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

Draft Regulatory Impact Analysis

United States
Environmental Protection
Agency

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

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EPA420-D-07-004
April 2007

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Executive Summary

The Environmental Protection Agency (EPA) is proposing 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 proposed 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 Proposed 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), 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, eutrophication, and regional haze.

Millions of Americans continue to live in areas with unhealthy air quality that may endanger public health and welfare. As of October 2006 approximately 157 million people live in the 116 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 PM2.5 NAAQS. Federal, state, and local governments are working to bring ozone and PM levels into attainment with the NAAQS. The reductions included in this proposed rule will be useful to states in attaining and maintaining the ozone, CO, and PM NAAQS.

In 2001, emissions from land-based nonroad Small SI engines and Marine SI engines were estimated to be about 28 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 assures NONROAD inventories from rules to date are maintained or continue to decrease.

Figure 1: Small SI VOC+NOx NONROAD Inventories for Baseline and Phase 3 Control (Exhaust plus Evaporative)

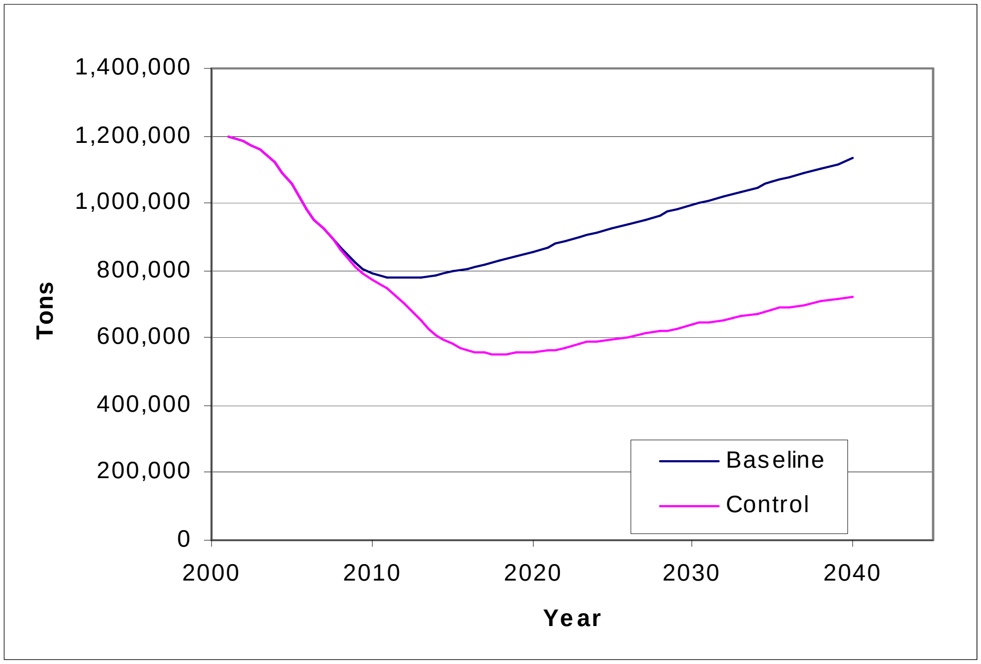
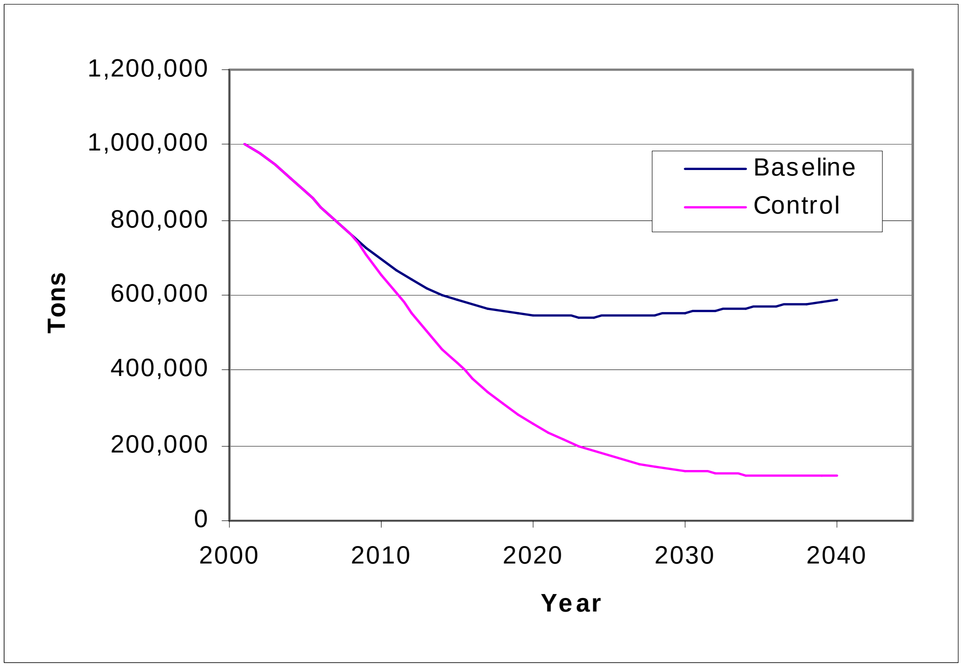


Figure 2: Marine SI VOC+NOx NONROAD Inventories for Baseline and Phase 3 Control (Exhaust plus Evaporative)



Proposed Exhaust and Evaporative Emission Standards

Tables 1 through 4 show the exhaust and evaporative emission standards and when they are proposed to apply. For Small SI engines, the standards are expected to require the use of aftertreatment systems with 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 proposed rule includes other provisions designed to address the transition to meeting the standards.

Table 1: Small SI Engine HC+NOx Exhaust Emission Standards and Schedule

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

[a] 5 g/kW-hr CO for Small SI engines powering marine generators.

Table 2: Small SI Equipment Evaporative Emission Standards and Schedule

	Fuel Line Permeation	Tank Permeation	Diffusion	Running Loss	General Evaporative Requirements
Standard Level	15 $g/m^2/day$	1.5 $g/m^2/day$	0.80 g/day	Design Standard	Design standards and good engineering judgment
Handheld	2012[a]	2009-2013[b,c]	NA	NA	2010
Class I	2008	2012	2012	2012	2012
Class II	2008	2011	2011	2011	2011

[a] 2013 for small-volume families; cold weather applications are excluded.

[b] 2.5 $g/m^2/day$ for structurally integrated nylon fuel tanks.

[c] 2009 for families certified in California, 2013 for small-volume families, 2010 for remaining families.

Table 3: Marine SI Engine HC+NOx Exhaust Standards and Schedule

	Engine Power	Model Year	HC+ NOx [g/kW-hr]	CO [g/kW-hr]
OB/PWC[ac]	≤ 40 kW	2009	28-0.3 x P[b]	500-5.0 x P[b]
	> 40 kW	2009	16	300
SD/I[ac]	all	2009	5	75

[a] Seeking comment on modest phase-in for these new standards.

[b] P = maximum engine power in kilowatts (kW).

[c] SD/I and OB/PWC also have NTE requirements; seeking comment on alternative standards for high-performance engines (>373kW).

Table 4: Marine SI Engine Evaporative Emissions Standards and Schedule

	Fuel Line Permeation	Tank Permeation	Diurnal	General Evaporative Requirements
Standard Level	15 g/m^2/day	1.5 g/m^2/day	0.40 g/gal/day	Design standards and good engineering judgment
Portable Tanks	2009	2011	2009[a]	2009
PWC	2009	2011	2009	2009
Other Installed Tanks	2009	2012	2010[b]	2010

[a] Design standard.

[b] Fuel tanks installed in non-trailerable boats (≥ 26 ft. in length) may meet a standard of 0.16 g/gal/day over an alternative test cycle.

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 Proposed 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 proposed 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 proposing new, more stringent exhaust HC+NOx standards for Class I and II Small SI engines. We are also proposing 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 2005 model year, manufacturers certified over 500 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, several engine families in both classes are currently certified at levels that would comply with the proposed 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 proposed 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 proposed 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. Nonetheless, some applications may require the use of both technologies. 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 proposed 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 Proposed Marine SI Exhaust Emission Standards

The technology is available for marine engine manufacturers to use to meet the proposed 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 can meet the proposed 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 can also meet the proposed 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 proposed standards. In addition, the majority of four-stroke engines would meet the proposed CO standards as well.

