterndrive engines are known to be greater than thought in 1994, and because their use is concentrated on weekend days when the highest levels of ozone are experienced.

In addition to providing needed emission reductions in the South Coast Air Basin, the proposed marine engine regulations will also help achieve and maintain:

- The federal 1-hour ozone standard in regions such as the San Joaquin Valley and the Sacramento area,
- The federal 8-hour ozone and particulate matter standards in a number of areas,
- And the State ozone and particulate matter standards throughout California.

IV. SUMMARY OF PROPOSAL

A. Introduction

Currently, California’s gasoline marine engine regulations, which affect outboard engines and personal watercraft, consist of exhaust emission standards, certification test procedures, new-engine and in-use-engine compliance provisions, consumer provisions such as environmental labeling, and warranty requirements for engines used in personal watercraft and outboards. The proposed regulation described in this report would establish comparable requirements for gasoline inboard and sterndrive marine engine.

In crafting this proposal, ARB staff met with various stakeholders. Individual and group meetings took place from April 2000 through May 2001, including a general public workshop on September 19, 2000, and an industry meeting on March 15, 2001. The U.S. EPA participated in both the September and March meetings. During the development of this proposal, staff visited two engine manufacturing plants and one boat-builder. At the meeting in March, the manufacturers, catalyst vendors, Coast Guard, ARB and U.S. EPA worked out a cooperative in-boat testing program, and a two-phase set of emission standards. Staff met with the California State Department of Boating and Waterways and the Boating and Waterways Commission to discuss safety concerns of catalyst-equipped engines on boats. This proposal incorporates many of the comments and suggestions of all interested parties.

The following is a brief summary of each element of this regulatory proposal. A more detailed discussion, including a description of the provisions and an explanation of the intent, follows in Section V. The amended text of California's gasoline marine engine regulations is contained in Attachment A. Attachment B contains the amended text of the Test Procedures.

B. Applicability

The proposed regulation applies to new gasoline inboard and sterndrive marine engines produced for model-year 2003 and later, with exceptions provided for competition racing boats. With adoption of this proposal, all gasoline engines except for those in airplanes, snowmobiles, and on-road motorcycles with engine displacements less than 50 cubic centimeters will be subject to emission standards. Diesel engines used as recreational marine propulsion engines are excluded from these regulations. Marine diesel engines less than 50 horsepower are subject to existing off-road diesel engine standards. It is anticipated that federal regulations will be promulgated in 2002 to cover marine diesel engines over 50 horsepower.

C. Definitions

The definitions included in this proposal are consistent with both the California and the U.S. EPA gasoline marine engine rulemakings for personal watercraft and outboards. However, additional definitions have been added for program elements specific to the proposed on-board diagnostic system. "Small-volume manufacturer" and "competition" have also been defined in terms specific to this proposal.

D. Emission Standards and Test Procedures

1. Emission Standards

The staff proposes an $HC+NO_x$ emission standard beginning in 2003. A more stringent $HC+NO_x$ emission standard would be phased-in between 2007 and 2009. The standards are shown in Table 4.

The standards were selected to provide industry with flexibility regarding the choice of technology for compliance; however, staff anticipates that in order to meet the 2003 emission standards the manufacturers can either use present-day air-fuel ratio calibrations or the leaner air-fuel calibration designed to meet the European standards, and the 2007 standards will require the use of three-way catalysts with closed-loop air-fuel control.

Table 4
Inboard and Sterndrive Emission Standards

Model Year	HC+NOx Emission Standard g/kW-hr
2003	15.0*
2007**	5.0

* This standard applies to an engine manufacturer's engines, on a sales-weighted corporate average basis.

** 10% of California sales must comply with this standard in 2007. 50% of sales must comply in 2008. 100% of sales must comply in 2009.

The staff proposes to phase-in the more stringent, catalyst-based exhaust emission standards for inboard and sterndrive marine engines commencing in the 2007 model-year. Manufacturers will be required to introduce one engine family representing at least 10% of California sales in 2007. In 2008, the manufacturers will be required to produce 50% of their California sales as complying models. With the 2009 model year, all new engines produced for sale in California will be subject to the emission standards.

The proposed regulation allows no emissions to be emitted from the crankcase of these engines into the ambient atmosphere.

Small-volume manufacturers and engines over 500 horsepower would not have to comply with the standards until 2009.

2. Test Procedures

The ARB adopted the ISO 8178-4 E4 test cycle for recreational marine gasoline personal watercraft and outboard engines. Staff is proposing to use that test procedure for inboard and sterndrive engines also.

E. Certification and Environmental Labels

For new 2003 and later gasoline marine inboard and sterndrive engines sold in California, staff proposes the same labeling requirements as for outboards:

(1) an engine label, and
(2) an environmental label.

The engine label would be permanently affixed to the engine and would serve to denote a California-certified gasoline marine engine.

The environmental label, placed on the boat, would provide prospective engine owners, current engine owners, and enforcement personnel with information about the relative cleanliness of the engine, according to the Air Resources Board's standards. Staff is proposing to add a 4-star label to the regulations for inboard and sterndrive engines complying with the proposed 2007 standards.

F. Selective Enforcement Audit Testing

The proposal would implement selective enforcement audit (SEA) testing beginning in 2003. The proposed SEA testing is procedurally identical to the SEA program that is used by the U.S. EPA and, as that name implies, would be used when the Executive Officer has reason to believe that the emissions of the engines being produced may exceed the standards. Since SEA testing can be imposed on the engine manufacturer at any time and under short notice, manufacturers are more likely to ensure that their production engines are built exactly as certified, rather than risk the potential noncompliance.

G. In-Use Compliance Program

Compliance with the proposed regulations would require manufacturers to demonstrate that their post-2008 engines will comply with the emission standards throughout their certification life of 480 hours or ten years, whichever first occurs. To ensure that these certified engines are meeting the emission standards throughout their certification lives when properly maintained, staff proposes to incorporate California's existing in-use testing program for inboard and sterndrive engines. This testing program has a longstanding history with on-road mobile sources, and more recently has been incorporated into off-road rulemakings, such as those for off-road motorcycles and large off-road compression-ignition engines. Testing under this program is typically ordered and performed by ARB when there is evidence to indicate a possibility of noncompliance.

H. Defects Warranty Provisions and Emission Control Warranty Statement

Staff expects engine manufacturers to ensure the engines they build have emission-related components that are reliable, durable and capable of complying with the applicable emission standards for the useful life of the engine. It is believed that an adequate defects warranty acts as an incentive for both the engine manufacturers and the part suppliers alike to produce an overall high-quality product. Staff, therefore, proposes a two-year emissions defects warranty for inboard and sterndrive engines starting in 2003, increasing to three years in 2009. Currently, most inboard and sterndrive engines are warranted by the manufacturer for one to two years. For comparison, the emission warranty for a comparable car engine is three years, with higher cost parts warranted for seven years.

I. On-board Diagnostics

In order to keep the emission control system working at optimum levels of efficiency, staff is proposing that 2007 and later inboard and sterndrive marine engines meeting the 5.0 g/kW-hr HC+NOx emission standard be equipped with an on-board diagnostics marine (OBD-M) system. The OBD-M system will be responsible for monitoring the catalyst, oxygen sensor, fuel system, and comprehensive components (sensor and solenoids) for proper operation in-use. Staff is also proposing that misfire monitoring be required on 2009 and later engines. In case of malfunction, a light or other indicator would be illuminated or activated on 2009 and later engines.

V. DISCUSSION OF PROPOSAL

A. Applicability

The proposal would require compliance with applicable emission standards and other requirements for all gasoline inboard and sterndrive marine engines. All other gasoline marine engines, and diesel engines under 50 horsepower, are already subject to emission requirements.

B. Definitions

The definition “used solely for competition” is incorporated into the staff proposal and uses regulatory language that harmonizes with U.S. EPA’s diesel commercial marine rule. Harmonization, where possible, is beneficial to industry because it establishes one set of requirements.

The ARB is precluded from regulating racing vehicles (Health & Safety Code §43001(a)). This statutory prohibition does not directly apply to competition boats. Staff believes that the intent of the statutory exemption is to be consistent for all mobile sources, vehicles, and mobile engines, and that the statutory language changes are lagging. Therefore staff is proposing to exempt competition engines so designated by the engine manufacturer. The criteria for this exemption are taken from U.S. EPA's 1999 final rulemaking for diesel marine engines (64 FR 73305), as extended to marine engine manufacturers. They are:

- Exhibiting features which make non-competition use unsafe, impractical, or unlikely; for example the presence of superchargers, or a highly reduced recommended rebuild interval.
- The vessel is registered with a nationally recognized organization that sanctions professional competitive events.

In order to offer flexibility, staff has also incorporated the definition of a "small-volume manufacturer" for purposes of identifying those manufacturers that would be eligible to delay certification and compliance requirements until 2009. A small-volume manufacturer is defined as an engine manufacturer with less than 2000 inboard and sterndrive engine sales per year nationwide. Thus, by 2009, the production of all California inboard and sterndrive engines would be emission-compliant.

Small-volume manufacturers will be required to "certify" on an annual basis. The process is expected to be very simple. The manufacturer would provide U.S. inboard and sterndrive sales from past and future years and descriptions of engines intended for sale into California to the Executive Officer.

C. Emission Standards and Test Procedures

Marine inboard and sterndrive gasoline engines are essentially automobile or truck engines adapted for use in boats. As derivatives of automobile engines, the engines are well suited for the use of automotive controls. There already exist compatible exhaust aftertreatment systems and electronic control systems. Staff relied on the emission reduction capability of this technology (closed-loop fuel control, three-way exhaust catalyst) as demonstrated on a laboratory test engine to develop the proposed 2007 emission standard of 5.0 g/kW-hr HC+NOx (3.7 g/hp-hr) for gasoline inboard and sterndrive engines. A summary of data used by staff is provided below.

1. Summary of Emissions Tests

ARB staff has gathered emission data using the E4 test cycle from the U.S. EPA (who performed in-house tests) and Mercury Marine. These data are shown in Attachment C to this staff report. The data show that carbureted uncontrolled (new) engines produce emissions of about 8 g/kW-hr HC and 6 g/kW-hr NOx, and rich-calibration (open-loop) electronically fuel-injected (EFI) engines produce emissions of about 5 g/kW-hr HC and 10 g/kW-hr NOx. Since about 1997, the engine makers have been phasing out production of carbureted engines. Currently, however, the existing fleet of gasoline inboard and sterndrive engines is still largely composed of carbureted engines. It is expected that all new marine engines will be electronic multi-point fuel-injected by 2005. Some manufacturers have been recalibrating their engines in response to the European standards which are proposed to take effect in 2002. Some manufacturers are expected to sell these recalibrated engines in the United States even though they are not yet required to meet the emission levels. The average of the emission results for these engines is 3.5 g/kW-hr HC and 13.0 g/kW-hr NOx on the E4 cycle. The population this was based on was not extensive, and the calibrations were not optimized.

