Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment

Final Regulatory Impact Analysis

Executive Summary

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

EPA United States Environmental Protection Agency

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Executive Summary

The Environmental Protection Agency (EPA) is establishing new requirements to reduce emissions of hydrocarbon (HC) and oxides of nitrogen (NOx) from nonroad small spark ignited engines below 19kW ("Small SI engines") and marine spark ignited engines ("Marine SI engines"). This rule includes exhaust and evaporative emission standards for these engines as well as related gasoline fuel tanks and fuel lines.

This executive summary describes the relevant air-quality issues, highlights the new exhaust and evaporative emission standards, and gives an overview of the analyses in the rest of this document.

Air Quality Background and Environmental Impact of the Rule

Emissions from Small SI engines and equipment and Marine SI engines and vessels contribute to a number of serious air pollution problems and will continue to do so in the future absent further reduction measures. Such emissions lead to adverse health and welfare effects associated with ozone, particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOC) including toxic compounds, and carbon monoxide (CO). These emissions also cause significant public welfare harm, such as damage to crops and regional haze.

Millions of Americans continue to live in areas with unhealthy air quality that may endanger public health and welfare. As of March 2008 approximately 139 million people live in the 72 areas that are designated as nonattainment for the 8-hour ozone National Ambient Air Quality Standards (NAAQS). In addition, approximately 88 million people live in areas that are designated as nonattainment for the $PM_{2.5}$ NAAQS. Federal, state, and local governments are working to bring ozone and PM levels into attainment with the NAAQS. The reductions included in this rule will be useful to states in attaining and maintaining the ozone, CO, and PM NAAQS.

In 2002, emissions from land-based nonroad Small SI engines and Marine SI engines were estimated to be about 26 percent of the total mobile-source inventory of VOC emissions and 1 percent of the NOx inventory. As presented in Figures 1 and 2, this rule will significantly reduce future Small SI and Marine SI emission inventories.

Figure 1: Small Spark Ignition VOC+NOx Baseline and Phase 3 Control Emission Inventory

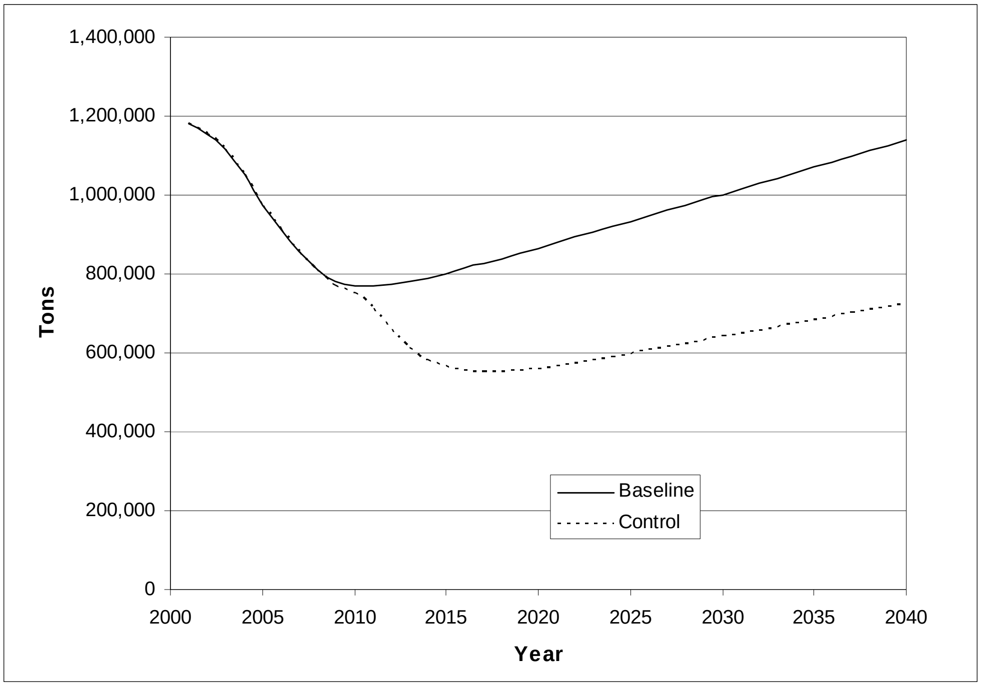
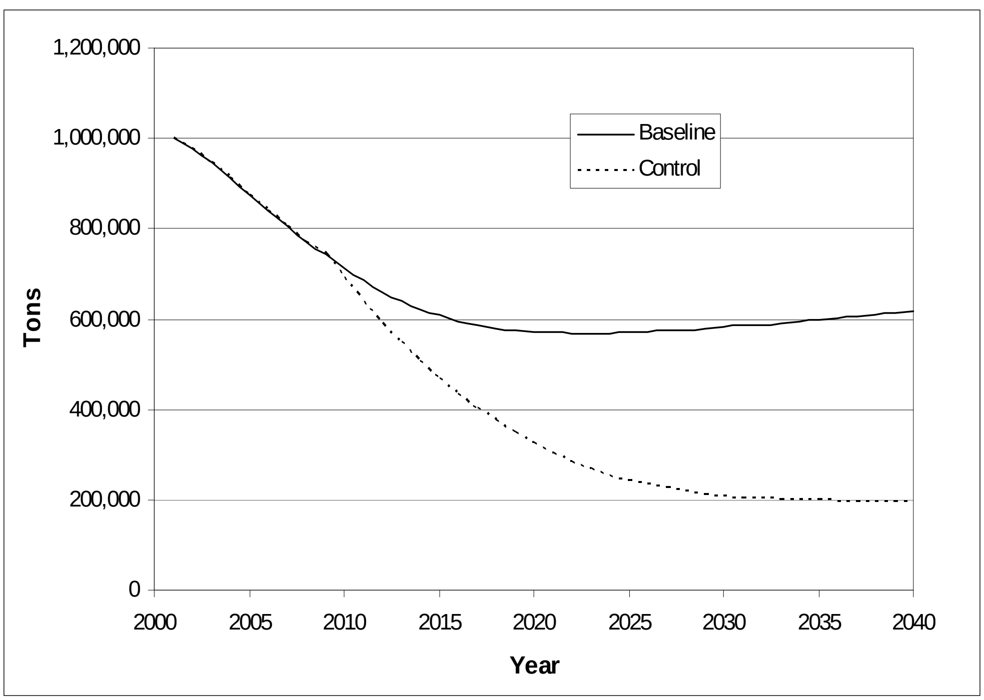