We therefore believe the proposed 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 current certification data to the proposed 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 prior to 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, demonstration programs have shown that emissions may be reduced by 70 to 80 percent for HC+NOx and 30 to 50 percent for CO over the various modes of the proposed 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. In addition, we are currently engaged in testing that includes accumulating hours on catalyst equipped SD/I engines in boats operating in saltwater. Earlier this year, one SD/I engine manufacturer began selling engines equipped with catalysts.

They have certified their engines to the California ARB standards, and are selling their catalyst-equipped engines nationwide. This manufacturer indicated that they have successfully completed durability testing, including extended in-use testing on saltwater.

Feasibility of Meeting the Proposed Evaporative Emission Standards

There are many feasible control technologies that manufacturers can use to meet the proposed evaporative emission standards. We have collected and will continue to collect 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 proposed 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 proposed 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 or polybutylene terephthalate (PBT). 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 proposed 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 proposed 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 proposed 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. Other approaches would be to move the fuel tank away from heat sources or to use heat protection such as a shield or directed air flow.

Many manufacturers today use fuel caps that by their design effectively limit the diffusion of gasoline from fuel tanks. In fact, the proposed diffusion emission standard for Small SI equipment is based to a large degree on the diffusion control capabilities of these fuel caps. As discussed in Chapter 5, venting a fuel tank through a tube (rather than through an open orifice) also greatly reduces diffusion. We have conducted additional testing with short, narrow-diameter vent lines which shows that these lines provide enough resistance to diffusion to meet the proposed emission standards.

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. The annualized cost for Small SI emission regulations are $265 million without fuel savings and $203 million with fuel savings for exhaust only. For evaporative and exhaust combined, the annualized cost for Small SI emission regulation are $332 million without fuel savings and $218 with fuel savings.

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	$11 to $23	$39 to $85	$0.30
	Long Term	$9 to $15	$22 to $47	$0.00
Evaporative	Near Term	$3.16	$6.90	$0.82
	Long Term	$2.29	$5.30	$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 Engines w/ and w/o EFI	$0.29
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 proposed 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	$267	$63
Evaporative	$67	$52
Aggregate	$334	$115

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%	$1450	$950

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 (Installed)	SD/I (Installed)
Exhaust			
Near Term	$284	$359	$362
Long Term	$219	$272	$274
Evaporative			
Near Term	$12	$17	$74
Long Term	$8	$11	$62
Total (without fuel savings)			
Near Term	$296	$376	$436
Long Term	$227	$283	$336
Total (with fuel savings)			
Near Term	$201	$221	$285
Long Term	$132	$128	$185
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.

Chapter 6 presents aggregate costs of compliance for the proposed 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	$141	$67
Evaporative	$26	$25
Aggregate	$167	$92

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	$350

Economic Impact Analysis

We prepared a draft Economic Impact Analysis estimate the market and social welfare impacts of the proposed 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 ($195) as a result of the proposed standards, and the average price of a Marine SI vessel is projected to increase by between 0.5 percent and 2.1 percent ($160 to $496), depending on the type of vessel. The average price of a Small SI engine in 2030 is projected to increase by about 9.1 percent ($17), and the average price of Small SI nonhandheld equipment is projected to increase by between 0.3 percent and 5.6 percent ($10 to $25), depending on equipment class. Changes in quantity produced are expected to be small, at less than 2 percent. The exceptions are PWC (4.2 percent) and Class II equipment (2.8 percent).

The total social costs of the program in 2030 are estimated to be $241 million. This includes $569 million of direct compliance costs and $327 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: 66 percent of the Marine SI program social costs in 2030, and 79 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 62 percent.

Benefits

We estimate that the requirements in this proposal will result in substantial benefits to public health and welfare and the environment, as described in Chapter 8. EPA typically quantifies PM- and ozone-related benefits in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and

Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments. In addition, the Agency has sought advice on characterizing and communicating the uncertainty associated with each of these aspects in health benefit analyses.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed locomotive and marine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. Our analysis, however, indicates that the rule's monetized PM2.5 benefits alone substantially exceed our estimate of the costs.

The $PM_{2.5}$ benefits are scaled based on relative changes in direct PM emissions between this rule and the proposed Clean Air Nonroad Diesel (CAND) rule. As explained in Section 8.2.1, the $PM_{2.5}$ benefits scaling approach is limited to those studies, health impacts, and assumptions that were used in the proposed CAND analysis. As a result, PM-related premature mortality is based on the updated analysis of the American Cancer Society cohort (ACS; Pope et al., 2002). However, it is important to note that since the CAND rule, EPA's Office of Air and Radiation (OAR) has adopted a different format for its benefits analysis in which characterization of the uncertainty in the concentration-response function is integrated into the main benefits analysis. Within this context, additional data sources are available, including a recent expert elicitation and updated analysis of the Six-Cities Study cohort (Laden et al., 2006). Please see the PM NAAQS RIA for an indication of the sensitivity of our results to use of alternative concentration-response functions.

The analysis presented here assumes a PM threshold of 3 μg/m3, equivalent to background. Through the RIA for the Clean Air Interstate Rule (CAIR), EPA's consistent approach had been to model premature mortality associated with PM exposure as a nonthreshold effect; that is, with harmful effects to exposed populations modeled regardless of the absolute level of ambient PM concentrations. This approach had been supported by advice from EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). However, EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies," (p. 9-44). Furthermore, in the RIA for the PM NAAQS we used a threshold of 10 μg/m3 based on recommendations by the Clean Air Scientific Advisory Committee (CASAC) for the Staff Paper analysis. We consider the impact of a potential, assumed threshold in the PM-mortality concentration response function in Section 8.6.2. The monetized benefits associated with the proposed program are presented in Table 11. These estimates are in year 2005 dollars.

We estimate that in 2030, the annual PM-related emission reductions associated with the proposed standards would annually prevent 450 premature deaths (based on the ACS cohort study), 52,000 work days lost, 500 hospital admissions, and 310,000 minor restricted-activity days.

Table 11: Estimated Monetized PM-Related Health Benefits of the Proposed Standards

	Total Benefits[a, b, c] (billions 2005$)	
	2020	2030
Using a 3% discount rate	$2.1 + B	$3.4 + B
Using a 7% discount rate	$1.9 + B	$3.1 + B

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints. PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 µg/m3). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 8.6.

[b] For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. A detailed listing of unquantified health and welfare effects is provided in Table 8.1-2 of the RIA.

[c] Results reflect the use of two different discount rates: 3 and 7 percent, which are 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.

Impact on Small Businesses

Chapter 10 discusses our Initial Regulatory Flexibility Analysis, which evaluates the potential impacts of the proposed 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 proposed 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 proposed standards on small entities, and recommended that we propose and seek comment on the flexibilities. Chapter 10 discusses the flexibilities recommended by the Panel, the regulatory alternatives we considered in developing the proposal, and the flexibilities we are proposing. We have proposed 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 proposed provisions include extra lead time for the proposed standards, reduced testing requirements for demonstrating compliance with the standards, and hardship provisions to address significant economic impacts and unusual circumstances related to the standards. These proposed provisions are intended to reduce the burden on small entities that will be required to meet the new emission standards when they are implemented.

Alternative Program Options

In developing the proposed 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 proposed 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 standards we are proposing 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 propose 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 are proposing for the program. We believe it would be more effective to implement the Phase 3 standards we are proposing 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.

Marine SI Engines

For Marine SI 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 proposed 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 proposed 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 proposed 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 and diffusion 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. Other approaches would be to move the fuel tank away from heat sources or to use heat protection such as a shield or directed air flow. Diffusion can be controlled by simply using a tortuous tank vent path, which is often used today on Small SI equipment to prevent fuel splashing or spilling. These emission control technologies are relatively straight-forward, inexpensive, and achievable in the near term. 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 some important issues would need to be resolved for diurnal emission control, such as cost, packaging, and vibration. 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 proposed 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 proposed 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.

CHAPTER 1: Industry Characterization

The information contained in this chapter on the Small SI engine and Marine SI engine industries was assembled by RTI International, a Health, Social and Economics Research firm in cooperation with EPA. RTI prepared one report each on the Small SI and Marine SI industries, "Industry Profile for Small Nonroad Spark Ignition Engines and Equipment"[1] and "Industry Profile for Marine SI Industry"[2] report. The following sections provide a brief report overview. The reader is encouraged to refer to the reports for greater detail. In addition, this chapter includes an overview of production practices for fuel system component manufacturers. Chapter 10 provides information on the businesses that would be affected by the proposed standards.