2. Engine Test Program

The ARB and U.S. EPA have been testing and developing a catalyst-equipped, oxygen-feedback electronically fuel-controlled marine engine. The data and the experimental set-up are described and shown in Attachment C. GM Powertrain and Mercury Marine each donated 454 cubic-inch displacement engines and Southwest Research Institute installed, optimized, and evaluated the performance of the various control schemes. Engelhard and DCL International have developed and donated candidate catalysts.

Various combinations of stoichiometric air-fuel control (performed with exhaust oxygen sensing, and feedback to the electronic engine control module), exhaust gas recirculation, and three-way exhaust catalysts have been tested. The most successful combinations were a set of 1.7-liter space-unlimited catalysts placed horizontally downstream of the exhaust riser, and a set of compact 0.8-liter catalysts placed vertically in the exhaust riser. Both candidates had good HC+NOx conversion, were integrated with the engine’s water cooling system, and did not unacceptably affect the engine’s operating properties or size.

With twin 1.7-liter catalysts installed on the engine with oxygen-feedback stoichiometric air-fuel control, a composite emission rate of 3.2 g/kW-hr HC+NOx was achieved. The engine, in its baseline configuration (*i.e.*, without a catalyst or stoichiometric air-fuel control), produced emission levels of 12.9 g/kW-hr HC+NOx. Adding exhaust gas recirculation to the catalyst-controlled engine, 3.0 g/kW-hr HC+NOx was achieved. The large, space-unlimited 1.7-liter catalysts, placed close to the water-mixing point in the exhaust pipes, resulted in no power degradation of the engine. Another set of compact 0.8-liter catalysts, placed well upstream of the water mixing point in the exhaust pipes, achieved composite emission results of 3.6 g/kW-hr HC+NOx and resulted in a power loss of the engine of about 6 kW (from 219 kW base-engine to 213 kW with catalysts). This corresponds to a base-engine exhaust backpressure at full power of 10 inches of mercury gauge, and a backpressure with catalysts of 14 inches of mercury gauge. This is a relatively small, acceptable power loss, and a correspondingly acceptable backpressure increase.

The compact catalyst design alternative represents a compromise between catalyst vessel inside cross-sectional flow area, outside dimensions, and the amount or volume of precious metal catalyst. The size of the compact catalysts was chosen to keep the engine width approximately the same as a standard engine, but instead increasing the height of the engine "envelope" by six inches. This was the same increase of dimensions as obtained from installing commonly available exhaust riser extensions. Keeping the catalyst width to be the same as the rest of the exhaust system results in a high exhaust flow-velocity (due to a small exhaust-pipe inner cross-sectional area). This can lead to engine power degradation due to the increased resistance-to-flow of the exhaust gases leaving the engine. The other dimensional constraint on the catalyst is the interfacial area available to contact the exhaust gases, which is directly proportional to the internal volume (length times cross-sectional area) and proportional to the substrate cell spacing to the one-half power. The normal 7.4-liter engine in a truck would have a single catalyst vessel of about 3 liters in volume. The two rectangular riser catalysts we tried were about one-quarter of this size combined. The expanded diameter cylindrical riser catalysts were about half of this volume combined.

3. Proposed Standards

<u>2003 Emission Standards</u>: The 2003 emission standard was selected to maintain the current average emission level from inboard and sterndrive marine engines. Staff is proposing an HC+NOx cap of 15 g/kW-hr starting in 2003. Staff estimates that in 2003 half the inboard and sterndrive sales will be carbureted and half will be fuel-injected. To achieve the proposed 2003 cap standards, the engine manufacturers can use their present-day air-fuel ratio calibration or can use the leaner calibrations developed for the European standards. Thus, the need for additional hardware or recalibration to comply with the proposed standards is not expected.

The objective of the HC+NOx emission cap is to assure that NOx emissions do not increase excessively due to air-fuel ratio enleanment. In the absence of the cap, excess enleanment could increase NOx emissions beyond what is necessary, and result in a net increase in HC+NOx relative to the baseline. The proposed cap is set just above the current inboard and sterndrive marine engine HC+NOx levels of 14 and 14.6 g/kW-hr HC+NOx for carbureted and fuel-injected designs, respectively, as shown in Table 5 below. Test data indicate that lean-calibration (European-compliant) engines may have HC+NOx emission levels ranging from 14 to 16 g/kW-hr, which can be corporate-averaged with lower-emitting engines to meet the proposed cap. Thus, this standard will provide California with assurance that ozone precursor emissions will not increase over current levels.

Table 5

Expected Candidate Engine Emissions

	HC g/kW-hr	NOx g/kW-hr	HC+NOx g/kW-hr
Baseline Carbureted	7.8	6.2	14.0
Baseline Electronically Fuel-injected	4.7	9.9	14.6
Lean Calibration, Carbureted	2.5	11.7	14.2
Lean Calibration, EFI	2.8	13.6	16.4

Figures shown are for new engines
EFI means electronically fuel-injected

These 2003 emission standards are more stringent than the standards under consideration in Europe in 2002 (approximately 19 g/kW-hr HC+NOx), for which the engine manufacturers have been preparing and offering complying engines and retrofit kits since 1993. However, the proposed European standards have a relatively stringent CO standard of 60 g/kW-hr, which tends to drive emission results to undercut the proposed European HC standard of 4.0 to 4.5 g/kW-hr, with higher NOx. The European standards are based on a different test cycle (the BSO 9-mode cycle) than our proposed test cycle (the 5-mode E4 cycle) and the standards vary based on the power of the engine. In addition, HC results on the E4 test-cycle are about 10% higher than HC results using the BSO cycle. Staff is proposing to allow the manufacturers to average their emission results across their product lines, allowing some high models as long as there is an offsetting number of low models.

2007 Standard. The proposed 2007 emission standard for inboard and sterndrive engines is 5 g/kW-hr HC+NOx. The uncontrolled levels are about 15 g/kW-hr HC+NOx, so this represents a nominal 67% reduction. Emission testing at Southwest Research Institute with automotive-style catalysts achieved 3 to 4 g/kW-hr HC+NOx. Since 1996, the Swiss have required boats on Lake Constance to meet about 6 g/kW-hr HC+NOx. Large off-road gasoline engines sold in California this year will be meeting 4 g/kW-hr HC+NOx. A level of 5 g/kW-hr HC+NOx represents a significant reduction from the uncontrolled level, but one which is still higher than the best achievable. This was done in recognition that our test engine might represent the worst-case engine, that other engines might not perform as well, and to allow for aging (deterioration of emission conversion) in service (emission tests were performed with new (green) catalysts).

The proposal does not contain CO standards for inboard marine engines. Nevertheless, the application of feedback catalyst control to these engines is expected to result in a 50% reduction of carbon monoxide emissions over uncontrolled engines.

Improvements in catalyst conversion efficiency could likely be achieved with greater catalyst volumes and precious-metal loading. However, one of the test modes is wide-open throttle full speed, and air-fuel ratios must be rich to prolong engine life of these engines in this condition. In addition, an oxidizing catalyst is ineffective in this condition because of lack of oxygen reactant. This mode alone contributes approximately 0.7 g/kW-hr of HC to the weighted E4 results, thus levels below 1 g/kW-hr HC+NOx are probably unachievable with conventional gasoline engine designs.

<u>Compliance Period</u>: The proposal requires that engines meet the 2007 model year emission standard for 480 hours. This represents about 7 years of average use--a lower compliance period compared to other off-road categories. The shorter compliance period is proposed because marine engines typically operate under a unique duty cycle (wide-open throttle for sustained periods of time) and this leads to a shorter engine life.

<u>Expected deterioration</u>: Certification emission test-results from a new engine will have a “deterioration factor” added or applied to it to account for growth of emissions by the age of 480 hours. The manufacturers determine the deterioration factor from tests or from good engineering judgment. Estimates obtained from engine manufacturers indicate that HC+NOx emissions will likely increase by about 20% over 480 hours of operation on the water.

4. Phase-in

The proposal requires that 10% of each manufacturer’s engine sales must comply with 5.0 g/kW-hr HC+NOx in 2007, 50% in 2008, and 100% in 2009. This will allow manufacturers to resolve any unforeseen technical challenges on a small scale prior to full-line production in 2009. Model-year 2007 was chosen because it provides adequate lead time for development efforts to be completed following the conclusion of an in-boat catalyst test program with U.S. EPA and the ARB at Southwest Research Institute. For the industry as a whole, the 350 cubic-inch displacement V-8 represents more than a third of sales, so this will be the likely first model to be introduced with a catalyst. The manufacturers may choose which engine families to introduce, but it must constitute the California sales fractions indicated.

5. Small Volume Manufacturers

Engines from small-volume manufacturers represent approximately 1.5 percent of the total engines (1999 nationwide and California sales) in this category. The staff recognizes that small-volume manufacturers may be less able to fund research and development programs to integrate automotive controls on their engines and will have to utilize equipment or packages developed by others. Therefore, the proposal would provide a time-delay for manufacturers that produce less than 2000 inboard and sterndrive gasoline marine engines annually for the United States. Small-volume manufacturers would not be required to comply until 2009, at which time, like all other manufacturers, 100 percent of production would have to comply. The staff also proposes to allow the small-volume manufacturers to use an assigned deterioration factor.

D. Labeling Requirements

In order to clearly identify California-certified gasoline marine engines, staff proposes that each engine be affixed with a permanent engine label that would indicate that the engine complies with California's regulations. Also, the label would serve as an effective tool for in-use testing and other enforcement programs. It provides the engine family name, a list of emission-related devices, fuel to be used, date produced, and engine displacement. The label provisions also allow manufacturers some flexibility to include other relevant engine and compliance information. Engine certification labels are currently required as part of all of California's on- and off-road mobile source regulations.

Manufacturers of engines used solely for competition are encouraged to incorporate engine labels to identify the engines for their intended use. Staff proposes that such labels be done in accordance with the engine label specifications noted above. The labeling of competition engines provides a simple mechanism for field enforcement.

Since it is common for marine engine manufacturers to sell their certified engines to boat-builders, the proposal allows for some flexibility in the labeling provisions. For example, instead of the engine manufacturer's name on the certification label, the engine manufacturer is permitted to indicate the corporate name and trademark of a watercraft manufacturer, or third-party distributor. This will facilitate marketing decisions in which the secondary parties wish to be identified as the sole manufacturer of their watercraft, including the engine itself. This action will not impact the certifying manufacturer since its unique identification code is integrated into the engine family name.