Figure 2: Marine Spark Ignition VOC+NOx Baseline and Phase 3 Control Emission Inventory



Exhaust and Evaporative Emission Standards

Tables 1 through 4 show the exhaust and evaporative emission standards and when they will apply. For Small SI nonhandheld engines, the standards are expected to result in the use of engine modificiations, aftertreatment systems, and some use of electronic fuel injection in Class II engines. As shown in Tables 1 through 4, we are phasing in many of the standards over time to address considerations of lead time, workload, and overall feasibility. In addition, the rule includes other provisions designed to address the transition to meeting the standards.

Table 1: Small SI Nonhandheld Engine Exhaust Emission Standards and Schedule

Engine Class	Model Year	HC+NOx [g/kW-hr]	CO[a] [g/kW-hr]
Class I (>80cc to <225cc)[b]	2012	10.0	610
Class II (≥225cc)	2011	8.0	610

[a] 5 g/kW-hr CO for Small SI engines powering marine generators.
[b] Nonhandheld engines at or below 80cc will be subject to the emission standards for handheld engines.

Table 2: Small SI Equipment Evaporative Emission Standards and Schedule

	Fuel Line Permeation	Tank Permeation	Running Loss
Standard Level	15 $g/m^2/day$	1.5 $g/m^2/day$	Design Standard
Handheld	2012[a,b]	2009-2013[c]	NA
Class I	2009	2012	2012
Class II	2009	2011	2011

[a] 2013 for small-volume families.
[b] A separate set of declining fuel line permeation standards applies for cold-weather equipment from 2012 through 2016. A standard of 225 $g/m^2/day$ for cold-weather equipment fuel lines applies for 2016 and later.
[c] 2009 for families certified in California, 2013 for small-volume families, 2011 for structurally integrated nylon fuel tanks, and 2010 for remaining families.

Table 3a: Outboard/PWC Marine SI Engine Exhaust Standards and Schedule[a]

Pollutant	Power[b]	Emission Standard[b]	Model Year
HC+NOx	$P \leq 4.3$ kW	30.0	2010
	P> 4.3 kW	$2.1 + 0.09 \times (151 + 557/P^{0.9})$	2010
CO	$P \leq 40$ kW	$500 – 5.0 \times P$	2010
	P> 40 kW	300	2010

[a] These engines are also subject to not-to-exceed standards
[b] P = maximum engine power in kilowatts (kW).

Table 3b: Sterndrive/Inboard Marine SI Engine Exhaust Standards and Schedule

Power[a]	Model Year	HC+NOx [g/kW-hr]	CO [g/kW-hr]
$P \leq 373$ kW[b]	2010[c]	5.0	75
High-performance engines $\leq$ 485 kW [d]	2010	20.0	350
	2011	25.0	350
High-performance engines $\leq$ 485 kW [d]	2010	16.0	350
	2011	22.0	350

[a] P = maximum engine power in kilowatts (kW).
[b] These engines are also subject to not-to-exceed standards. This category also includes engines >373 kW that do not otherwise meet the definition of "high-performance."
[c] 2011 for small-businesses and for engines built using the 4.3L or 8.1L GM engine blocks.
[d] For small businesses, the 2010 standards do not apply and the 2011 standards are delayed until 2013.

Table 4: Marine SI Engine Evaporative Emissions Standards and Schedule

	Fuel Line Permeation	Tank Permeation	Diurnal
Standard Level	15 $g/m^2/day$	1.5 $g/m^2/day$	0.40 g/gal/day
Portable Tanks	2009[a]	2011	2010[b]
PWC	2009	2011	2010
Other Installed Tanks	2009[a]	2012	2011[c,d]

[a] 2011 for primer bulbs. Phase-in for under cowl fuel lines, by length, on OB engines: 30% 2010, 60% 2011, 90% 2012, 100% 2015.
[b] Design standard.
[c] Fuel tanks installed in nontrailerable boats ($\geq$ 26 ft. in length or >8.5 ft. in width) may meet a standard of 0.16 g/gal/day over an alternative test cycle.
[d] The standard is effective July 31, 2011. For boats with installed fuel tanks, this standard is phased-in 50%/100% over the first two years. As an alternative, small manufacturers may participate in a diurnal allowance program.

EPA has also taken steps to ensure that engines built to these standards achieve more accurate emissions reductions and is upgrading the test requirements to those listed in 40CFR1065 as outlined in Preamble Section IX General Test Procedures.