1.1 Manufacturers of Small SI Engines

The nonroad spark-ignition (SI) industry includes a wide variety of handheld and nonhandheld equipment. Nonhandheld equipment is powered mainly by four-stroke gasoline engines; handheld equipment is powered mainly by two-stroke gasoline engines. Comprising much of what the general public considers "lawn and garden (L&G) equipment," this industry also produces significant numbers of generators, compressors, and construction and maintenance equipment. The industry often refers to itself as the "outdoor power equipment" industry.

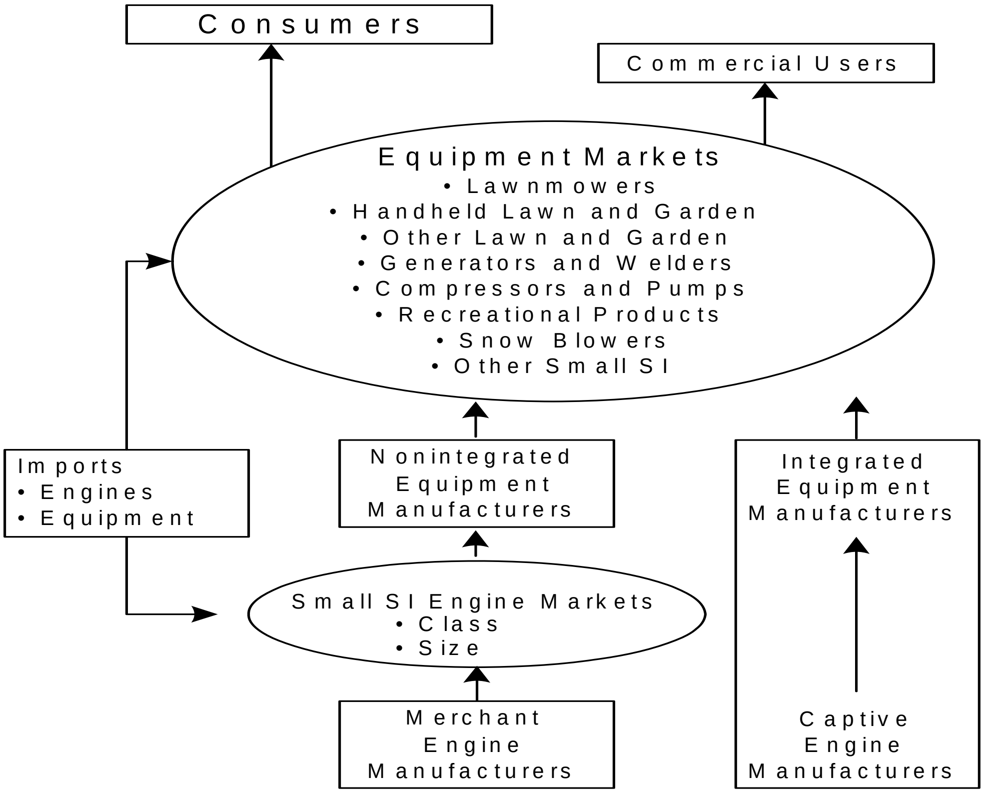
This profile provides background information on the engines and equipment that make up the small nonroad SI industry, defined as those products rated less than or equal to 19 kilowatt (kW) (roughly equivalent to 25 horsepower [hp]). This profile describes markets for engines and equipment, and discusses their use in both consumer and commercial applications. In each market, producers and consumers are described, along with product attributes and the effect of those attributes on production cost and demand. The market analysis emphasizes assessing suppliers' cost of production and industry structure, along with demanders' price responsiveness and consumption alternatives.

The variety of products in this industry is usefully partitioned by both application categories and engine type. Figure 1-1 illustrates the links between the market segments of the Small SI engine supply chain included in the profile, from engine manufacturing and sale to equipment production, and on to purchase by consumers and commercial customers. Although more than 98 percent of total unit sales in the L&G equipment sector go to households, other sectors' sales are dominated by commercial equipment. Because of the significantly higher prices of commercial units, commercial sales represent a considerable share of the total value of production.

It should be noted that there is a fair amount of vertical integration in the handheld industry, with the same parent firm making both engines and the equipment in which those engines are used. Handheld equipment includes string trimmers, leaf blowers, and chainsaws. This situation is known as "captive" engine production; data on internal consumption of engines and transfer prices are typically not available outside the firm. The makers of non-handheld engines typically sell their engines to independent equipment manufacturers in a merchant engine market, where prices and quantities exchanged can be directly observed.

The industry profile for Small SI presents information on product characteristics, supply-side considerations, consumer demand, and market structure for small nonroad SI engines. The report also includes similar types of information on equipment markets, broken down by application category. Considerations related to consumer and commercial markets are included in the demand subsection of that section.

Figure 1-1: The Small Nonroad SI Industry



1.2 Manufacturers of Marine Spark-Ignition Engines

The Marine SI industry is dominated by recreational applications with some commercial use and includes markets for several types of boats, personal watercraft (PWC), and SI engines that power them. The industry profile presented in the “Industry Profile for Marine SI Industry” report by RTI describes producers and consumers for each market segment; product attributes and the effects of these attributes on production costs and demand are described as well. As part of the market characterization, particular emphasis is placed on assessing suppliers’ industrial organization and cost of production and demanders’ price responsiveness and substitution possibilities. The Marine SI industry is divided into three applications areas: outboard (OB) boats, sterndrive and inboard (SD/I) boats, and PWC.

1.2.1 OB Boats

An OB boat is a vessel powered by one or more gasoline engines, which are located outside the hull at the back of the boat. The engine and drive unit are combined in a single package. An engine can easily be removed from the boat for inspection or repair, and it is quite common for the boat owner to change engines during the life of the vessel. The OB boat segment is the largest of the three application areas; in 2002, 213,000 units were sold, which is more than the combined sales of SD/I and PWC.

The OB application area can be further divided into “recreational” and “luxury” categories. The luxury category includes more-expensive vessels, for which the engine constitutes only a small portion of the cost of the entire vessel. The NMMA distinguishes between 14 types of OB vessels, 10 of which are considered recreational and 4 luxury.

1.2.2 SD/I Boats

SD/I vessels have an engine installed inside the hull of the vessel. An inboard vessel is a boat in which the engine is located inside the hull at the center of the boat with a propeller shaft going through the rear of the boat. A sterndrive (or inboard/outboard) vessel is a boat in which the engine is located inside the hull at the back of the boat with a drive assembly couple directly to the propeller. propeller shaft going through the rear of the boat. In contrast to OB vessels, SD/I vessels’ engine is an integral part. Removal or replacement is significantly more difficult, so most repair work is done with the engine in place. Just like OBs, the SD/I application area is divided into recreational and luxury categories.

1.2.3 PWC

According to the Personal Watercraft Industry Association (PWIA), a PWC is defined as a “vessel with an inboard motor powering a water jet pump as its primary source of motive power, and which is designed to be operated by a person sitting, standing, or kneeling on the vessel.”

The PWC application area is divided into the entry level, high end, and performance categories based on the horsepower ratings of the vessel. These categories correspond to 50 to 100 hp, 100 to 175 hp, and over 175 hp accordingly. Our study considers two categories that were available in 2002: entry level and high end. The performance category was introduced in 2003.

1.2.4 Marine SI Engines

Some OB engine manufacturers specifically build their engines to be incorporated into boats produced by another division within the same parent company. Other manufacturers produce and sell their engines to independent OB boat builders or consumers who need a replacement engine. SD/I engine manufacturers typically build custom engines for SD/I boats by marinizing automotive engines. All PWC vessel manufacturers build their own engines for their vessels

Marine SI engines sold today are a mix of three primary technologies: crankcase scavenged two-stroke engines, direct-injection two-stroke engines, and four-stroke engines. Table 6.2.2-11 in Chapter 6 presents our best estimate of the technology mix for OB and PWC engines by power class. This technology mix is based on data submitted by manufacturers when the certify to our existing HC+NOx exhaust emission standards. Prior to the implementation of the existing standards, the vast majority of outboard and PWC engines were crankcase scavenged two-stroke engines.

The following Figures show the flow of engines from the engine manufacturer to the consumer for the different engine types.