Besides the certification label, the proposal extends the 3-tiered environmental labeling program already in place for outboards and personal watercraft engines to inboard and sterndrive engine applications. Inboard and sterndrive marine engines complying with the 2003 standards will be eligible for the 3-star environmental label. This is the same emission level required for 2008 model-year outboard and personal watercraft engine applications. A new, four-star label, indicating super ultra-low emissions would be used on inboard and sterndrive watercraft that comply with the 2007 5.0 g/kW-hr standard for HC+NOx.

Examples are shown below in Figure 7.

Figure 7
Marine Engine Consumer Labels

The primary purpose of the labeling program is to inform consumers of the relative emissions level of new engines. Staff anticipates that increased consumer awareness of these engines may establish a positive market trend toward clean technologies, thereby accelerating the benefits of the program by encouraging the acquisition of engines that comply with more stringent emission standards than required at the time of purchase.

E. Emission Parts Warranty Requirements

The proposed warranty requirements apply to engine components that affect emissions performance. The warranty requirements do not cover routine and scheduled maintenance, and do not cover parts past their designed replacement interval. For each new marine engine sold in California, the engine manufacturers would be required to include an explanation of their emissions defect warranty, the warranty responsibilities of the owner, and proper maintenance instructions in the owner's manual.

F. In-Use Compliance Program

To ensure that certified engines are meeting the emission standards through the compliance period, the staff proposes to incorporate inboard and sterndrive marine engines into the existing California in-use test program. The ARB administers and funds the in-use test program. Based on a variety of data collected, the ARB could choose an engine family to test. The ARB procures a limited sample of engines from a given engine family. The engines are restored to the manufacturer’s specifications, and tested in accordance with the applicable test procedures. ARB and the manufacturer's representatives are present to oversee all aspects of the test program. Should a noncompliance situation occur within a given engine family, the ARB will work with the manufacturer to correct the problem on all affected engines. The corrective action is usually in the form of a statewide recall in which the manufacturer will notify all affected engine owners and state when and where to seek the recall repair. The cost of the repair and service is free to the engine owner.

G. Emission Control On-board Diagnostics

Staff proposes that inboard and sterndrive engines certified to meet the 2007 and later standards be equipped with an on-board malfunction detection system (OBD-M). The detection system is required to identify emission-related engine malfunctions and store such information in non-volatile computer memory as standardized diagnostic trouble codes. Emission-related malfunctions are not limited to emission control components and systems only, but to any other electronic component or system that can affect emissions including the on-board computer itself. Additionally, the diagnostic system is required to alert the operator after a malfunction has been detected by means of either an audio or visual alert device.

Staff is proposing that the minimum complement of monitoring be:

- Catalyst Monitoring (conversion efficiency)
- Oxygen Sensor Monitoring, if equipped (checks sensor response rate and lean-to-rich and rich-to-lean switch times; also checks for proper temperature if sensor is heated)
- Engine control module (verifies that the module's memory is working properly
- Fuel system monitoring (checks for appropriate long and short term fuel correction and learning)
- Misfire monitoring (checks for incomplete or completely absent combustion events)
- Sensor and solenoid monitoring (checks for the proper performance of comprehensive components such as manifold air pressure sensor, coolant temperature sensor, throttle-position sensor, crankshaft position sensor
- Engine control module self-check

In addition, the diagnostic system information must be accessible through a generic scan-tool connected to a standardized data link connector within the boat, and the diagnostic fault codes must be standardized according to Society of Automotive Engineers protocol.

This system is designed to assure proper performance and facilitate the maintenance of emission control systems and components. Thus, the proposal exempts from OBD-M compliance inboard and sterndrive engines not required to meet the 5 g/kW-hr HC+NOx standard (through 2008). Note also that, for the phase-in years of 2007 and 2008, the catalyst-controlled engine families will be required to incorporate all these monitors except for misfire monitoring and the more advanced features associated with the comprehensive components (rationality monitoring). Furthermore, manufacturers will not be required to activate the audio or visual alert device for catalyst, fuel system, and oxygen sensor functional malfunctions until 2009. Only fault codes need be stored for those malfunctions. This is to allow the manufacturers to concentrate on introducing the catalyst systems, and not have to simultaneously debug the malfunction indication system.

H. Technology Review

Staff believes that three-way catalyst, closed-loop controls provide excellent emission reduction capability, and that those reductions can be maintained over the life of gasoline marine engine applications. Nevertheless, staff believes that additional emissions durability testing would be beneficial to support the proposed 2007 emission standards. Staff believes that this can be best accomplished through co-funded demonstrations to confirm that the emission standards can be met in-use with the technology of choice. Plans are underway for a cooperative effort between U.S. EPA, ARB, the National Marine Manufacturers' Association, and the U.S. Coast Guard to develop and test these systems in boats on the water, resolve any problems of salt water exposure, heat management, boat space, *etc*, and share the results among the manufacturers. The results of this multi-government/ industry effort would be presented to the Board as part of a technology review.

For these reasons, the staff proposes to hold a technology review in 2003, and if necessary, in 2005. The review(s) will enable industry and ARB to determine how the application of technology is progressing, identify any unforeseen challenges, and recommend regulatory changes if warranted.

VI. TECHNOLOGICAL FEASIBILITY

A. Overview

The proposed measure would require emission control technologies on inboard and sterndrive engines which have already proved successful on automotive engines. The engine manufacturers have been phasing out their carbureted engines in favor of electronic fuel-injection over the last 5 or 7 years. The proposed exhaust emission standards remain performance-based;

manufacturers will have the flexibility to employ the emission control technology of their choice to accomplish the ultimate emission reduction goals. However, practically speaking, the staff's proposal would, in the near-term, likely require manufacturers to accelerate the introduction of lean air-fuel calibration strategies and, in the mid-term, likely require the use of aftertreatment strategies (*e.g.* catalytic converters) to achieve significant emission reductions. A discussion of these control strategies follows.

B. Control Technology Options

1. Lean Air-fuel Calibration

Marine gasoline engines are normally calibrated for slightly rich air-fuel mixture. “Rich” means fuel rich or less air than is theoretically required to combust all the hydrogen and carbon in the fuel. Compared to stoichiometric or lean operation, running slightly rich keeps combustion temperatures low, which helps protect the engine, and usually results in lower NOx emissions. However, it also typically results in poorer fuel economy and higher HC and CO emissions.

A lean air-fuel calibration slightly leans the fuel-air mixture closer to stoichiometric, resulting in more efficient combustion, thereby resulting in lower HC and CO emissions. The result is often a concomitant increase of NOx emissions due to the higher temperatures. This technology by itself will typically reduce emissions from a carbureted engine by about half for HC, but is estimated to increase NOx emissions also by about half. This strategy is currently being employed in boats for sale to Europe and, to some extent, in the United States as well.

2. Electronic Fuel Injection

A fuel system which introduces the fuel for combustion through individual injectors is used to precisely time and meter fueling (electronic fuel injection). This is an improvement over the older fuel metering system of carburetion, where constant air-fuel ratio is achieved by introducing liquid fuel at the neck of a venturi which the air is drawn through. The difference in emissions between an EFI engine and a carbureted engine with a factory-set calibration is about 40% (reduction) for HC and 60% (increase) for NOx. This technology is already available as an option on most inboard and sterndrive engine models.

3. Oxygen-Feedback Fuel Control

Oxygen-feedback fuel-control uses a sensor which measures the oxygen content of the exhaust gases. The signal is used by the engine control module to lean or richen the air-fuel mixture as needed to achieve the proper air-fuel set-point. Feedback to the engine control module allows the air-fuel mixture to be “tailored” and set precisely. Precisely setting the air-fuel mixture lean or near stoichiometric in and of itself reduces HC and CO. This mixture range is also optimum for three-way (reducing and oxidizing) catalysts, which are discussed below. The difference in emissions between a stoichiometric feedback-controlled EFI engine and a "basic" EFI engine is about 25% (reduction) for HC and about 20% (increase) for NOx. This technology is not now available on inboard/stern-drive engines.

4. Catalytic Converters

The catalytic converter is the primary technology responsible for the remarkable improvements in automotive emission control over the past two to three decades. Due largely to the use of the catalytic converter on gasoline automobile engines, ozone-forming emissions from a modern automobile are less than ten percent of the levels of an uncontrolled vehicle of the 1960s, with improved operability and fuel economy as an added bonus.

A "catalyst" or "catalytically active material" is a material which causes a chemical reaction to happen more quickly without being itself consumed. Since chemical reactions are sped by higher temperatures, the catalyst allows a reaction which would normally happen only at a high temperature to be performed at a much lower temperature. In this case, we are speaking of gas-phase reactions of HC, NOx, CO, and O_2, reacting on the surface of a solid. The solid must be refractory (resistant to the high temperatures which happen as the oxidation reactions proceed) and have a high specific surface area to maximize the interaction of the gas molecules.

The typical modern automotive catalytic converter consists of an active catalytic material (usually one or more noble metals such as platinum, palladium or rhodium) applied as a washcoat to a substrate (usually ceramic or metal), surrounded by a mat and placed in a housing ("can"). The can and inlet/ plumbing act to direct the exhaust flow over the active material to be exposed to the porous surface containing the grains or sites of active metals.

The most common and successful type of catalytic converter is called a "three-way" catalyst because it simultaneously allows reduction of nitric oxide to nitrogen, and oxidation of unburned HC and CO to water and carbon dioxide.

Controlling the amount of air entering the catalyst is particularly important for NOx control. As previously mentioned, precise air-fuel-ratio control is done by measuring the oxygen content in the exhaust gases and sending the resulting signal to the air-fuel controller in the engine control module. The engine control module then sends a signal to the fuel-injectors to increase or decrease fuel delivery to achieve the desired air-fuel ratio. Thus the engine control module and oxygen sensor are critically important for the proper performance of the catalyst.

While it has been used on automobiles for nearly 30 years, the catalytic converter has not been commercially demonstrated on boat engines with their wet exhaust systems. The concern is that water exposure can poison or severely damage both the catalyst and the oxygen sensor. However, recent studies have shown that exhaust systems can be modified to minimize water exposure, and thus this technical challenge will likely be resolved in the next few years. A further discussion on this durability issue can be found later in this report.

ARB testing of three-way catalysts in combination with stoichiometric feedback air-fuel control resulted in reductions of 60% for HC and 80% for NOx compared to a factory-set EFI engine without a catalyst and feedback control system.

5. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is an emission control strategy aimed at reducing NOx. By recirculating inert exhaust gases into the combustion chamber, less oxygen is available to oxidize nitrogen to form NOx.

While EGR has been demonstrated to be very effective at reducing NOx in automotive applications, little is known on how effective it would be in marine applications. Of particular concern is the EGR valve (which controls the amount of EGR flow). The durability of this valve in a marine environment has not been fully demonstrated. Emission reductions with the use of EGR are typically found to be about 40% for NOx.