Feasibility of Meeting the Small SI Engine Exhaust Emission Standards

Since 1997, exhaust emission control development for Small SI engines has concentrated on engine redesign including carburetor design, improved engine combustion and engine cooling. The primary technical focus of the new emission standards will be engine upgrades as needed, catalyst application to the majority of Small SI engines and electronic fuel injection on some Class II engines. Related information is in Chapter 4.

We are finalizing, more stringent exhaust HC+NOx standards for Class I and II Small SI engines. We are also establishing a new CO standard for Small SI engines used in marine generator applications. The standards differ by engine size. Class I engines have a total engine displacement of < 225cc. Class II engines have a total engine displacement of ≥225cc.

In the 2008 model year, manufacturers certified nearly 235 Class I and II engine families to the Phase 2 standards using a variety of engine designs and emission control technology. All Class I engines were produced using carbureted air-fuel induction systems and are air cooled. An extremely small number of engines used catalyst-based emission control technology. Similarly, Class II engines were predominantly carbureted and air cooled. A limited number of these engines used catalyst technology, electronic engine controls and fuel injection, and/or water
cooling.

The market focus has a large part to play in the engine design and quality. The large number of residential and commercial applications have led to a wide variety of engine qualities and designs in the marketplace today. Some of the more durable engine designs already incorporate the base design requirements needed to incorporate a catalyst to meet the Phase 3 emission standards. In addition, a number of engine families in both classes are currently certified at levels that would comply with the Phase 3 standards.

Based on our own testing of advanced technology for these engines, our engineering assessments, and statements from the affected industry, we believe the requirements will lead many engine manufacturers to adopt exhaust aftertreatment technology using catalyst-based systems. Other likely engine changes include improvements in engine designs, cooling system designs and fuel delivery systems. The addition of electronic controls and/or fuel injection systems to some Class II engine families may obviate the need for catalytic aftertreatment, with the most likely candidates being multi-cylinder engine designs.

Information herein on the feasibility assessment of exhaust emissions on Small SI engines includes the emission evaluation of current product and advanced technology engines. Areas covered include laboratory and field evaluations, review of patents of existing catalyst/muffler designs for Class I engines, discussions with engine manufacturers and suppliers of emission control-related engine components regarding recent and expected advances in emissions performance, and an analysis of catalyst/muffler units that were already in mass production by an original equipment manufacturer for use on European walk-behind lawn mowers.

EPA used this information to design, build and emission test prototype catalyst-based emission control systems that were capable of effectively and safely achieving the Phase 3 emission standards on both Class I and Class II engines. Chapter 4 projects that in some cases manufacturers of Class I and Class II engines may need to improve the durability of their basic engine designs, cooling system designs, ignition systems, or fuel metering systems for some engines in order to comply with the Phase 3 emission regulations over the useful life. EPA also built and tested electronic fuel injection systems on two twin cylinder Class II engines and emission tested them with and without catalysts. EFI improves the management of air-fuel mixtures and ignition spark timing and each of the engines achieved the requisite emission limit for HC+NOx (e.g., 8.0 g/kW-hr). Based on this work and information from one manufacturer of emission controls, we believe that either a catalyst-based system or electronic engine controls appear sufficient to meet the standard. Manufacturers adopting the EFI approach will likely realize other advantages such as easier starting, more stable and reliable engine operation, and reduced fuel consumption.

We also used the information and the results of our engine testing to assess the potential need for improvements to engine, cooling and fuel system designs. A great deal of this effort was conducted in association with our more in-depth study regarding the efficacy and safety of implementing advanced exhaust emission controls on Small SI and recreational Marine SI engines, as well as new evaporative requirements for these engines, equipment, and vessels. The results of that study are also discussed in Chapter 4.

There are a number of Class II engines that use gaseous fuels (i.e., liquid propane gas or compressed natural gas). Based on our engineering evaluation of current and likely emission control technology for these engines, we conclude that these engines will use catalysts, or larger catalysts than current, in order to achieve the Phase 3 HC+NOx standard. Some engines currently meet the Phase 3 emission standards.

Regarding the marine generator CO standard, two manufacturers that produce the majority of marine generators have announced that as a result of boat builder demand, they are converting their marine generator product lines to new designs which can achieve more than a 99 percent reduction in CO emissions in order to reduce the risk of CO poisoning. These low CO emission designs used closed-loop electronic fuel injection and catalytic control on engines which are water cooled using the lake or sea water. Both of these manufacturers have certified some low CO engines and have expressed their intent to convert their full product lines in the near future. These manufacturers also make use of electronic controls to monitor catalyst function.

Feasibility of Meeting the Marine SI Exhaust Emission Standards

The technology is available for marine engine manufacturers to use to meet the new standards. This technology is the same that manufacturers are anticipated to use to meet the California ARB standards in 2008. For outboards and personal watercraft (OB/PWC) this largely means extended use of lower-emitting engine technology widely used today. For sterndrive and inboard (SD/I) marine engines, this means the use of catalytic converters in the exhaust system. Chapter 4 includes detailed descriptions of low emission technologies for marine engines, including emissions test data on these technologies.

OB/PWC

Over the past several years, manufacturers have demonstrated their ability to achieve significant HC+NOx emission reductions from OB/PWC engines. This has largely been accomplished through the introduction of two-stroke direct injection engines in some applications and conversion to four-stroke engines. Current certification data for these types of engines show that these technologies may be used to achieve emission levels significantly below the existing exhaust emission standards. In fact, California has adopted standards requiring a 65 percent reduction beyond the current federal standards beginning in 2008.