Figure 1-2. OB Marine Economic Model Conceptual Flow Chart

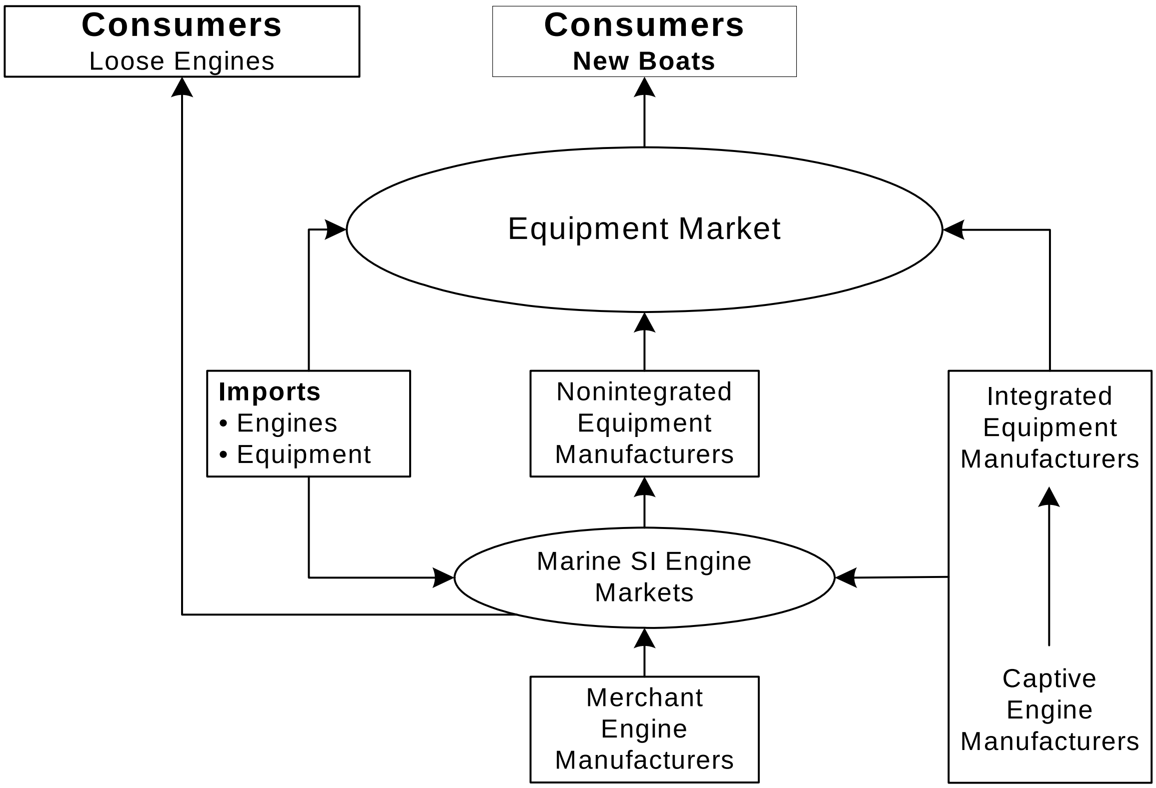


Figure 1-3: PWC Economic Model Conceptual Flow Chart

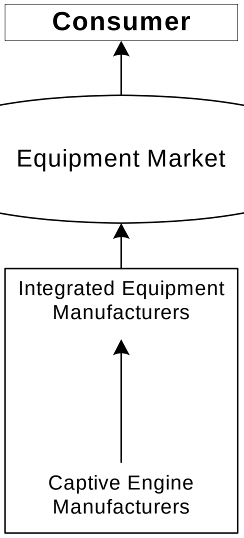
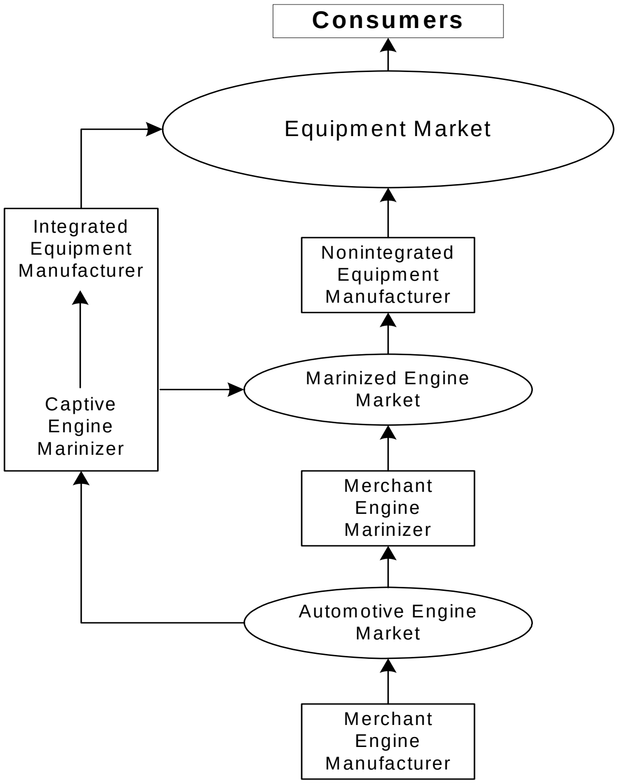


Figure 1-4: Inboard Marine Economic Model Conceptual Flow Chart



1.3 Fuel System Components

The primary fuel system components that would be affected by the proposed rule are the fuel tanks and fuel lines on affected equipment and vessels. This section gives an overview of the production practices for these products.

1.3.1 Fuel Tank Production Practices

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

Smaller fuel tanks used in Small SI equipment are often injection-molded. In the injection molding process, fuel tanks are formed by forcing heated plastic into molds at high pressure. Generally, two fuel tank halves are formed, which are later fused together. This process requires high tooling costs, but lower total fixed costs than blow-molding. Injection-molding is typically used for smaller fuel tanks and has the advantage of giving manufacturers the ability to work with complex tank designs.

Larger fuel tanks used on Class II equipment and in boats with installed fuel tanks are typically rotational-molded out of cross-link polyethylene. Rotational-molding is a lower cost alternative for smaller production volumes. In this method, a mold is filled with a powder form of polyethylene with a catalyst material. The mold is rotated in an oven; the heat melts the plastic and activates the catalyst which causes a strong cross-link material structure to form. This method is used for Class II fuel tanks where the tanks are unshielded on the equipment. These fuel tanks also used meet specific size and shape requirements for boats and are preferred because they do not rust like metal tanks, but at the same time are more fire resistant than high-density polyethylene fuel tanks.

Metal fuel tanks are also used on both Small SI equipment and boats. Typically, metal tanks on Small SI equipment are made of steel. These tanks are typically stamped out in two pieces and either welded or formed together with a seal. Aluminum fuel tanks are also used primarily for installed marine fuel tanks because aluminum is more resistant to oxidation than steel. In the marine industry, tank manufacturers generally custom make each tank to meet the boat manufacturers needs. Generally, sheet aluminum is used and is cut, bent, and welded into the required configuration.

1.3.2 Fuel Hose Production Practices

Marine hose is designed to meet the Coast Guard performance requirements as defined by the Society of Automotive Engineer’s recommended practice SAE J 1527. For fuel supply lines, this includes a permeation rate of 100 g/m^2/day at 23°C (Class 1). For other fuel hose not normally continuously in contact with fuel (vent and fuel fill neck), the permeation standard is 300 g/m^2/day (Class 2). In general, boat builders will use Class 1 hose for both fuel supply and vent lines for simplicity. Some boat builders use low permeation barrier hose which is well below the permeation levels in SAE J 1527. For fuel fill necks, boat builders generally use Class 2 hose. Small SI hose is typically produced to manufacturer specifications. However, manufacturers may specify hose based on industry standards such as those listed in SAE J30.

Most fuel supply and vent hose is extruded nitrile rubber with a coating for better wear and flame resistance. Hose may also be reinforced with fabric or wire. (In contrast, plastic automotive fuel lines are extruded without reinforcement and are generally referred to as “tubing.”) Hose manufacturers offer a wide variety of fuel hoses including those with a barrier layer of low permeability material, such as nylon, THV, FKM or ethyl vinyl alcohol, either on the inside surface or sandwiched between layers of nitrile rubber. These technologies are discussed in more detail in Chapter 5.

Fuel fill hose used on boats is generally manufactured by hand wrapping layers of rubber and reinforcement materials around a steel mandril. This hose is then heated to cure the rubber. Fuel fill hose generally has a much larger diameter than fuel supply and vent hose and this process offers an effective method of producing this larger diameter hose.