6. Malfunction Indication

The emission performance of an engine certified to the proposed 2007 emission standard is primarily dependent on the proper function of the oxygen sensor and catalyst. Thus the staff proposal includes provisions which would require an on-board system to monitor and indicate emission control-related malfunctions.

The on-board diagnostic system would be designed to alert the boat operator if the emission control devices are not performing properly. The indicators required by this regulation are not envisioned to limit the performance of the boat engine, merely to notify the owner of a problem.

The proposal would require marine inboard and sterndrive engines to have malfunction-indication systems installed, similar to the automobiles for which the engines were designed, which monitor

- Catalyst performance (done in cars by timing the duration of warm-up or by comparison of inlet and outlet oxygen concentrations)

- Fuel-controller trim (checks that the engine control module’s ability to correct air-fuel ratios is still within controllable limits)
- Oxygen sensor performance (checks sensor response rate and lean-to-rich and rich-to-lean switch times; also checks for proper temperature if sensor is heated)
- Cylinder misfire monitoring (done by monitoring camshaft acceleration or changes in exhaust pressure) to prevent catalyst overheat damage
- Comprehensive component checks (circuit continuity, and ‘rationality’ or ‘functionality’ monitoring for crank speed/position sensor, throttle-position sensor, manifold air pressure sensor, coolant temperature sensor, *etc.*)
- Engine control module self-check, memory integrity, execution timing, software revision date, program checksum.

With the exceptions of fuel system and comprehensive component monitoring, these parameters are, in general, not monitored continuously like oil pressure and engine coolant temperature, but instead are polled or checked at least once per engine operation. Sensor/solenoid continuity, misfire, and the fuel system are checked on a continuous basis. Two successive failures are required to trigger a fault code. The indicators, in case of a fault, are not required to limit engine performance in any way, unlike some engines which are designed to cut fuel or spark on overspeed, for example.

The technology and programs for all these checks exist today, and have been proved for many years now. The marine engines are presently, or will be by 2004, supplied with an engine control module which is ready for and capable of precise fuel-control and storage of programs and fault codes. Staff expects that the engine manufacturers will purchase systems developed by others for their products derived from the automotive field. However, at least one manufacturer has developed its own controller which is reportedly more sophisticated than the standard General Motors version available today. The Mercury “PCM 555” controller on the new 8.1-liter engine introduced in 2000 was developed in-house and has truly sequential fuel-injection, an advance over the factory-installed multi-point fuel-injection or port fuel-injection.

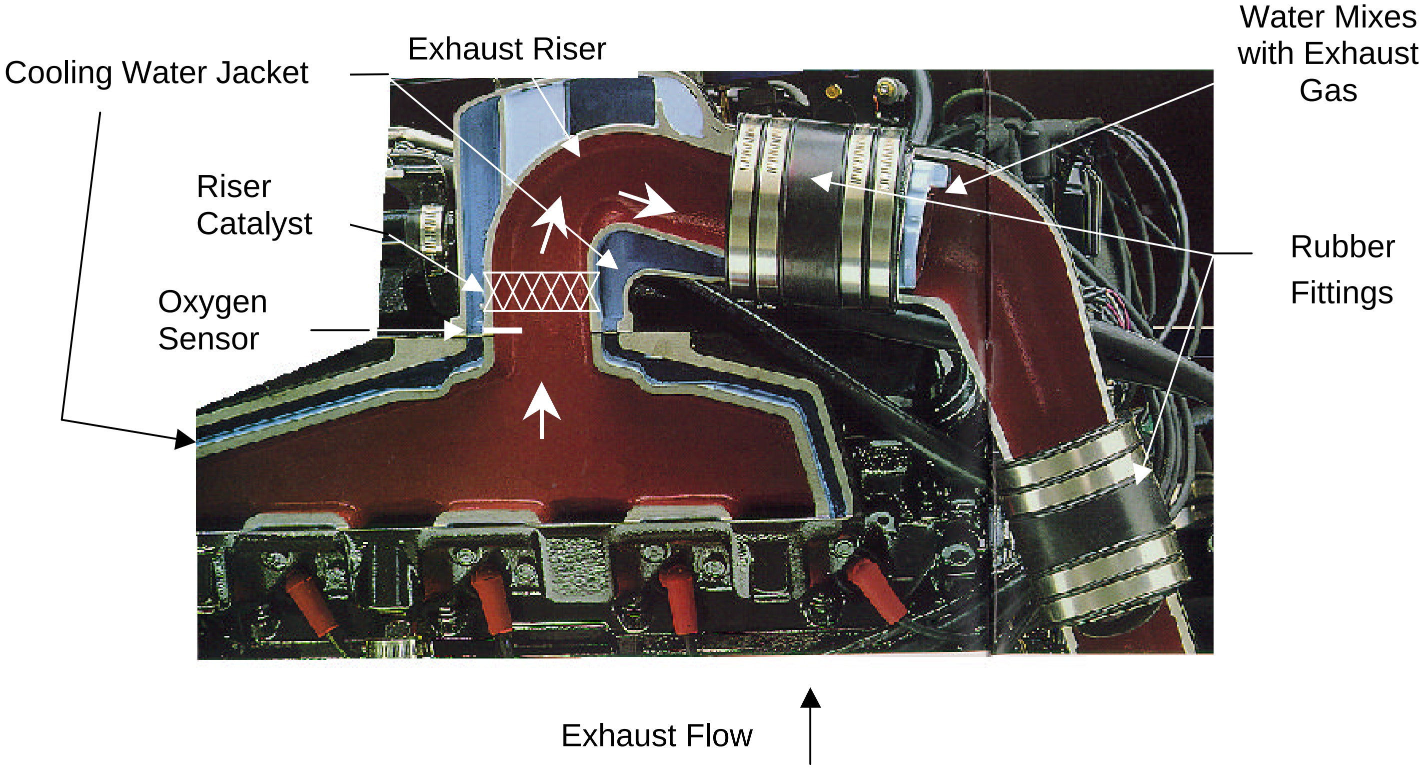
C. Marine Durability Issues

1. Catalytic Converters

As previously discussed water is mixed with the exhaust gases in inboard and sterndrive engines. This practice of mixing water with the exhaust gases has been the biggest technical challenge to the application of the three-way catalyst and feedback air-fuel control to these otherwise automobile-like engines. The presence of liquid water in the exhaust gases requires that the catalyst (as well as the oxygen sensor) be placed upstream of the exhaust gas/water mixing point.

Thus the choice of the location for a catalyst and oxygen sensor is limited. Figure 8 below illustrates a likely location of the catalyst and oxygen sensor. Exposing a three-way catalyst to lake or sea water could be detrimental because of potential for thermal shock and poisoning or masking by soluble salts. Sodium (a component of sea salt) is known to poison catalyst metal sites. The effect, however, is slow and cumulative, happening over many applications. Thermal shock from a sudden exposure of water would likely result in immediate and catastrophic breakage of the ceramic core of an oxygen sensor and ceramic catalyst substrate. It is unlikely that spraying a mist on a hot catalyst could do this; it is more likely that actual immersion in water would be required.

Figure 8
Cut-away view of marine exhaust manifold



Located upstream (and above) the water injection point, the catalyst is protected from immersion and spray exposure because the exhaust gases and cooling water spray flow away from the catalyst. However, during periods of sudden deceleration or sudden closing of the throttle, vacuum can build up in the exhaust manifold and this cooling water spray can reverse direction, traveling back into the exhaust manifold and, in some cases, back as far as the cylinders.

To address this concern, ARB is funding an in-boat study of water ingestion/accumulation at Southwest Research Institute. After 200 hours of testing of a marine engine on a test-cell, no catalyst degradation or evidence of water exposure has been observed. Southwest Research Institute also relocated the oxygen sensor to the joint between the exhaust manifold and riser and, as a result, has not observed any oxygen sensor failures. The results indicate thus far that condensation of the water from the combustion process is the main source of water, and that redirecting the manifold cooling water to keep the manifolds warm eliminates this problem. Thus staff believes that this problem is entirely resolvable in the next few years, well before catalysts are used in 2007.

Yamaha has offered for the last two years a personal watercraft with a catalyst-controlled engine. The engine is a three-cylinder 1.2-liter displacement carbureted two-stroke. With the catalyst, the HC emissions are reduced about 50% compared to a typical personal watercraft engine (to about 80 g/kW-hr).

2. Diagnostics/Malfunction Indication

The proposed malfunction indication system would warn or alert the boater to a malfunction through the use of a light or other warning device. The durability issue raised by some manufacturers for the proposed malfunction indication system is one of false test-failures or failures of fragile components that could potentially affect the startability or performance of the boat engine. However, the proposal does not require the malfunction indication system to interfere in any way with the engine performance or inhibit or interlock starting or full-throttle operation.

D. Safety Issues

Several concerns have been raised primarily over catalyst control systems in boats. The U.S. Coast Guard, in particular, is concerned with the following:

- Hot surfaces would be present in the engine compartment leading to burning or damage of the boat hull materials, personnel burns, or igniting of fugitive gasoline vapors.
- Catalysts may continue to heat up or “run away” in situations of idling or after the engine is shut off.
- Leakage or increased chance of leakage of CO-containing gas (engine exhaust) from the exhaust pipes due to an increased number of joints or connections required, or increased frequency of disassembly of exhaust components for inspection or repair.

1. Hot Surfaces/Engine Compartment Cooling

Concerns have been expressed over potential hot surfaces caused by the inclusion of three-way catalysts in the exhaust system. This is of concern to minimize the potential for

- ignition or combustion of materials in the boat or hull materials
- melting or weakening of the hull materials,
- burning of people's skin on contact with hot surfaces such as exhaust pipes.

The most common practice to address these issues is to employ water-jacketing and cooling with raw water or circulating engine-jacket water. As previously discussed, the exhaust gases are most commonly cooled downstream of the water-jacketed exhaust manifolds by direct mixing with the cooling water. As shown in Figure 8 a likely catalyst location would be in the exhaust riser upstream of the exhaust gas/water mixing point. The catalyst will cause exhaust manifold/riser temperatures to increase because as the hot exhaust passes through it, it generates additional heat due to the oxidation process. Also, increased resistance-to-flow in the exhaust system due to the presence of the catalyst can cause high exhaust temperatures.

In a boat engine after the engine ignition is turned off, the combustion of gasoline (thus the generation of heat) ceases immediately, but heat radiation or convection continues from the warm engine block walls and exhaust pipe walls (so called "thermal mass"). At this time raw water cooling has ceased when the engine ceases to turn, but the lake or sea water remains in the engine block, and probably drains out of the exhaust manifolds, leaving them warm and dry.

The point is, after the engine and cooling water are shut off, heat is still released into the engine compartment, but at no faster a rate than when the engine is running. Residual heat release after the engine is shut off will proceed from the engine block walls, which are kept by the cooling water during operation to approximately 170 to 180°F.