Our own analysis of recent certification data shows that most four-stroke outboard engines and many two-stroke direct injection outboard engines currently meet the new HC+NOx standard. Similarly, although PWC engines tend to have higher HC+NOx emissions, presumably due to their higher power densities, many of these engines also meet the new HC+NOx standard. Although there is currently not a CO emission standard for OB/PWC engines, OB/PWC manufacturers are required to report CO emissions from their engines. These emissions are based on test data from new engines and do not consider deterioration or compliance margins. Based on this data, all of the two-stroke direct injection engines show emissions well below the new standards. In addition, the majority of four-stroke engines meet the CO standards as well.

We therefore believe the HC+NOx and CO emission standards can be achieved by phasing out conventional carbureted two-stroke engines and replacing them with four-stroke engines or two-stroke direct injection engines. This has been the market-driven trend over the last five years. Chapter 4 compares recent certification data to the new standards.

SD/I

Engine manufacturers can adapt readily available technologies to control emissions from SD/I engines. Electronically controlled fuel injection gives manufacturers more precise control of the air/fuel ratio in each cylinder, thereby giving them greater flexibility in how they calibrate their engines. With the addition of an oxygen sensor, electronic controls give manufacturers the ability to use closed-loop control, which is especially valuable when using a catalyst. In addition, manufacturers can achieve HC+NOx reductions through the use of exhaust gas recirculation. However, the most effective technology for controlling emissions is a three-way catalyst in the exhaust stream.

In SD/I engines, the exhaust manifolds are water-jacketed and the water mixes with the exhaust stream before exiting the vessel. Manufacturers add a water jacket to the exhaust manifold to meet temperature-safety protocol. They route this cooling water into the exhaust to protect the exhaust couplings and to reduce engine noise. Catalysts must therefore be placed upstream of the point where the exhaust and water mix-this ensures the effectiveness and durability of the catalyst. Because the catalyst must be small enough to fit in the exhaust manifold, potential emission reductions are not likely to exceed 90 percent, as is common in land-based applications. However, as discussed in Chapter 4 of the Final RIA, data on catalyst-equipped SD/I engines show that emissions may be reduced by 70 to 80 percent for HC+NOx and 30 to 50 percent for CO over the test cycle. Larger reductions, especially for CO, have been achieved at lower-speed operation.

Chapter 4 discusses issues that have been addressed in catalyst designs for SD/I engines such as sustained operation at high load, potential saltwater effects on catalyst efficiency, and thermal shock from cold water contacting a hot catalyst. Test programs have been performed to evaluate catalysts in the laboratory and on the water. Three SD/I engine manufacturers have certified SD/I engines to the California ARB standards, and some catalyst-equipped engines are available for purchase nationwide. Manufacturers have indicated that they have successfully completed durability testing, including extended in-use testing on saltwater.

Feasibility of Meeting the Evaporative Emission Standards

There are many feasible control technologies that manufacturers can use to meet the evaporative emission standards. We have collected emission test data on a wide range of technologies for controlling evaporative emissions. Chapter 5 presents a description of the evaporative emission sources which include permeation, diurnal, running loss, hot soak, and refueling emissions. In addition, Chapter 5 presents evaporative emission test data for current Small SI and marine fuel systems and on a wide range of evaporative emission control technologies. Below is an overview of technologies that are available for meeting the evaporative emission standards.

Low-permeation fuel lines are in production today. One fuel line design, already used in some marine applications, uses a thermoplastic layer between two rubber layers to control permeation. This thermoplastic barrier may either be nylon or ethyl vinyl acetate (EVOH). Barrier approaches in automotive applications include fuel lines with fluoroelastomers such as FKM and fluoroplastics such as Teflon and THV. In addition to presenting data on low-permeation fuel lines, Chapter 5 lists several fuel-system materials and their permeation rates. Molded rubber fuel line components, such as primer bulbs and some handheld fuel lines, could meet the standard by using a fluoroelastomer such as FKM.

Plastic fuel tanks used in Small SI and Marine SI applications can be molded using several processes. While no fuel tank permeation control strategy will work for all production processes and materials, there are multiple control strategies available for fuel tanks manufactured with each of the molding processes. These molding processes include blow-molding, injection-molding, thermoforming, rotational-molding, and hand built constructions (fiberglass).

Multi-layer fuel tanks can be formed using most of these molding processes. These fuel tank constructions include a barrier layer of a low permeation material such as ethylene vinyl alcohol (EVOH) or nylon. This technology has been used in blow-molded fuel tanks for automotive applications for many years and can achieve emission levels well below the new standard. For thermoformed fuel tanks, a similar barrier formed into the plastic sheet that is later molded into a fuel tank. Rotationally-molded fuel tanks can be produced with an inner barrier layer such as nylon. As an alternative, in the blow-molding process, a low-permeable resin can be blended with polyethylene and extruded it with a single screw. Although the barrier is not continuous, this strategy can still be used to meet the permeation standard. A similar strategy may be used for fiberglass fuel tank where the barrier material is clay nanocomposites. Finally, fuel tanks may be formed entirely out of a low permeation material such as nylon or an acetal copolymer. Many fuel tanks used with handheld equipment use nylon fuel tanks.

Another approach to producing fuel tanks that meet the permeation standards would be to create permeation barrier through a post-processing step. Regardless of the molding process, another type of low-permeation technology for high-density polyethylene fuel tanks would be to treat the surfaces with a barrier layer. Two ways of achieving this are known as fluorination and sulfonation. In these processes, the tanks are exposed to a gas which forms a permeation barrier on the surfaces of the fuel tank. Either of these processes can be used to reduce gasoline permeation by more than 95 percent. Additionally, a barrier layer can be put onto a fuel tank with the use of an epoxy barrier coating.