Pre-formed fuel lines are made in two ways. The first, and more common method, is to cut lengths of extruded hose, before it is vulcanized, and slip them over a contoured mandril. The hose is then vulcanized in the oven on the mandril to give it a preformed shape. The second way, primarily used on handheld equipment, but also for some outboard engine fuel system components, is to injection-mold small parts. To make the parts hollow, they are molded with a mandril inside. To remove the mandril, the part is typically inflated with air for just long enough to pull it off the mandril. Primer bulbs are also made in this manner.

Chapter 1 References

1. “Industry Profile for Small Nonroad Spark-Ignition Engines and Equipment,” RTI International, March 2006.

2. “Industry Profile for Marine SI Industry,” RTI International, October 2006.

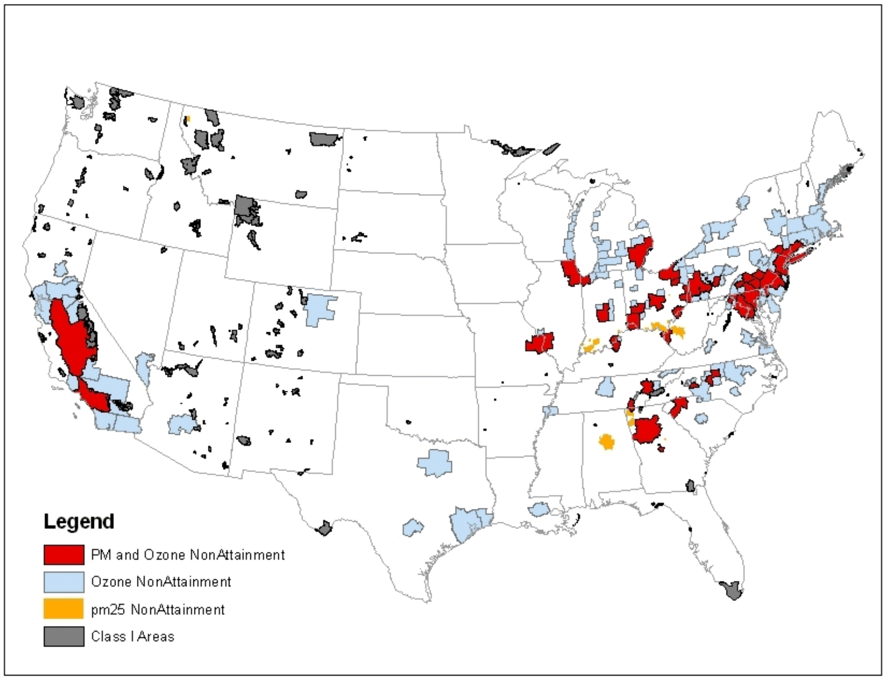
CHAPTER 2: Air Quality, Health, and Welfare Concerns

The proposed standards would reduce emissions of hydrocarbons (HC), oxides of nitrogen (NOx), carbon monoxide (CO) and air toxics from the engines, vessels and equipment subject to this proposal. These pollutants contribute to ozone, PM and CO nonattainment and to adverse health effects associated with air toxics. The emissions from these engines, vessels and equipment can also impact health through personal exposure and contribute to adverse environmental effects including visibility impairment both in mandatory class I federal areas and in areas where people live, work and recreate.

The health and environmental effects associated with emissions from Small SI engines and equipment and Marine SI engines and vessels are a classic example of a negative externality (an activity that imposes uncompensated costs on others). With a negative externality, a activity's social cost (the cost on society imposed as a result of the activity taking place) exceeds its private cost (the cost to those directly engaged in the activity). In this case, as described in this chapter, emissions from Small SI engines and equipment and Marine SI engines and vessels impose public health and environmental costs on society. The market system itself cannot correct this externality. The end users of the equipment and vessels are often unaware of the environmental impacts of their use for lawn care or recreation. Because of this, consumers fail to send the market a signal to provide cleaner equipment and vessels. In addition, producers of these engines, equipment, and vessels are rewarded for emphasizing other aspects of these products (e.g., total power). To correct this market failure and reduce the negative externality, it is necessary to give producers social cost signals. The standards EPA is proposing will accomplish this by mandating that Small SI engines and equipment and Marine SI engines and vessels reduce their emissions to a technologically feasible limit. In other words, with this proposed rule the costs of the services provided by these engines and equipment will account for social costs more fully.

In this Chapter we will discuss the impacts of the pollutants emitted by Small SI engines and equipment and Marine SI engines and vessels on health and welfare, National Ambient Air Quality Standard (NAAQS) attainment and personal exposure. Air quality modeling and monitoring data presented in this chapter indicate that a large number of our citizens continue to be affected by these emissions. Figure 2-1 illustrates the widespread nature of these problems. Shown in this figure are counties designated as nonattainment for either or both of the 8-hour ozone or $PM_{2.5}$ NAAQS, also depicted are the mandatory class I federal areas. The emission standards proposed in this rule would help reduce HC, NOx, air toxic and CO emissions and their associated health and environmental effects.

Figure 2-1: 8-Hour Ozone and $PM_{2.5}$ Nonattainment Areas and Mandatory Class I Federal Areas



2.1 Ozone

In this section we review the health and welfare effects of ozone. We also describe the air quality monitoring and modeling data which indicates that people in many areas across the country continue to be exposed to high levels of ambient ozone and will continue to be into the future. Emissions of volatile organic compounds (VOCs) and NOx from the engines, vessels and equipment subject to this proposed rule contribute to these ozone concentrations. Information on air quality was gathered from a variety of sources, including monitored ozone concentrations, air quality modeling forecasts conducted for this rulemaking, and other state and local air quality information.

2.1.1 Science of Ozone Formation

Ground-level ozone pollution is formed by the reaction of VOCs, of which HC are the major subset, and NOx in the atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway and nonroad motor vehicles (including those subject to this proposed rule), power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex.[1] Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. Ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NOx emissions.

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

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

Rural areas are almost always NOx-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NOx-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NOx, VOC, and ozone, all of which change with time and location.

2.1.2 Health Effects of Ozone Pollution

Exposure to ambient ozone contributes to a wide range of adverse health effects.[1] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[2,3] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

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[1] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentration but also by the individuals breathing route and rate.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, inflammation of the lungs, and a variety of other respiratory effects. There is also evidence that ozone may contribute to cardiovascular health effects. People who are more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. There is also suggestive evidence that certain people may have greater genetic susceptibility. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., outdoor workers) are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to higher ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[4, 5, 6, 7, 8, 9] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[10, 11, 12, 13, 14] Repeated exposure to sufficient concentrations of ozone can also cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses, such as emphysema and chronic bronchitis.[15, 16, 17, 18]

Children and adults who are outdoors and active during the summer months, such as construction workers and other outdoor workers, are among those most at risk of elevated ozone exposures.[19] Children and outdoor workers tend to have higher ozone exposures because they typically are active outside, working, playing and exercising, during times of day and seasons (e.g., the summer) when ozone levels are highest.[20] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported significant reductions in lung function in children who are active outdoors.[21, 22, 23, 24, 25, 26, 27, 28] Further, children are more at risk of experiencing health effects from ozone exposure than adults because their respiratory systems are still developing. These individuals (as well as people with respiratory illnesses such as asthma, especially asthmatic children) can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.[29, 30, 31, 32]

EPA typically quantifies ozone-related health impacts in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed small engine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. For more information regarding the quantified benefits included in this analysis, please refer to Chapter 8.

2.1.3 Current and Projected Ozone Levels

The Clean Air Act (CAA) requires EPA to set NAAQS for wide-spread pollutants from diverse sources considered harmful to public health and the environment. The CAA established two types of NAAQS: primary standards to protect public health, secondary standards to protect public welfare. The primary and secondary ozone NAAQS are identical. The 8-hour ozone standard is met when the 3-year average of the annual 4th highest daily maximum 8-hour ozone concentration is less than 0.08 ppm (62 FR 38855, July 18, 1997).

The proposed emission reductions from this rule would assist 8-hour ozone nonattainment and maintenance areas in reaching the standard by each area’s respective attainment date, and maintaining the 8-hour ozone standard in the future. The emission reductions would also help continue to lower ambient ozone levels and resulting health impacts into the future. In this section we present information on current and projected future 8-hour ozone levels.