The addition of a catalyst in the exhaust riser will add some thermal mass to the exhaust system. In the catalyst, oxidation of CO and HC will stop immediately when the exhaust gases stop flowing, but during operation the catalytic surface sees local temperatures up to 1600°F, building up heat in the catalyst substrate. On shutdown, the catalyst water jacket will drain away, leaving an air gap between the inner and outer steel walls of the catalyst vessel. This gap will tend to insulate and impede cooling of the catalyst substrate by conduction and natural convection to the air in the engine compartment. It is possible that the steel flanges connecting the catalyst to the rest of the exhaust system could heat up above 200°F during catalyst residual cool-down. This is thought to be an unlikely event, and one that could be easily designed around through either thermally insulating the catalyst brick from the shell, or improving the water-jacketing surrounding the catalyst to provide more heat transfer.

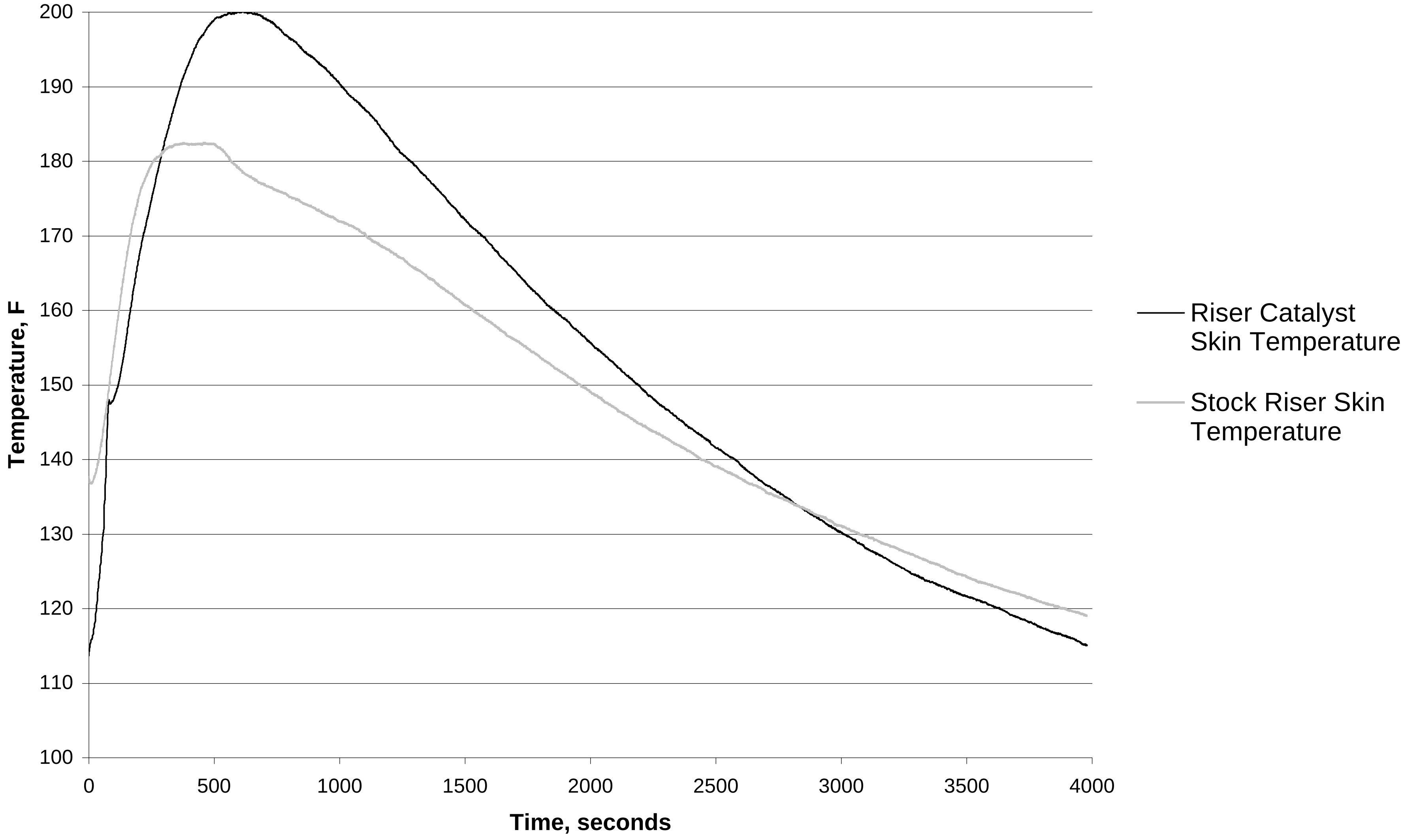
To study this phenomenon, Southwest Research Institute instrumented and ran a marine engine with thermocouples on the exhaust pipe skin and the skin of the exhaust riser surrounding the catalyst. After the catalyst reached highest observed operating temperature, the engine was shut off, the exhaust manifolds were drained of water, and temperatures were recorded as the engine cooled down.

The temperature traces are shown in Figure 9. The lighter, stippled curve is the skin temperature of a factory cast-iron riser with no catalyst in it. The solid curve is the skin temperature of a cylindrical riser catalyst placed in the same position.

In this cooling run the outer exhaust skin temperature of the original factory riser rose about 40°F in 7 minutes, then cooled to where it started in about 40 minutes. The skin temperature of the riser with a catalyst in it rose 85°F in 12 minutes, then cooled back to where it started in about 70 minutes. The reason for this high, fast rise was that the catalyst held a lot of heat, and the cylindrical riser catalyst had a relatively low “thermal mass” in the wall material or packaging.

The skin temperature rose up to the criterion of 200°F, although this was done dry (no jacket water). The 200°F criterion is the threshold for insulation, covering, or water-jacketing for exhaust systems in boats from American Boating and Yachting Council Standard P-1 paragraph 1.5.9.

Figure 9
Comparison of Marine Engine Exhaust Skin Temperatures with and without Catalyst



2. Catalyst Overheating

As discussed above, ARB staff expects the catalyst to reach temperatures up to 1600°F during operation. This is based on observed on-engine tests. Overheating of the catalyst would only occur when both fuel and air reach the catalyst simultaneously. This could occur inadvertently during a major misfire event, where fuel is not combusted and oxygen is not consumed in the combustion chambers. The remedy for arresting this situation would be to stop the engine. Once the oxygen in the exhaust is consumed, the heating would stop. This would be an emergency situation and the malfunction diagnosis system would be designed to detect and warn against this occurrence.

ARB's contractor for the engine testing (Southwest Research Institute) noticed only one incident of catalyst overheating in over 200 hours and a year of testing. All the catalysts tested were water-jacketed. The catalyst in the incident heated up to about 1600°F (in the bed) at idle. The catalyst bed on the other exhaust bank of the engine did not overheat. An ignition miss was noted (by low exhaust port temperatures) in three of the cylinders on the bank that the catalyst was installed on. The incident was ended by turning off the engine. The situation that led to the overheating was a loss of compression due to warped intake valves (probably as a result of running the engine at full power and speed with stoichiometric air)[*]. The situation was corrected by replacing the cylinder heads with new ones and installing a more advanced fuel controller. No more overheating events were noted after 100 further hours of testing. The catalyst was reused without cleaning or loss of performance.

3. Carbon Monoxide Exposure

The U.S. Coast Guard has commented that installing equipment in the exhaust system of the engines will lead to more exhaust pipe connections or joints which would increase the chance of an exhaust gas CO leak into the engine compartment or into occupied areas of the boat. The U.S. Coast Guard also commented that increased inspection requirements that involve periodic disassembly of the exhaust pipe connections might also lead to higher frequency of CO leaks.

While the chances of CO exposure are higher in a boat, especially where non-ventilated living areas conjoin the engine compartment, the conventional leak-

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[*] The engine was run at full speed, wide-open throttle with stoichiometric air in order to achieve the maximum amount of emission reductions over the whole operating range of the engine. The engine maker warned us that structurally the engine could only stand a few minutes at this condition before deformation damage might occur. This apparently is an inherent problem with even the state-of-the-art aluminum overhead-cam catalyst-controlled engines. We understand that lean-burn gasoline engines used in Europe can withstand these conditions. Of course, diesel engine blocks, heads and valves withstand these conditions also.

minimization strategy has been to minimize the number of connections and joints in the lines carrying exhaust gas, and to design the few remaining joints not to leak. The addition of the catalyst vessel could be done with one extra flanged connection on each side of a V-8 engine. The catalyst flange connections would be identical to the present successful flanged designs used on boats.

Also, since the exhaust manifolds and pipes in boats are typically water-jacketed for some of their length, and then the water is mixed inside into the exhaust gases, leakage sites would leak water first (for the jacketed length) or the leak would be accompanied with water. That water would be the first sign of a leak, conversely water-tight would signify "exhaust gas leak-tight." In addition it should be noted that installing catalysts which convert CO to carbon dioxide would reduce the CO concentration in the exhaust downstream of the catalyst by a factor of four during cruise and by a factor of 10 during idle compared to a non catalyst-equipped engine. The leaner engine calibration will also reduce the CO concentration upstream of the catalyst. The lower CO emissions from engines meeting the proposed standards will therefore reduce potential harm from leaks anywhere in the exhaust system.

VII. COST OF COMPLIANCE/COST BENEFIT

A. Cost Methodology

Component costs were estimated for a 350 cubic-inch displacement V-8 engine, the most popular engine size for inboard and sterndrive engines, representing 30 to 40 percent of all sales. Component costs for other engines which are smaller (the V-6 and the in-line 4-cylinder) will probably be less than shown. Conversely, component costs for the large V-8 engines will be larger than shown. Wholesale or vendor costs were solicited to determine the incremental cost of applying feedback fuel-control automotive components and a three-way catalyst to a base-calibration electronically fuel-injected engine. For these cost estimates, the baseline engine was assumed to be equipped with fuel injectors and an engine control module already. The engine manufacturers expect that new marine engines will be 100% electronic fuel-injected models by 2005.

As part of the rule development process, all the engine manufacturers were queried by questionnaire and by telephone interview for the estimated control-system costs. Two catalyst vendors were also contacted about the packaging and canning of their products. As part of the development of the ARB off-road large gasoline engine regulations, Southwest Research Institute surveyed engine parts vendors and estimated the costs of adding catalyst control to a 2.5-liter 4-cylinder gasoline industrial engine (White *et al*. 1999). These are valuable for comparison to the marine case because they estimated the costs of applying automotive feedback catalyst control to previously uncontrolled automobile derived engines for land-based off-road engines. In addition, previous ARB analyses of applying on-board diagnostics to automobiles (ARB 1994a; ARB 1998b) were consulted.