There are several technologies that can be used to reduce diurnal emissions from marine fuel tanks. The simplest approach is to seal the fuel tank. Portable fuel tanks currently use manual valves that can be closed to seal the fuel tank. PWC typically use sealed fuel systems with pressure relief valves that open at pressures ranging from 0.5 to 4.0 psi. For other vessels with installed fuel tanks, manufacturers have commented that even 1.0 psi of pressure would be too high for their applications. Through the use of a carbon canister in the vent line, diurnal emissions can be controlled from these fuel tanks without creating significant pressure in the fuel tank. With this technology, vapor generated in the tank is vented to a canister containing activated carbon. The fuel tank must be sealed such that the only venting that occurs is through the carbon canister. The activated carbon collects and stores the hydrocarbons. The activated carbon bed in the canister is refreshed by purging the vapors with air flow. The standard is based on the air flow being generated by the natural breathing of the fuel tank as it heats and cools.

Running loss emissions can be controlled from Small SI equipment by sealing the fuel cap and routing vapors from the fuel tank to the engine intake. In doing so, vapors generated by heat from the engine will be burned in the engine's combustion chamber. It may be necessary to use a valve or limited-flow orifice in the purge line to prevent too much fuel vapor from reaching the engine and to prevent liquid fuel from entering the line if the equipment flips over. Depending on the configuration of the fuel system and purge line, a one-way valve in the fuel cap may be desired to prevent a vacuum in the fuel tank during engine operation. We anticipate that a system like this would eliminate running loss emissions. However, higher temperatures during operation and the additional length of vapor line would slightly increase permeation.

Considering these effects, we still believe that the system described here would reduce running losses from Small SI equipment by more than 90 percent.

Many manufacturers today use fuel caps that by their design effectively limit the diffusion of gasoline from fuel tanks. In any case, we expect that the new running loss design standard will limit any diffusion emissions from this equipment. As discussed in Chapter 5, venting a fuel tank through a tube (rather than through an open orifice) greatly reduces diffusion.

Estimated Costs and Cost-Effectiveness for Small SI Engines and Equipment

There are approximately 410 nonroad equipment manufacturers using Small SI engines in over a thousand different equipment models. There are more than 50 engine manufacturers certifying Small SI engine families for these applications. Fixed costs consider engine research and development, engine tooling, engine certification, and equipment redesign. Variable costs include estimates for new emission-control hardware. Near-term and long-term costs for some example pieces of equipment are shown in Table 5. Also shown in Table 5 are typical prices for each piece of equipment for reference. See Chapter 6 for detailed information related to our engine and equipment cost analysis.

Table 5: Estimated Costs for Several Example Pieces of Equipment ($2005)[a] Over the Range of Useful Life Categories for Small SI Engines[b]

		Class I	Class II	Handheld (Class III-V)
Exhaust	Near Term	$10 to $26	$17 to $60	$0.28
	Long Term	$10 to $12	$12 to $30	$0.00
Evaporative	Near Term	$3.05	$6.73	$0.82
	Long Term	$2.20	$5.16	$0.69
Total (without fuel savings)				
	Near Term	$14 to $26	$46 to $92	$1.12
	Long Term	$11 to $17	$27 to $52	$0.69
Total (with fuel savings)[c]				
	Near Term	$13 to $25	$1-$48/$40-$86	$0.72
	Long Term	$10 to $16	-$18-$6/$21-$46	$0.29
			Engines w/ and w/o EFI	
Estimated Equipment Price Range		$100-$2,800	$300-$6800	$210 avg

[a] Near-term costs include both variable costs and fixed costs; long-term costs include only variable costs and represent those costs that remain following recovery of all fixed costs.
[b] Class I (125,250, or 500 hours), Class II (250, 500, or 1000 hours)
[c] Class I, Class II and handheld have fuel savings from evaporative measures. Class II engines with EFI have fuel savings of $39 based on the lifetime savings in the use of a residential ride on mower. There are no fuel savings related to compliance with the exhaust emission standard for Class I, handheld, or Class II engines without EFI.

Chapter 6 presents aggregate costs of compliance for the new exhaust and evaporative emission standards for Small SI engines. Table 6 presents the annualized aggregate costs and fuel savings for the period from 2008-2037. The annualized fuel savings for Small SI engines are due to reduced fuel costs form the sue of electronic fuel injection on Class II engines as well as fuel savings from evaporative measures on all Small SI engines.

Table 6: Estimated Annualized Cost to manufacturers and Annualized Fuel Savings for Small SI Engines and Equipment at a 7% Discount Rate (2005$)

	Annualized Cost to Manufacturers (millions/yr)	Annualized fuel savings (millions/yr)
Exhaust	$182	$24
Evaporative	$65	$53
Aggregate	$247	$77

Chapter 7 describes the cost effectiveness analysis. In this analysis, the aggregate costs of compliance are determined for the period 2008-2037. The discounted aggregate costs for the period are divided by the discounted aggregate HC_NOx emission reductions.

Table 7: Aggregate Cost per Ton for Small SI Engines and Equipment 2008-2037 Net Present Values at 7% Discount Rate ($2005)

Pollutant NOx+HC	Aggregate Discounted Lifetime Cost per ton Without Fuel Savings	Aggregate Discounted Lifetime Cost per ton With Fuel Savings
7%	$978	$650

Estimated Costs and Cost-Effectiveness for Marine SI Engines

According to the US Coast Guard there are well over a thousand different boat builders using Marine SI engines. There are about 10 engine manufacturers certifying to the current OB/PWC exhaust emission standards. We have identified more than 30 companies manufacturing SD/I marine engines. Fixed costs consider engine research and development, engine tooling, engine certification, and equipment redesign. Variable costs include estimates for new emission-control hardware. Near-term and long-term costs for three different Marine SI applications are shown in Table 8. Also shown in Table 8 are typical prices for these types of marine vessels. See Chapter 6 for detailed information related to our engine and equipment cost analysis.