2.1.3.1 Current 8-Hour Ozone Levels

A nonattainment area is defined in the CAA as an area that is violating a NAAQS or is contributing to a nearby area that is violating the NAAQS. EPA designated nonattainment areas for the 8-hour ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 8-hour Ozone NAAQS (69 FR 23858, April 30, 2004) lays out the factors that EPA considered in making the 8-hour ozone nonattainment designations, including 2001-2003 measured data, air quality in adjacent areas, and other factors.[2]

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[2] An ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values are determined based on three consecutive-year monitoring periods. For example, an 8-hour design value is the fourth highest daily maximum 8-hour average ozone concentration measured over a three-year period at a given monitor. The full details of these determinations

As of October 2006, approximately 157 million people live in the 116 areas that are designated as nonattainment for either failing to meet the 8-hour ozone NAAQS or for contributing to poor air quality in a nearby area.[3] There are 461 full or partial counties that make up the 116 8-hour ozone nonattainment areas, as shown in Figure 2-1.

Counties designated as ozone nonattainment were categorized, on the basis of their one-hour ozone design value, as Subpart 1 or Subpart 2. Areas categorized as Subpart 2 were then further classified, on the basis of their 8-hour ozone design value, as marginal, moderate, serious, severe or extreme. The maximum attainment date assigned to an ozone nonattainment area is based on the area's classification.

States with 8-hour ozone nonattainment areas are required to take action to bring those areas into compliance prior to the ozone season in the attainment year. Based on the final rule designating and classifying 8-hour ozone nonattainment areas, most 8-hour ozone nonattainment areas will be required to attain the 8-hour ozone NAAQS in the 2007 to 2014 time frame and then be required to maintain the 8-hour ozone NAAQS thereafter.[4] The emission standards being proposed in this action would become effective between 2008 and 2013. Thus, the expected ozone precursor emission inventory reductions from the standards proposed in this action would be useful to states in attaining and/or maintaining the 8-hour ozone NAAQS.

EPA's review of the ozone NAAQS is currently underway and a proposed decision in this review is scheduled for June 2007 with a final rule scheduled for March 2008. If the ozone NAAQS is revised then new nonattainment areas could be designated. While EPA is not relying on it for purposes of justifying this rule, the emission reductions from this proposal would also be helpful to states if there is an ozone NAAQS revision.

2.1.3.2 Projected 8-Hour Ozone Levels

Air quality modeling analyses completed for this proposed rule included assessing ambient ozone concentrations with and without the proposed emission controls. The air quality modeling predicts that without additional local, regional or national controls there will continue

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(including accounting for missing values and other complexities) are given in Appendices H and I of 40 CFR Part 50. Due to the precision with which the standards are expressed (0.08 parts per million (ppm) for the 8-hour), a violation of the 8-hour standard is defined as a design value greater than or equal to 0.085 ppm or 85 parts per billion (ppb). For a county, the design value is the highest design value from among all the monitors with valid design values within that county. If a county does not contain an ozone monitor, it does not have a design value. However, readers should note that ozone design values generally represent air quality across a broad area and that absence of a design value does not imply that the county is in compliance with the ozone NAAQS. Therefore, our analysis may underestimate the number of counties with design values above the level of NAAQS.

[3] The 8-hour ozone nonattainment areas are listed in a Memo to the Docket titled "Nonattainment Areas and Mandatory Class I Federal Areas" and contained in Docket EPA-HQ-OAR-2004-0008.

[4] The Los Angeles Southcoast Air Basin 8-hour ozone nonattainment area will have to attain before June 15, 2021.

to be a need for reductions in 8-hour ozone concentrations in some areas in the future.

We performed a series of ozone air quality modeling simulations for the Eastern United States using the Comprehensive Air Quality Model with Extension (CAMx). The air quality modeling performed for this proposed rule was based upon the same modeling system as was used in the Clean Air Interstate rule (CAIR) and Clean Air Nonroad Diesel (CAND) legislation. The model simulations were performed for five emission scenarios: a 2001 baseline projection, a 2020 baseline projection and a 2020 projection with controls, a 2030 baseline projection and a 2030 projection with controls.

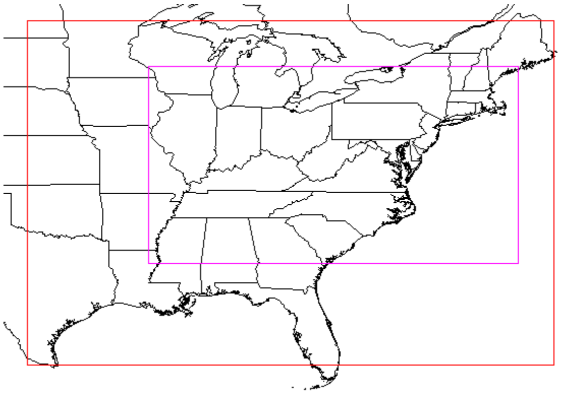
The impacts of the proposed emission standards were determined by comparing the model results in the future year control runs against the baseline simulations of the same year. This modeling supports the conclusion that the proposed controls would help reduce ambient ozone concentrations across the country.

2.1.3.2.1 Ozone Modeling Methodology

CAMx was utilized to estimate base and future-year ozone concentrations over the Eastern United States for various emission scenarios. CAMx simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone. CAMx is a photochemical grid model that numerically simulates the effects of emissions, advection, diffusion, chemistry, and surface removal processes on pollutant concentrations within a three-dimensional grid. This model is commonly used in developing attainment demonstration State Implementation Plans (SIPs) as well as estimating the ozone reductions expected to occur from a reduction in emitted pollutants. The following sections provide an overview of the ozone modeling completed as part of this rulemaking. More detailed information is included in the air quality modeling technical support document (TSD), which is located in the docket for this rule.

The modeling domain used for this analysis and in the recent CAIR includes 37 states in the Eastern U.S., see Figure 2.1-2. The Eastern modeling domain encompasses the area from the East coast to mid-Texas and consists of two grids with differing resolutions. The model resolution was 36 km over the outer portions of the domain and 12 km in the inner portion of the grids. The vertical height of the eastern modeling domain is 4,000 meters above ground level with 9 vertical layers.

Figure 2.1-2: Map of CAIR Modeling Domain



Note: The inner area represents fine grid modeling at 12 km resolution. The outer area represents the coarse grid modeling at 36 km resolution.

The simulation periods modeled by CAMx included several multi-day periods when ambient measurements were representative of ozone episodes over the Eastern U.S. A simulation period, or episode, consists of meteorological data characterized over a block of days that are used as inputs to the air quality model. Three multi-day meteorological scenarios during the summer of 1995 were used in the model simulations over the Eastern U.S.: June 12-24, July 5-15, and August 7-21. In general, these episodes do not represent extreme ozone events but, instead, are generally representative of ozone levels near local design values. Each of the emission scenarios were simulated for the selected episodes.

The meteorological data required for input into CAMx (wind, temperature, vertical mixing, etc.) was developed by a separate meteorological model. For the Eastern U.S., the gridded meteorological data for the three historical 1995 episodes were developed using the Regional Atmospheric Modeling System (RAMS), version 3b. This model provided needed data at every grid cell on an hourly basis. The meteorological modeling results were evaluated against observed weather conditions before being input into CAMx and it was concluded that the model fields were adequate representations of the historical meteorology. A more detailed description of the settings and assorted input files employed in these applications is provided in the air quality modeling TSD, which is located in the docket for this rule.

The modeling assumed background pollutant levels at the top and along the periphery of the domain as in CAIR. Additionally, initial conditions were assumed to be relatively clean as well. Given the ramp-up days and the expansive domains, it is expected that these assumptions will not affect the modeling results, except in areas near the boundary (e.g., Dallas-Fort Worth TX). The other non-emission CAMx inputs (land use, photolysis rates, etc.) were developed using procedures employed in the highway light duty Tier 2/OTAG regional modeling. The development of model inputs is discussed in greater detail in the air quality modeling TSD.

Future-year estimates of 8-hour ozone design values were calculated based on relative reduction factors (RRF) between the future simulations, the 2001 base year simulation and 2001-2003 8-hour ozone design values. The procedures for determining the RRFs are similar to those in EPA's guidance for modeling for an 8-hour ozone standard.[33] Hourly model predictions were processed to determine daily maximum 8-hour concentrations for each grid cell for each day modeled. The RRF for a monitoring site was determined by first calculating the multi-day mean of the 8-hour daily maximum predictions in the nine grid cells surrounding the site using only those predictions greater than or equal to 70 ppb, as recommended in the guidance. This calculation was performed for the base year scenario and each of the future-year baselines. The RRF for a site is the ratio of the mean prediction in the future-year scenario to the mean prediction in the base year scenario. RRFs were calculated on a site-by-site basis. The future-year design value projections were then calculated by county, based on the highest resultant design values for a site within that county from the RRF application. For more information see the air quality modeling TSD.