B. Costs of 2003-2008 Model-year Standards

Compliance with the proposed 2003 emission standards can be done with present-day air-fuel calibrations, or by leaning the engine’s air-fuel mixture without the addition of any other exhaust control or fuel-control devices, resulting in lowered HC emissions.

Since no hardware needs to be added by the manufacturers to comply with the standards, minimal costs will be incurred. There might be some costs incurred with testing recalibrated engines, but the number of such engines is expected to be small. For these reasons no costs are shown for compliance with the proposed 2003 standards.

C. Costs of Catalyst-based (2007) Emission Standards

The incremental cost of complying with the 2007 catalyst-based standard is $756 to $1231 per engine. Table 6 identifies the individual component and system costs. The fixed research and development costs account for the greatest cost, due to the relatively low sales volume of these engines, followed by the catalyst and the on-board diagnostic system. These estimates are based on information from engine manufacturers, the catalyst vendors, and ARB staff reports on automotive engine emission regulations (ARB 1994a; ARB 1998b). They assume all engines will have changed from carburetors to fuel-injection by 2005 even in the absence of regulations, following the current industry trend. Thus the engine control module, fuel pump/regulator/rail, and gasoline-to-water cooler are considered to be part of the base engine, and their cost is not included in estimating the cost of this proposal.

Table 6
Control System Costs for a Typical Marine Engine—2007 Standards ($/engine)

	Catalyst-Controlled Engine (Incremental Cost)
Fuel Injection Injectors Fuel Pump, Pressure Regulator, Fuel rail Intake Manifold, Throttle body and position sensor, Fuel Cooler	$5
Engine Control Module Intake Air Temperature Manifold Air Pressure Crank Position Sensor Wiring	25
Front Oxygen Sensors (2)	38
Exhaust Manifold	20
Catalysts, including canning Cylindrical riser cat	200
Total Capital	288
Malfunction Indication Basic mandatory system: Post-catalyst O_2 Sensors + programming	183
Manufacturer and Retailing costs	
Tooling, R&D, Assembly labor	216-648
Dealer markup	69-112
Total	$756-1231

The $183 cost of the basic malfunction indication system is primarily due to the hardware required, as shown in Table 7. The hardware includes two additional oxygen sensors used to monitor catalyst efficiency, and the cost of splitting the catalyst into two bricks to allow installation of the oxygen sensor within the catalyst. This was the incremental quote from the catalyst vendor for a two-piece catalyst in comparison with a one-piece. Staff believes that with commercialization and economies of scale this incremental cost will decrease with time. The camshaft position sensor may be standard on many engines, especially distributorless engines, but for the sake of providing a conservative cost estimate, a $25 cost is included. A nominal cost of $20 per unit was estimated for additional engine control module programming. This estimate was based on assuming 3 person-months of programming time distributed over about 3000 units per engine family (one-year payout).

Table 7 **Malfunction Indication Costs for 350 Cubic-Inch Displacement Engine**	
Item	**Cost $/unit**
Mandatory malfunction indication	
Rear Oxygen Sensors	$138
ECM Programming	20
Camshaft Position Sensor	25
Total per unit cost	$183

Table 8 provides a breakdown of R&D and tooling costs. Depending on whether these fixed costs are written off against national sales (in anticipation of U.S. EPA adopting a similar standard) or only California sales, $48 to $480 is the cost per engine sold. Added to this is $8 for engine-specific R&D, $137 for engine manufacturer's incremental mark-up, and $23 incremental warranty mark-up, yielding the $216 to $648 incremental cost per engine shown in Table 6 for Manufacturing and Retailing Costs.

Table 8 **R&D Costs for the Marine Inboard Industry**	
Item	**Total Cost**
Engineering Labor, Technical Support, Other Engineering Costs	$39,000,000
Test Costs	200,000
Tooling Costs	9,000,000
Total R&D and Tooling	48,200,000
10 years of Engine Sales (nationwide)	1,000,000
10 years of Engine Sales (California only)	100,000
Per unit cost	$48-480

Total costs for 5 manufacturers, 30 product lines. For test costs, the biggest two manufacturers were assumed to already have their own in-house emissions test equipment.

D. Cost Effectiveness

To determine the cost effectiveness of the proposed regulations, the incremental cost per engine for the expected emission controls is divided by the expected emission reductions per engine due to the use of those controls. Table 9 presents the anticipated lifetime emission reductions for an engine complying with the 2003-2008 standards, and an engine meeting the proposed 2007 standards. The lifetime emissions are derived using the average power rating of the engine, annual usage, load factor, and lifetime for inboard and sterndrive engines. The emission factors shown in columns 3 and 4 of Table 9 are the lifetime-average emission factors. The lifetime emission reduction is the difference between the lifetime emissions of the engines complying with the 2003 emission standards and those complying with the 2007 emission standards.

Table 9
Benefit of the Proposed 2007 Emission Standards
Lifetime Emissions for an Average Inboard and Sterndrive Engine

	Usage, kW-hr/LT	HC g/kW-hr	NOx g/kW-hr	HC+NOx lb/LT
Pre-2007 Engine	15,860	4.9	9.9	517
Catalyst-based (2007 standard)	15,860	2.1	2.3	154
Benefit				363

* Based on 21% load factor, 157 kW engine power rating, and a 480-hr lifetime. Emission levels are the lifetime-average values.

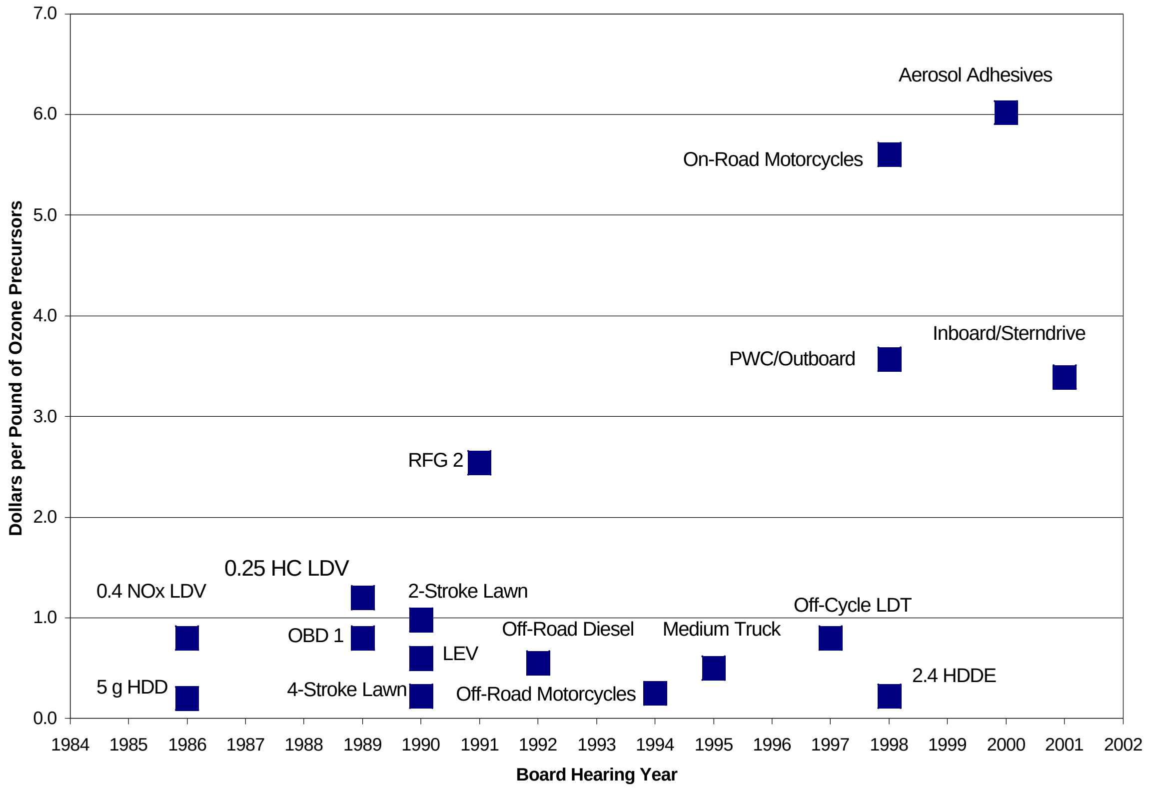
Thus the cost-effectiveness associated with the staff's proposal is

$756 to 1231/unit/lifetime ÷ (517-154) lb HC+NOx benefit/unit/lifetime = $2.08 to 3.39/lb HC+NOx reduced

Below in Figure 10 are shown the cost-effectiveness values for many of the ozone reduction measures adopted over the last 15 years. The cost-effectiveness of the proposal is well within the range of cost-effectiveness for other mobile source control measures.

Figure 10

Cost Effectiveness of Major Regulations
Mobile Sources and Fuel



VIII. AIR QUALITY, ENVIRONMENTAL AND ECONOMIC IMPACTS

A. Air Quality Impacts

1. Statewide Inventory/Effect of Proposal

The emission inventory assumptions have been updated since the adopted marine inventory (ARB 1998c). These changes have been detailed in Attachment D.

The emissions inventory for inboard and sterndrive gasoline boats is shown in Table 10 for the 2020 and 2010 calendar years. As shown in the table, emission levels associated with summer weekend operation are approximately 3.6 times higher than corresponding annual average levels due to increased boating activity during the summer months. This is especially relevant since ozone levels reach their highest values during summer weekends. Therefore, to properly represent the benefits from this control measure, emission reduction comparisons in this report are presented using summer weekend values rather than annual averages.

Table 10

Inboard and Sterndrive Statewide Baseline Emissions Inventory

2020 BASELINE INVENTORY			
AIR BASIN	POLLUTANT	BASELINE (TPD)	RATIO TO STATEWIDE ANNUAL
STATEWIDE *Annual Average*	HC	18.55	**1.00**
	NOx	31.20	**1.00**
STATEWIDE *Summer Average*	HC	30.23	**1.63**
	NOx	50.85	**1.63**
STATEWIDE *Summer Weekend*	HC	67.51	**3.64**
	NOx	113.56	**3.64**
SOUTH COAST *Annual Average*	HC	5.01	**0.27**
	NOx	8.42	**0.27**
2010 BASELINE INVENTORY			
AIR BASIN	POLLUTANT	BASELINE (TPD)	RATIO TO STATEWIDE ANNUAL
STATEWIDE *Annual Average*	HC	18.46	**1.00**
	NOx	23.48	**1.00**
STATEWIDE *Summer Average*	HC	30.10	**1.63**
	NOx	38.27	**1.63**
STATEWIDE *Summer Weekend*	HC	67.21	**3.64**
	NOx	85.47	**3.64**
SOUTH COAST *Annual Average*	HC	4.99	**0.27**
	NOx	6.34	**0.27**

Table 10 lists baseline hydrocarbon emissions which are very close (given the precision of our estimating methods) in 2010 and 2020. While the boat population increases by about 16% over the 10 years as shown in Table D-1, the hydrocarbon emissions are not projected to increase commensurately because of the shift of the boat population from carbureted engines (about 80% of the population in 2010, about 40% of the population in 2020) emitting high hydrocarbons to fuel-injected engines emitting 65% less hydrocarbons.