Table 8: Estimated Average Incremental Costs for SI Marine Engines and Vessels ($2005)[a]

Engine Category (Fuel Storage System)	Outboard (Portable)	PWC	SD/I (Installed)
Exhaust			
Near Term	$291	$359	$355
Long Term	$224	$272	$266
Evaporative			
Near Term	$12	$17	$74
Long Term	$8	$11	$62
Total (without fuel savings)[b]			
Near Term	$433	$376	$487
Long Term	$336	$283	$376
Total (with fuel savings)[b]			
Near Term	$245	$165	$348
Long Term	$148	$72	$237
Estimated Vessel Price Range	$10,000-50,000	$6,000-12,000	$20,000-200,000

[a] Near-term costs include both variable costs and fixed costs; long-term costs include only variable costs and represent those costs that remain following recovery of all fixed costs.

[b] Total costs are presented as an average per boat and consider that many boats have multiple engines.

Chapter 6 presents aggregate costs of compliance for the new exhaust and evaporative emission standards for Marine SI engines. Table 9 presents the annualized aggregate costs and fuel savings for the period from 2008-2037. The annualized fuel savings for Marine SI engines are due to reduced fuel costs from the use of more fuel efficient engines as well as fuel savings from evaporative measures.

Table 9: Estimated Annualized Cost to Manufacturers and Annualized Fuel Savings for Marine SI Engines and Vessels at a 7% Discount Rate (2005$)

	Annualized Cost to Manufacturers (millions/yr)	Annualized Fuel Savings (millions/year)
Exhaust	$123	$56
Evaporative	$22	$22
Aggregate	$144	$78

Chapter 7 describes the cost effectiveness analysis. In this analysis, the aggregate costs of compliance are determined for the period 2008-2037. The discounted aggregate costs for the period are divided by the discounted aggregate HC+NOx emission reductions over that same period. Table 10 presents the cost per ton estimates with and without fuel savings.

Table 10: Aggregate Cost per Ton for SI Marine Engines and Vessels 2008-2037 Net Present Values at 7% Discount Rate ($2005)

Pollutant NOx+HC	Aggregate Discounted Lifetime Cost per ton Without Fuel Savings	Aggregate Discounted Lifetime Cost per ton With Fuel Savings
7%	$780	$360

Economic Impact Analysis

We prepared a final Economic Impact Analysis estimate the market and social welfare impacts of the new standards. This analysis can be found in Chapter 9. According to this analysis, the average price of a Marine SI engine in 2030 is projected to increase by less than 2 percent ($213) as a result of the new standards, and the average price of a Marine SI vessel is projected to increase by between 0.7 percent and 2.4 percent ($218 to $702), depending on the type of vessel. The average price of a Small SI engine in 2030 is projected to increase by about 7.4 percent ($12), and the average price of Small SI nonhandheld equipment is projected to increase by between 2.2 percent and 5.6 percent ($15 to $20), depending on equipment class. Changes in quantity produced are expected to be small, at less than 2 percent. The exceptions are PWC (4.8 percent) and Class II equipment (2.4 percent).

The net social costs of the program in 2030 are estimated to be $186 million. This includes $459 million of direct social costs and $273 million on fuel savings for the end users of these products. Overall, the consumers of Marine SI vessels and Small SI equipment are expected to bear the majority of the costs of complying with the program: 76 percent of the Marine SI program social costs in 2030, and 91 percent of the Small SI program social costs. However, when the fuel savings are considered, the social costs burden for consumers of Marine SI equipment becomes a net benefit (the fuel savings are greater than the compliance costs of the program), while the end-user share of the Small SI program drops to 86 percent.

Benefits

We estimate that the requirements in this rulemaking will result in substantial benefits to public health and welfare and the environment, as described in Chapter 8. The benefits analysis performed for this rulemaking uses sophisticated air quality and benefit modeling tools and is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality and peer-reviewed studies of the dollar values of those public health and welfare effects.

The range of benefits associated with this program are estimated based on the risk of several sources of PM- and ozone-related mortality effect estimates, along with all other PM and ozone non-mortality related benefits information. These benefits are presented in Table 11. The benefits reflect two different sources of information about the impact of reductions in PM on reduction in the risk of premature death, including an estimate of mortality derived from the epidemiological literature (the American Cancer Society (ACS) cohort study - Pope et al., 2002) and an expert elicitation study conducted by EPA in 2006. In order to provide an indication of the sensitivity of the benefits estimates to alternative assumptions, in Chapter 8 of the RIA we present a variety of benefits estimates based on two epidemiological studies (including the ACS Study and the Six Cities Study) and the expert elicitation. EPA intends to ask the Science Advisory Board to provide additional advice as to which scientific studies should be used in future RIAs to estimate the benefits of reductions in PM.

The range of ozone benefits associated with the final standards is also estimated based on risk reductions estimated using several sources of ozone-related mortality effect estimates. There is considerable uncertainty in the magnitude of the association between ozone and premature mortality. This analysis presents four alternative estimates for the association based upon different functions reported in the scientific literature. We use the National Morbidity, Mortality and Air Pollution Study (NMMAPS), which was used as the primary basis for the risk analysis in the ozone Staff Paper and reviewed by the Clean Air Science Advisory Committee (CASAC). We also use three studies that synthesize ozone mortality data across a large number of individual studies. Note that there are uncertainties within each study that are not fully captured by this range of estimates. Chapter 8 of the RIA presents the results of each of the ozone mortality studies separately.