The inventories that underlie the ozone modeling conducted for this rulemaking included emission reductions from all current or committed federal, State, and local controls including the recent CAIR and, for the control case, including this proposed rulemaking.

Finally, it should be noted that the emission control scenarios used as input for the air quality and benefits modeling are slightly different than the emission control program being proposed. The proposed levels of the standards have changed, in response to new information on the emission control technologies under consideration and other factors, since we performed the air quality modeling for this proposed rule. Additional detail is provided in Section 3.6.

2.1.3.2.2 Areas at Risk of Future 8-Hour Ozone Violations

This section summarizes the results of recent ozone air quality modeling from the CAIR analysis. Specifically, it provides information on our calculations of the number of people estimated to live in counties in which ozone monitors are predicted to exceed the 8-hour ozone NAAQS or to be within 10 percent of the 8-hour ozone NAAQS in the future.

The determination that an area is at risk of exceeding the 8-hour ozone standard in the future was made for all areas with current design values greater than or equal to 85 ppb (or within a 10 percent margin) and with modeling evidence that concentrations at and above this level will persist into the future. Those interested in greater detail should review the CAIR air quality modeling TSD.

Based upon our CAIR air quality modeling, we anticipate that without emission reductions beyond those that were already required under promulgated regulation and approved SIPs, ozone nonattainment will likely persist into the future. With reductions from programs already in place (but excluding the emission reductions from this rule), the number of Eastern counties with projected 8-hour ozone design values at or above 85 ppb in 2010 is expected to be 37 counties where 24 million people are projected to live, see Table 2.1-1. In addition, in 2010, 148 Eastern counties where 61 million people are projected to live, will be within 10 percent of violating the 8-hour ozone NAAQS.

Table 2.1.3.2.2-1. Eastern Counties with 2010 projected 8-hour Ozone Concentrations Above and Within 10% of the 8-hour Ozone Standard

State	County	2010 Projected 8-hour Ozone Concentration (ppb)[a]	2000 pop[b]	2010 pop[c]
Arkansas	Crittenden Co	80.8	50,866	52,889
Connecticut	Fairfield Co	**92.2**	882,567	891,694
Connecticut	Hartford Co	80.1	857,183	859,080
Connecticut	Middlesex Co	**90.6**	155,071	164,202
Connecticut	New Haven Co	**91.3**	824,008	829,181
Connecticut	New London Co	83.4	259,088	267,199
Connecticut	Tolland Co	82.7	136,364	142,988
D.C.	Washington Co	**85**	572,058	554,474
Delaware	Kent Co	78.7	126,697	139,376
Delaware	New Castle Co	84.7	500,264	534,631
Delaware	Sussex Co	80.3	156,638	181,962
Georgia	Bibb Co	80	153,887	158,291
Georgia	Cobb Co	79.4	607,750	744,488
Georgia	Coweta Co	76.6	89,215	111,522
Georgia	De Kalb Co	81.9	665,864	698,335
Georgia	Douglas Co	78.7	92,174	114,380
Georgia	Fayette Co	76.7	91,263	117,580
Georgia	Fulton Co	**85.1**	816,005	855,826
Georgia	Henry Co	80.3	119,341	153,957
Georgia	Rockdale Co	80.4	70,111	87,977
Illinois	Cook Co	81.8	5,376,739	5,363,464
Illinois	Jersey Co	77	21,668	22,905
Illinois	Lake Co	76.8	644,356	731,690
Illinois	McHenry Co	76.6	260,077	307,400
Indiana	Boone Co	78.1	46,107	54,035
Indiana	Clark Co	78.4	96,472	107,096
Indiana	Hamilton Co	81.7	182,740	230,565
Indiana	Hancock Co	80.4	55,391	65,282
Indiana	La Porte Co	81.8	110,106	111,566
Indiana	Lake Co	82.8	484,563	489,220
Indiana	Madison Co	78.6	133,358	137,710
Indiana	Marion Co	79.6	860,453	879,932
Indiana	Porter Co	81.1	146,798	165,350
Indiana	Shelby Co	81.6	43,445	46,565
Indiana	St Joseph Co	77.8	265,559	275,031
Kentucky	Campbell Co	81.5	88,616	92,109
Louisiana	Bossier Parish	77	98,310	110,838
Louisiana	East Baton Rouge Parish	80.6	412,852	465,411
Louisiana	Iberville Parish	79.4	33,320	33,089
Louisiana	Jefferson Parish	78.6	455,466	493,359
Louisiana	Livingston Parish	77.8	91,814	124,895
Louisiana	West Baton Rouge Parish	78.8	21,601	22,672
Maine	Hancock Co	80.5	51,791	53,886
Maine	York Co	80.2	186,742	201,082
Maryland	Anne Arundel Co	**88.6**	489,656	543,785
Maryland	Baltimore Co	83.7	754,292	792,284
Maryland	Carroll Co	80	150,897	179,918
Maryland	Cecil Co	**89.5**	85,951	96,574
Maryland	Charles Co	78.7	120,546	145,763

Maryland	Frederick Co	78.1	195,277	234,304
Maryland	Harford Co	**92.8**	218,590	268,207
Maryland	Kent Co	**85.8**	19,197	20,233
Maryland	Montgomery Co	79.3	873,341	940,126
Maryland	Prince Georges Co	84.2	801,515	842,221
Massachusetts	Barnstable Co	83.6	222,230	249,495
Massachusetts	Bristol Co	83	534,678	558,460
Massachusetts	Essex Co	81.7	723,419	747,556
Massachusetts	Hampden Co	80.2	456,228	452,718
Massachusetts	Hampshire Co	78	152,251	158,130
Massachusetts	Middlesex Co	79.1	1,465,396	1,486,428
Massachusetts	Suffolk Co	78.1	689,807	674,179
Michigan	Allegan Co	82.1	105,665	121,415
Michigan	Benzie Co	77.9	15,998	17,849
Michigan	Berrien Co	78.1	162,453	164,727
Michigan	Cass Co	78.2	51,104	53,544
Michigan	Genesee Co	76.7	436,141	441,196
Michigan	Macomb Co	**85.4**	788,149	838,353
Michigan	Mason Co	78.9	28,274	30,667
Michigan	Muskegon Co	82	170,200	175,901
Michigan	Oakland Co	80.7	1,194,155	1,299,592
Michigan	Ottawa Co	76.6	238,314	277,400
Michigan	St Clair Co	80.6	164,235	178,391
Michigan	Washtenaw Co	81	322,895	344,398
Michigan	Wayne Co	84.7	2,061,161	1,964,209
Missouri	Clay Co	76.5	184,006	213,643
Missouri	Jefferson Co	76.7	198,099	230,539
Missouri	St Charles Co	80.5	283,883	341,686
Missouri	St Louis City	79.4	348,188	324,156
Missouri	St Louis Co	80.5	1,016,315	1,024,964
New Hampshire	Hillsborough Co	76.6	380,841	412,071
New Jersey	Atlantic Co	80.4	252,552	269,754
New Jersey	Bergen Co	**86**	884,118	898,450
New Jersey	Camden Co	**91.6**	508,932	509,912
New Jersey	Cumberland Co	84.4	146,438	149,595
New Jersey	Gloucester Co	**91.3**	254,673	278,612
New Jersey	Hudson Co	84.3	608,975	607,256
New Jersey	Hunterdon Co	**88.6**	121,989	139,641
New Jersey	Mercer Co	**95.2**	350,761	359,912
New Jersey	Middlesex Co	**92.1**	750,162	805,537
New Jersey	Monmouth Co	**86.4**	615,301	670,971
New Jersey	Morris Co	**85.5**	470,212	500,033
New Jersey	Ocean Co	**100.3**	510,916	572,364
New Jersey	Passaic Co	79.7	489,049	495,610
New York	Bronx Co	79.7	1,332,649	1,298,206
New York	Chautauqua Co	81.8	139,750	139,909
New York	Dutchess Co	81	280,150	291,098
New York	Erie Co	**86.9**	950,265	953,085
New York	Essex Co	77.6	38,851	39,545
New York	Jefferson Co	80.5	111,738	113,075
New York	Monroe Co	76.9	735,343	745,350
New York	Niagara Co	82.3	219,846	220,407
New York	Orange Co	77.1	341,367	371,434
New York	Putnam Co	82.3	95,745	107,967
New York	Queens Co	78.3	2,229,379	2,239,026
New York	Richmond Co	**87.1**	443,728	488,728
New York	Suffolk Co	**90.8**	1,419,369	1,472,127
New York	Westchester Co	84.7	923,459	944,535