A summary of the benefits of the proposal is shown in Table 11 for 2020 and 2010. The emission reductions of the proposal were determined by assuming emission controlled engines will meet the applicable emission standards for the certification periods. Table 11 shows that the combined HC+NOx emissions from inboard and sterndrive marine engines are reduced by about 30% compared to the baseline condition by 2020. This is a reduction of 56 tons of HC+NOx per day (summer weekend average), or the equivalent of the exhaust emitted by 1,600,000 cars in 2020 (based on annual-average tail-pipe emissions).

Table 11

Statewide Emissions Benefits from Proposed Emission Standards

2020 STATEWIDE EMISSIONS BENEFITS				
AIR BASIN	POLLUTANT	BASELINE (TPD)	CONTROL (TPD)	BENEFIT (TPD)
STATEWIDE *Summer Weekend*	HC	67.5	56.1	**11.4**
	NOx	113.6	68.8	**44.8**
2010 STATEWIDE EMISSIONS BENEFITS				
AIR BASIN	POLLUTANT	BASELINE (TPD)	CONTROL (TPD)	BENEFIT (TPD)
STATEWIDE *Summer Weekend*	HC	67.2	65.5	**1.7**
	NOx	85.5	77.2	**8.3**

Organic toxic gases present in the exhaust of gasoline engines will also be reduced to a similar extent as the reduction of HC. The important organic toxic species are benzene, toluene, 1,3 butadiene, formaldehyde and acetaldehyde, which, in total, constitute about 15% of the measured HC (U.S. EPA 2000).

Table 12 lists the emission factors used to develop these inventories. From this table the reader can judge quickly what the relative improvements in emission control rates are.

Table 12

Gasoline Inboard and Sterndrive Zero-Hour Emission Factors

Emission Factors	HC g/kW-hr	NOx g/kW-hr	HC+NOx g/kW-hr
Baseline Carbureted	7.80	6.23	14.03
Baseline EFI	4.73	9.92	14.65
Catalyst	1.88	2.01	3.89

Note: EFI means electronic fuel-injected

2. Comparison with 1994 State Implementation Plan (SIP)

Table 13 presents the emission rates and emission inventory for gasoline inboard and sterndrive engines in the South Coast Air Basin for the year 2010, as documented in the 1994 SIP (ARB 1994b). As the data in the table illustrate, the 1994 estimates of population and NOx emission rate were too low, and HC emission rate too high, compared to data used in the current inventory. The calculated reductions, based on using these estimates and staff's proposed standards and implementation schedule, fall short of the 1994 SIP HC emission reduction commitment of 2 tpd.

Table 13

SIP-basis 2010 emissions, South Coast Air Basin

	Population	HC g/kW-hr	NOx g/kW-hr	HC tpd	NOx tpd
Baseline	66,300	12	5	8	3
Reductions				1.1	(0.8)

Note: Numbers in parentheses are emission increases

B. Economic Impacts

Overall, the proposed amendments are not expected to impose a significant cost burden on sterndrive and inboard marine engine manufacturers. None of the major manufacturers are located inside California, although some may have small operations within the State. A few manufacturers control the bulk of the market share for these engines. Annual costs of the proposed amendments are estimated to be around $7 to 11 million in 2009. These costs are likely to be passed on by manufacturers to boat buyers, resulting in an increase of about 3 to 4 percent in average retail prices of a sterndrive or inboard boats. NMMA has indicated that marine engine sales are price-elastic, decreasing by about 2.7 percent for every one percent increase in price of the product. However, as a luxury good, it is also income-elastic, indicating that demand for boats tends to rise as income increases, and income has been rising steadily in California. The negative effect of the price increase on boat sales, thus, is likely to be at least partially offset by the positive effect of the income increase. As a result, and as explained in further detail below, staff expects the proposed amendments to impose no significant adverse impacts on California competitiveness, employment, and business status.

1. Legal Requirement

Section 11346.3 of the Government Code requires State agencies to assess the potential for adverse economic impacts on California business enterprises and individuals when proposing to adopt or amend any administrative regulation. The assessment must include a consideration of the impact of the proposed regulation on California jobs; business expansion, elimination, or creation; and the ability of California business to compete.

Also, State agencies are required to estimate the cost or savings to any state, local agency and school district in accordance with instructions adopted by the Department of Finance. The estimate must include any nondiscretionary cost or savings to local agencies and the cost or savings in federal funding to the state.

Health and Safety Code section 57005 requires the ARB to perform an economic impact analysis of submitted alternatives to a proposed regulation before adopting any major regulation. A major regulation is defined as a regulation that will have a potential cost to California business enterprises in an amount exceeding ten million dollars in any single year. The proposed amendments are not a major regulation.

2. Businesses Affected

Any business involved in manufacturing sterndrive and inboard gasoline marine engines would potentially be affected by the proposed amendments[2]. Also potentially affected are businesses that manufacture boats, supply parts to these manufacturers, and distribute, sell and service sterndrive and inboard marine engines.

The inboard and sterndrive marine industry consists of about 30 engine manufacturers and a large number of boat manufacturers nationwide. The largest four manufacturers control over 95 percent of the market. None of major engine manufacturers are located in California, although some may have part of

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[2] These manufacturers fall into the industry identified by SIC 3519.

their operations within the state. Table 14 provides a list of major manufacturers of sterndrive and inboard gasoline marine engines in the United States.

Table 14 **Major Inboard and Sterndrive Marine Engine Manufacturers**
Indmar Products Marine Power Mercury MerCruiser Volvo Penta of the Americas

3. Potential Impact on Engine Manufacturers

Inboard and sterndrive engine manufacturers currently are expected to use common automotive emission control technologies such as closed-loop fuel-control systems and three-way catalytic converters to comply with the proposed regulations.

Based on the application of the best available automotive technologies, staff estimates that the proposed amendments will increase average costs of manufacturing inboard and sterndrive marine engines by about $7 to 11 million annually. A small number of well-diversified manufacturers will incur the bulk of the cost increase. Low-volume manufacturers are unlikely to spend much of their own resources on this effort; they are more likely to rely on their suppliers. There is a large number of low-volume producers in the industry that tend to fill special market niches. These manufacturers tend to compete in the market based on non-price factors such as unique features of their products and superior service. These manufacturers are usually able to pass on the cost increase because their customers are less sensitive to price changes in the market. Large manufacturers are also likely to pass on the cost increase to consumers in the long run if they are unable to lower their production costs. Thus, the proposed amendments are not expected to have a noticeable adverse impact on affected manufacturers.

Industry representatives, however, have indicated that boat buyers are usually very sensitive to any price changes. They estimate that the long-term price elasticity is 2.7 for boats, implying that boat sales will fall by 2.7 percent for every one percent increase in boat prices. Although the initial boat price is a major factor in a buyer’s decision, it is not the crucial factor, according to the industry’s studies (NMMA, 1997). The purchase of a boat is a major decision for most boat buyers and usually it takes a boat buyer about six months of research before making a decision to purchase. Most boat buyers are concerned about the overall affordability of purchasing a boat. Many factors affect affordability including personal income, boat financing, storage cost, the initial price and maintenance routines. Industry studies indicate that maintenance routines are more important to a prospective buyer than the initial cost of a boat (NMMA, 1996). The industry indicates that most buyers would like to negotiate price because they believe that they can gain more specific product information during the negotiation process that justifies the purchase price. Thus, it is most likely that boat buyers are willing to pay higher prices for new boats that are more fuel-efficient and require less maintenance. Most manufacturers, therefore, should be able to pass on the cost increase to consumers in the long run if they are unable to lower their production costs. As a result, the proposed amendments are not expected to have a noticeable adverse impact on affected manufacturers.

4. Potential Impact on Distributors and Dealers

Most engine and boat manufacturers sell their products through distributors and dealers, some of which are owned by manufacturers and some are independent. Most independently owned dealers are small businesses. Some low-volume manufacturers also deal directly with their customers. The distributors and dealers sell about 11,000 units of sterndrive and inboard engines per year in California. Although they are not directly affected by the proposed amendments, the amendments may affect them indirectly if an increase in prices of inboard and sterndrive marine engines reduces sales volume. Dealers’ revenue would be affected adversely if the reduction in sales volume exceeds the increase in prices.

5. Potential Impact on Customers

The potential impact of the proposed amendments on the retail prices of sterndrive and inboard marine engines hinges on the ability of manufacturers to pass on the cost increases to their customers. In the short run, customer sensitivity to price increases and growing competition from used boat sales may prevent manufacturers from passing their cost increases on to customers. In the long run, however, if manufacturers are unable to bring down their costs of compliance, they would pass on their costs increases to marine engine customers. In such a case, staff estimates the average price of a marine engine would increase by $756 to 1231 for California customers. This represents an average increase of 3 to 4 percent in the price of an inboard or sterndrive boat. The price increase is within the range of California personal income gains in recent years. During 1990 to 1999, California personal income rose by about 1.8 to 8.1 percent annually (Department of Finance, 2001). Thus, the estimated price increase is not expected to have a significant impact on the marine engine demand in California.

6. Potential Impact on Business Competitiveness

The proposed amendments would have no significant impact on the ability of California marine engine manufacturers to compete with manufacturers of similar products in other states. This is because all manufacturers that produce inboard and sterndrive marine engines for sale in California are subject to the proposed amendments regardless of their location. None of the major manufacturers have engine-manufacturing facilities located in California.

7. Potential Impact on Employment

According to a survey of the industry by U.S. EPA as part of its rulemaking process, nationwide employment in inboard and sterndrive marine engine industry was about 1,600 persons in 2000. California accounted only for a small share of this employment. There were also 347 retail outlets in California in 1997 (U.S. Department of Commerce, 2000), which were primarily involved in the retail sale of new and used motorboats and other marine engines, marine supplies, and outboard and inboard motors. These retail outlets employed an estimated 2,000 employees with an annual payroll of approximately $58 million in California. These employees are not likely to be affected adversely, because a small price increase is unlikely to dampen the demand for sterndrive and inboard in California substantially, and these boats account for less than 20 percent of all boats sold. Thus, the proposed amendments are not expected to cause a noticeable adverse impact on the California employment.