In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure. The report also recommended that the estimation of ozone-related premature mortality be accompanied by broad uncertainty analyses while giving little or no weight to the assumption that there is no causal association between ozone exposure and premature mortality. Because EPA has yet to develop a coordinated response to the NRC report's findings and recommendations, however, we have retained the approach to estimating ozone-related premature mortality used in RIA for the final Ozone NAAQS. EPA will specifically address the report's findings and recommendations in future rulemakings.

The range of total ozone- and PM-related benefits associated with the final standards is presented in Table 11. We present total benefits based on the PM- and ozone-related premature mortality function used. The benefits ranges therefore reflect the addition of each estimate of ozone-related premature mortality (each with its own row in Table 11) to estimates of PM-related premature mortality, derived from either the epidemiological literature or the expert elicitation.

Table 11: Estimated Monetized PM- and Ozone-Related Health Benefits of the Small SI and Marine SI Engine Standards

2030 Total Ozone and PM Benefits - PM Mortality Derived from Epidemiology Studies[a]		
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2005$, 3% discount rate)[c,d]
NMMAPS	Bell et al., 2004	$2.4
Meta-analysis	Bell et al., 2005	$3.7
	Ito et al., 2005	$4.4
	Levy et al., 2005	$4.4
Assumption that association is not causal[e]		$1.8
2030 Total Ozone and PM Benefits - PM Mortality Derived from Expert Elicitation[b]		
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2005$, 3% discount rate)[c,d]
NMMAPS	Bell et al., 2004	$1.7 to $9.7
Meta-analysis	Bell et al., 2005	$3.0 to $11
	Ito et al., 2005	$3.7 to $12
	Levy et al., 2005	$3.7 to $12
Assumption that association is not causal[e]		$1.1 to $9.1

[a] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to an estimate of PM2.5-related premature mortality derived from the ACS (Pope et al., 2002) study.
[b] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.
[c] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 8.4-1.
[d] Results reflect the use of a 3 percent discount rate. Monetary results presented in Table 8.6-2 use both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.
[e]A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

We estimate that by 2030, the annual emission reductions associated with these more stringent standards will annually prevent 230 PM-related premature deaths (based on the ACS cohort study), between 77 and 350 ozone-related premature deaths (assuming a causal relationship between ozone and mortality), 1,700 hospital admissions and emergency room visits, 23,000 work days lost, and approximately 590,000 minor restricted-activity days.

Impact on Small Businesses

Chapter 10 discusses our Small Business Flexibility Analysis, which evaluates the impacts of the emission standards on small entities. As a part of this analysis, we interacted with several small entities representing the various affected sectors and convened a Small Business Advocacy Review (SBAR) Panel to gain feedback and advice from these representatives. The small entities that participated in the process included engine manufacturers, equipment manufacturers, vessel manufacturers, fuel tank manufacturers, and fuel hose manufacturers. The feedback from these companies was used to develop regulatory options which could address the impacts of the rule on small businesses. Small entities raised general concerns related to potential difficulties and costs of meeting the new standards.

The SBAR Panel consisted of representatives from EPA, the Office of Management and Budget, and the Small Business Administration. The Panel developed a wide range of regulatory flexibilities to mitigate the impacts of the standards on small entities, and recommended that we propose and seek comment on the flexibilities. Chapter 10 discusses the flexibilities recommended by the Panel, and the flexibilities we are finalizing with today's rule. We are establishing several provisions that give affected small entities several compliance options aimed specifically at reducing their compliance burdens. In general the options are similar to small entity provisions adopted in prior rulemakings where EPA set standards for other types of nonroad engines. The provisions include extra lead time for complying with the new standards, reduced testing requirements for demonstrating compliance with the new standards, and hardship provisions to address significant economic impacts and unusual circumstances related to the new standards. These provisions are intended to reduce the burden on small entities that will be required to meet the new emission standards when they are implemented. Given all of the flexibilities being adopted for small entities, we believe that this action will not have a significant economic impact on a substantial number of small entities.

Alternative Program Options

In developing the emission standards, we considered several alternatives including less and/or more stringent options. The paragraphs below summarize the information considered in Chapter 11 of the Draft RIA.

Small SI Engines

For Small SI engines, we considered what was achievable with catalyst technology. Our technology assessment work indicated that the emission standards are feasible in the context of provisions for establishing emission standards prescribed in section 213 of the Clean Air Act. We also considered what could be achieved with larger, more efficient catalysts and improved fuel induction systems. In particular, Chapter 4 of the Draft RIA presents data on Class I engines with more active catalysts and on Class II engines with closed-loop control fuel injection systems in addition to a catalyst. In both cases larger emission reductions were achieved.

Based on this work we considered HC+NOx standards which would have involved a 50 percent reduction for Class I engines and a 65-70 percent reduction for Class II engines. Chapter 11 of the Draft RIA evaluates these alternatives, including an assessment of the overall technology and costs of meeting more stringent standards. For Class I engines a 50 percent reduction standard would require base engine changes not necessarily involved with the new standards and the use of a more active catalyst. For Class II engines this would require the widespread use of closed loop control fuel injection systems rather than carburetors, some additional engine upgrades, and the use three-way catalysts. We believe it is not appropriate at this time to establish more stringent exhaust emission standards for Small SI engines. Our key concern is lead time. More stringent standards would require several years (3-5) more lead time beyond the 2011 model year start date. We believe it would be more effective to implement the Phase 3 standards we are finalizing today to achieve near-term emission reductions needed to reduce ozone precursor emissions and to minimize growth in the Small SI exhaust emissions inventory in the post 2010 time frame. More efficient catalysts, engine improvements, and closed loop electronic fuel injection could be the basis for more stringent emission standards at some point in the future.

<u>Marine SI Engines</u>

In developing the final emission standards for SD/I engines, we considered both what was achievable without catalysts and what could be achieved with larger, more efficient catalysts than those used in our test programs. Without catalysts, we believe exhaust gas recirculation is a technologically feasible and cost-effective approach to reducing emissions from SD/I marine engines. However, we believe greater reductions could be achieved through the use of catalysts. We considered basing an interim standard on EGR, but were concerned that this will divert manufacturers' resources away from catalyst development and could have the effect of delaying emission reductions from this sector.

Several of the marine engines with catalysts that were tested as part of the development of the standards had HC+NOx emission rates appreciably lower than 5 g/kW-hr, even with consideration of expected in-use emissions deterioration associated with catalyst aging. We considered a 2.5 g/kW-hr HC+NOx standard in our analysis of alternatives. However, we believe a standard of 5 g/kW-hr is still appropriate given the potential variability of in-use performance and in test data.

For OB/PWC engines, we considered a level of 10 g/kW-hr HC+NOx for OB/PWC engines greater than 40 kW with an equivalent percent reduction below the new standards for engines less than 40 kW. This second tier of standards could apply in the 2012 or later time frame. Such a standard would be consistent with currently certified emission levels from a significant number of four-stroke outboard engines. We have three concerns with adopting this second tier of OB/PWC standards. First, while some four-stroke engines may be able to meet a 10 g/kW-hr standard with improved calibrations, it is not clear that all engines could meet this standard without applying catalyst technology. As described in Section IV.H.3 of the preamble, we believe it is not appropriate to base standards in this rule on the use of catalysts for OB/PWC engines. The technology is yet to be adequately demonstrated. Second, certification data for personal watercraft engines show somewhat higher exhaust emission levels, so setting the standard at 10 g/kW-hr would likely require catalysts for many models. Third, two-stroke direct injection engines operate with lean air-fuel ratios, so reducing NOx emissions with any kind of aftertreatment is challenging.

Therefore, unlike the standards for SD/I engines, we are not pursuing OB/PWC standards that will require the use of catalysts. Catalyst technology would be necessary for significant additional control of HC+NOx and CO emissions. While there is good potential for eventual application of catalyst technology to OB/PWC engines, we believe the technology is not adequately demonstrated at this point.

Evaporative Emission Controls

We considered both less and more stringent evaporative emission control alternatives for fuel systems used in Small SI equipment and Marine SI vessels. Chapter 11 of the Draft RIA presents details on this analysis of regulatory alternatives. The results of this analysis are summarized below. We believe that the permeation standards are reflective of available technology and represent a step change in emissions performance. Therefore, we consider the same permeation control scenario in the less stringent and more stringent regulatory alternatives.

For Small SI equipment, we considered a less stringent alternative without running loss emission standards for Small SI engines. However, we believe that controlling running loss emissions from non-handheld equipment is feasible at a relatively low cost. Running loss emissions can be controlled by changing the fuel tank and cap venting scheme and routing vapors from the fuel tank to the engine intake. Not requiring these controls would be inconsistent with section 213 of the Clean Air Act. For a more stringent alternative, we considered applying a diurnal emission standard for all Small SI equipment. We believe that passively purging carbon canisters could reduce diurnal emissions by 50 to 60 percent from Small SI equipment. However, we believe there would be significant costs to add carbon canisters to all Small SI equipment nationwide, especially when taking packaging and vibration into account. The cost sensitivity is especially noteworthy given the relatively low emissions levels (on a per-equipment basis) from such small fuel tanks.

For Marine SI vessels, we considered a less stringent alternative, where there would be no diurnal emission standard for vessels with installed fuel tanks. However, installed fuel tanks on marine vessels are much larger in capacity than those used in Small SI applications. Our analysis indicates that traditional carbon canisters are feasible for boats at relatively low cost. While packaging and vibration are also issues with marine applications, we believe these issues have been addressed. Carbon canisters were installed on fourteen boats by industry in a pilot program. The results demonstrated the feasibility of this technology. The standards would be achievable through engineering design-based certification with canisters that are very much smaller than the fuel tanks. In addition, sealed systems, with pressure control strategies would be accepted under the engineering design-based certification. For a more stringent scenario, we consider a standard that would require boat builders to use an actively purged carbon canister. This means that, when the engine is operating, it would draw air through the canister to purge the canister of stored hydrocarbons. However, we rejected this option because active purge occurs infrequently due to the low hours of operation per year seen by many boats. The gain in overall efficiency would be quite small relative to the complexity active purge adds into the system in that the engine must be integrated into a vessel-based control strategy. The additional benefit of an actively purged diurnal control system is small in comparison to the cost and complexity of such a system.

Conclusion

We believe the new emission standards reflect what manufacturers can achieve through the application of available technology. We believe the lead time is necessary and adequate for manufacturers to select, design, and produce emission control strategies that will work best for their product lines. We expect that meeting these requirements will pose a challenge, but one that is feasible when taking into consideration the availability and cost of technology, lead time, noise, energy, and safety.