8. Potential Impact on Business Creation, Elimination, or Expansion

The proposed amendments would have no noticeable impact on the status of California marine engine manufacturers. As stated above, none of the major manufacturers of inboard and sterndrive engines is located in California. The amendments would potentially increase retail prices of marine engines by an average of about 4 percent. The increase in prices is unlikely to dampen demand for regulated products significantly because the impact of a price increase is likely to be offset by a faster rise in California personal income.

9. Potential Impact to State, Local or Federal Agencies

The only direct effect on local and federal agencies would be an increase in the price of boats they purchase. The number of boats purchased by these agencies in California is unknown, but is expected to be small.

The same is true for State agencies which purchase inboard and sterndrive boats. The State agencies involved in enforcing this rule; *i.e.,* the ARB, will incur higher costs due to inspecting boat dealerships for certified or complying engines, and the emission testing of in-use engines for compliance.

IX. ALTERNATIVES

A. Wait for the adoption of U.S. EPA Regulations

ARB staff has been working closely with U.S. EPA staff on a coordinated rulemaking process. ARB's intent has been to develop a regulation which is harmonized in terms of emission standards, applicability, and timing with the federal rule. Because the State's rulemaking process is currently on a faster track than U.S. EPA's, staff has proceeded to "take the lead" with its proposal. The alternative would be to allow the federal rule to be implemented in California at a later date and not adopt a specific state regulation.

The advantage of a national regulation is harmonization. Manufacturers would have to comply with only one set of regulations for all nationwide sales. The U.S. EPA has indicated it will consider harmonizing with adopted ARB standards, although with a potentially delayed implementation date.

The disadvantage of relying on the federal rulemaking is largely one of uncertainty and timing. U.S. EPA has yet to publish a proposed regulation, and thus adoption is at least one year away. Because of lead-time requirements, it is possible that future implementation may be delayed compared to the dates ARB staff has proposed. This will result in less emission reductions compared to adoption of the ARB staff proposal.

B. No Marine Inboard Engine Regulation

If no emission control regulation was pursued, the emission reduction needed to meet clean-air standards would not be achieved. The ARB's SIP obligation would not be met.

C. Lean-calibration engines from 2003 to 2008

Staff considered an emission control scenario under which manufacturers would have leaned the engines' air-fuel mixtures resulting in lower HC emissions but higher NOx emissions. Also under this scenario, only small numbers (10% of California sales) of catalyst-controlled engines were subject to the strict 5.0 g/kW-hr standards in 2007 and 2008. Staff based its proposal on the need to achieve early HC emission benefits as required by the SIP Settlement Agreement. HC+NOx emissions would increase during 2003 to 2008, based on recently obtained test data showing NOx increases at a faster rate than HC emissions decrease, due to enleanment of the air-fuel ratio. This alternative was rejected on this basis.

X. OUTSTANDING ISSUES

A. Emissions Inventory

Industry commented during the outboard engine rulemaking and early in the process for this rulemaking that the ARB's figures for the emissions impact due to boating were higher than their estimates. In Chapter VIII of this report, Air Quality, Environmental, and Economic Impacts, and in Attachment D, detailed changes to the emission inventory are summarized. A summary of the previous assumptions, industry's estimates and staff's revised estimates are shown in Table 14.

The changes in the inventory result in about a 3-fold reduction in the total estimated emissions contribution from inboard and sterndrive engines. Industry has still commented that the usage rate of 78 hours per year is much above their estimates. In Attachment D the various usage rate data and determinations are discussed. They are based on ECM operating hour data collected at service centers, mail survey of owners, reading of hour-meters at dockside, and boater surveys. They vary from about 55 hours per year to 100 hours per year. For comparison, an automobile driven 13,000 miles per year at 40 miles per hour annual average would have been used about 300 hours per year. Large gasoline engines used commercially see about 500 to 1000 hours per year of usage.

Table 14

Comparison of Emission Inventory Assumptions

	98 ARB inventory	Industry estimates	Present ARB estimates
Uncontrolled deteriorated emission factors*	14 g/kW-hr HC 7 g/kW-hr NOx		6** g/kW-hr HC 9** g/kW-hr NOx
State Inboard boat-engine population, 2010	445,000	114,000	387,000
Average Power	175 hp		211 hp
Usage load fraction	38%	21%	21%
Usage rate	78 hours per year	48 hr/yr	78 hr/yr
New engine replenishment rate	32,000/yr	11,400/yr	14,000/yr
Statewide HC 2010, annual average	83 tpd		19 tpd
Statewide NOx 2010, annual average	42 tpd		24 tpd

* Lifetime average, for 480-hour life

**Assumed 65% EFI, 35% Carbureted in 2010.

B. Catalyst Durability

The emission results from dynamometer testing are based on new catalysts on a young, optimized engine, operating in laboratory conditions. The marine engine manufacturers have raised concerns regarding catalyst durability and reliability in light of water ingestion or accumulation in the exhaust pipes, leading to catalyst or oxygen sensor damage.

ARB is presently funding in-boat tests to investigate the amount and causes of water accumulation and ingestion in wet marine exhaust manifolds. Testing has revealed oxygen sensors can easily be damaged by liquid water exposure, but this has been successfully avoided by locating the oxygen sensor upstream of the catalyst. The research project with Southwest Research Institute is expected to yield some relatively simple design fixes which will minimize this water exposure, and prolong oxygen sensor life. While the boat being tested does not have catalysts installed, we expect to install oxygen sensors and quantify the lifetime improvement.

ARB is presently developing a test program with Southwest Research Institute to further examine catalyst-equipped engines in boats. The envisioned program will be conducted in coordination with the engine manufacturers, U.S. Coast Guard, and the catalyst manufacturers. We expect to jointly tackle the remaining catalyst adaptability issues for the engine manufacturers large and small, well before the proposed 2003 technology review before the Board.

C. Safety

The U.S. Coast Guard expressed concerns about run-away catalyst overheating, potential carbon monoxide leakage from exhaust pipe joints, and increased engine-compartment heat load.

In many hours of testing, we have noticed only two incidents of catalyst overheating, and a few exhaust leaks (showed up by water leaks on initial installation of water jacket catalyst pieces). The catalyst overheating was caused by cylinder misfire from poor fuel control (worst at idle condition) and loss-of-compression (engine cylinder head damage) due to running the engine too hard during testing. Replacing the cylinder heads with new ones restored compression and engine performance, and upgrading the air-fuel control software has allowed precise and lean fuel-control at idle, eliminating misfires. In this incident the only damage was to the catalyst ceramic itself—sintering of the precious metal sites, leading to deactivation. The exterior exhaust pipe walls were cooled with water at all times. There was no explosion or burn-hazard.

The exhaust pipe leaks which could have led to carbon monoxide leaks were immediately visible as water leaks. Flattening or truing flat metal flange surfaces, applying good gaskets, and using gasket sealant on the joints took care of the water leaks, evidence of water-tight joints and therefore gas-tight joints.

We have performed a battery of dry cool-down tests on hot catalysts, and have found only mild, short temperature excursions of the cast-iron exhaust pipe metal. The temperatures stayed below the American Boating and Yacht Council (ABYC) consensus skin temperature limits.

The cooperative test program discussed above with the engine manufacturers, U.S. Coast Guard, and catalyst manufacturers will also address these issues.

D. Effect on low-end sales

The manufacturers have commented that the inclusion of equipment on engines which raises the cost by about $500 will seriously reduce sales of the small four-cylinder engines which now cost $3000 to 4000. These engines are offered as entry-level economy choices. They are now about the same price as a similar power two-stroke outboard. Starting this year in California only direct-fuel-injected two-strokes and four-stroke outboard engines are able to be sold. The direct-injection two-strokes cost about $3000 more than the conventional outboards.

The economy inboard 4-cylinder engines are now sold only as carbureted versions. Most of the increased cost for these engines due to the regulation will be the conversion of the engine to electronic multi-point fuel injection. Electronic fuel-injection is not specifically required to meet the standards proposed in this rule. However, it offers computer-control which is able to be integrated with exhaust oxygen feedback to optimize the performance of the three-way exhaust catalyst. So, while not being a required feature, it is a desirable or important one. It should be added that the maker of these engines, General Motors, has projected that the low-end 4-cylinder engine will be replaced by a sequentially fuel-injected version in 2005 or so. In 1997 General Motors started only supplying the larger engines (*e.g.*, 454 cubic inch displacement) as factory-installed multi-port fuel-injected. Last year, they completely replaced larger engines with a sequentially fuel-injected model.

The projected price increase is well within the range of California personal income gains in recent years. During 1990 to 1999, California personal income rose by about 1.8 to 8.1 percent annually (Department of Finance, 2001). Thus, the estimated price increase is not expected to have a significant impact on the marine engine demand in California.

E. Research costs for small-volume manufacturers

Section VII (Cost of Control) lists development costs of millions of dollars to adapt automotive control to on-boat engines. This is a large expense for a company the size of the Mercury MerCruiser Division, but it is a nearly impossible expense for the six-odd small companies which together share 20% of the inboard and sterndrive gasoline engine market.

The cost-effectiveness or per-engine costs shown in Section VII assume that this development cost is spread out over sales of about 3300 units per year. This is only true of a few model-lines from the large manufacturers on a nationwide basis. The other models and manufacturers have much lower sales to spread these costs over.

The ARB and U.S. EPA have already spent more than $350,000 to develop marine catalyst engines. We expect the knowledge gained on catalyst placement and life, advanced ECM programming, and water exposure of exhaust components to be available and shared by all the engine manufacturers and boat builders with equal opportunity. As previously mentioned, the ARB and U.S. EPA have recently committed to the industry to organize and contribute funding to a multi-year in-boat demonstration program to prove many of the issues of catalyst durability and engine driveability, safety *etc*. Again, we expect this information to be shared among all the boat builders and engine manufacturers.

XI. CONCLUSIONS

Staff's goal in developing this regulation is to achieve emission reductions from marine gasoline engines commensurate with that achieved by feedback air-fuel control with three-way exhaust catalysts, a successful automotive technology. This proposal was developed in coordination with U.S. EPA, the engine manufacturers, the boat-builders, the catalyst makers, the U.S. Coast Guard, and was backed up with marine engine emission control device development and emission tests and in-boat, on-the-water testing. The proposed standards are achievable by applying presently available and effective technology to these largely uncontrolled engines. Cooperative development and testing will continue, and the staff will conduct technology reviews to be shared with the Board in 2003 and 2005.

Staff recommends adoption of the proposed regulation, estimated to achieve 56 tpd of combined HC+NOx reductions statewide in 2020, a 30% reduction from present uncontrolled levels.

The proposed emission reductions are necessary to help meet commitments made in the 1994 SIP, and a subsequent settlement agreement.

Finally, the ARB has determined that no reasonable alternative considered by the agency or that has otherwise been identified and brought to the attention of the agency would be more effective in carrying out the purpose for which the action is proposed or would be as effective and less burdensome to affected private persons or businesses than the proposed action.

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