North Carolina	Mecklenburg Co	81.4	695,453	814,088
North Carolina	Rowan Co	80.1	130,340	143,729
North Carolina	Wake Co	77.2	627,846	787,707
Ohio	Allen Co	76.8	108,473	106,900
Ohio	Ashtabula Co	83.5	102,728	104,850
Ohio	Butler Co	78	332,806	384,410
Ohio	Clermont Co	78	177,977	205,365
Ohio	Clinton Co	81.4	40,543	47,137
Ohio	Cuyahoga Co	77.3	1,393,977	1,348,313
Ohio	Delaware Co	77.3	109,989	136,125
Ohio	Franklin Co	81.9	1,068,977	1,142,894
Ohio	Geauga Co	**86.6**	90,895	102,083
Ohio	Hamilton Co	78.6	845,302	843,226
Ohio	Knox Co	76.5	54,500	59,435
Ohio	Lake Co	82.2	227,511	237,161
Ohio	Lorain Co	78.5	284,664	292,040
Ohio	Lucas Co	80	455,053	447,302
Ohio	Medina Co	76.5	151,095	173,985
Ohio	Portage Co	79.8	152,061	162,685
Ohio	Summit Co	82.4	542,898	552,567
Ohio	Trumbull Co	79.7	225,116	226,157
Ohio	Warren Co	80	158,383	186,219
Ohio	Wood Co	77.4	121,065	129,124
Oklahoma	Tulsa Co	79.2	563,299	610,536
Pennsylvania	Allegheny Co	81.9	1,281,665	1,259,040
Pennsylvania	Armstrong Co	79.7	72,392	72,829
Pennsylvania	Beaver Co	79.6	181,412	183,693
Pennsylvania	Berks Co	81.7	373,637	388,194
Pennsylvania	Bucks Co	**94.3**	597,635	648,796
Pennsylvania	Cambria Co	76.9	152,598	146,811
Pennsylvania	Chester Co	**85.4**	433,501	478,460
Pennsylvania	Dauphin Co	80.8	251,798	265,019
Pennsylvania	Delaware Co	84	550,863	543,169
Pennsylvania	Erie Co	79.1	280,843	284,835
Pennsylvania	Franklin Co	80.2	129,313	135,088
Pennsylvania	Lancaster Co	83.6	470,657	513,684
Pennsylvania	Lehigh Co	82.1	312,090	323,215
Pennsylvania	Mercer Co	78.1	120,293	122,546
Pennsylvania	Montgomery Co	**87.6**	750,097	772,849
Pennsylvania	Northampton Co	81.8	267,066	279,797
Pennsylvania	Philadelphia Co	**89.9**	1,517,549	1,420,803
Pennsylvania	Washington Co	77.3	202,897	205,153
Pennsylvania	Westmoreland Co	76.7	369,993	372,941
Pennsylvania	York Co	79.4	381,750	404,807
Rhode Island	Kent Co	**86.2**	167,090	174,126
Rhode Island	Providence Co	81.2	621,602	621,355
Rhode Island	Washington Co	84.2	123,546	137,756
South Carolina	Richland Co	76.9	320,677	349,826
Tennessee	Sevier Co	76.5	71,170	96,097
Tennessee	Shelby Co	76.7	897,471	958,501
Texas	Brazoria Co	84.1	241,767	281,960
Texas	Collin Co	82.5	491,675	677,868
Texas	Dallas Co	82.2	2,218,899	2,382,657
Texas	Denton Co	**86.8**	432,976	554,033
Texas	Galveston Co	84.6	250,158	283,963
Texas	Gregg Co	79.1	111,379	121,241
Texas	Harris Co	**97.4**	3,400,577	3,770,129
Texas	Jefferson Co	**85**	252,051	260,847

Texas	Johnson Co	78.2	126,811	157,545
Texas	Montgomery Co	81.2	293,768	413,048
Texas	Tarrant Co	**87.2**	1,446,219	1,710,920
Virginia	Alexandria City	80.9	128,283	130,422
Virginia	Arlington Co	**86**	189,453	193,370
Virginia	Charles City Co	77.7	6,926	7,382
Virginia	Fairfax Co	**85.4**	969,749	1,085,483
Virginia	Hampton City	78.7	146,437	153,246
Virginia	Hanover Co	80.9	86,320	98,586
Virginia	Henrico Co	78.2	262,300	294,174
Virginia	Loudoun Co	78.6	169,599	214,469
Virginia	Suffolk City	77.5	63,677	69,003
Wisconsin	Door Co	82.1	27,961	30,508
Wisconsin	Kenosha Co	**91**	149,577	166,359
Wisconsin	Kewaunee Co	79.9	20,187	20,538
Wisconsin	Manitowoc Co	80	82,887	83,516
Wisconsin	Milwaukee Co	82.1	940,164	922,943
Wisconsin	Ozaukee Co	**85.8**	82,317	95,549
Wisconsin	Racine Co	83.9	188,831	199,178
Wisconsin	Sheboygan Co	**87.7**	112,646	118,866
Number of Violating Counties		37		
Population of Violating Counties			22,724,010	24,264,574
Number of Counties within 10%		148		
Population of Counties within 10%			58,453,962	61,409,062

a) Bolded concentrations indicate levels above the 8-hour ozone standard.
b) Populations are based on 2000 census data.
c) Populations are based on 2000 census projections.

The CAMx model also contains a source apportionment tool which can be used to estimate how emissions from individual source areas and regions impact modeled ozone concentrations. Small SI and Marine SI sector contributions were calculated for the areas which the CAIR modeling projected to have design values at or above 85 ppb in 2020. In those areas, Small SI and Marine SI emissions were estimated to be responsible for between one and seven percent of the ozone concentrations above 85 ppb. Additional information on the source apportionment tool and analysis can be found in the air quality modeling TSD for this proposal.

We have described the current nonattainment with the 8-hour ozone NAAQS and that absent additional controls, modeling predicts that there will continue to be people living in counties with 8-hour ozone levels above the NAAQS in the future. In addition, we have described how in the future, in areas which are projected to have ozone levels greater than 85 ppb, Small SI engines and equipment and Marine SI engines and vessels are projected to contribute to these ozone concentrations.

These analyses demonstrate the need for reductions in emissions from this proposed rule. As shown earlier in Figure 2-1, unhealthy ozone concentrations occur over wide geographic areas and the engines, vessels and equipment covered in this proposed rule contribute to the ozone precursors in and near these areas. Thus, reductions in ozone precursors from Small SI engines and equipment and Marine SI engines and vessels are needed to assist States in attaining and maintaining the 8-hour ozone NAAQS and reducing ozone exposures.

2.1.3.2.3 Modeling Projections of ozone with the proposed controls

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the reductions in Small SI engine and equipment and Marine SI engine and vessel emissions proposed in this action. Specifically, we compare baseline scenarios to scenarios with the proposed controls. Our modeling indicates that the reductions from this proposed rule would contribute to reducing ambient ozone concentrations and potential exposures in future years.

On a population-weighted basis, the average change in future year design values for the eastern U.S. would be a decrease of 0.7 ppb in 2020 and 0.8 ppb in 2030. In areas with larger design values, greater than 85 ppb, the population-weighted average decrease would be somewhat higher, 0.8 ppb in 2020 and 1.0 ppb in 2030.

Table 2.1-2 shows the average change in future year eight-hour ozone design values. Average changes are shown 1) for all counties with 2001-2003 8-hour ozone design values, 2) for counties with design values that did not meet the standard in 2001-2003 (“violating” counties), and 3) for counties that met the standard, but were within 10 percent of it in 2001-2003. This last category is intended to reflect counties that meet the standard, but will likely benefit from help in maintaining that status in the face of growth. The average and population-weighted average over all counties in Table 2.1-2 demonstrates a broad improvement in ozone air quality. The average across violating counties shows that the proposed rule would help bring these counties into attainment. Since some of the VOC and NOx emission reductions expected from this proposed rule would go into effect during the period when areas will need to attain the 8-hour ozone NAAQS, the projected reductions in emissions are expected to assist States and local agencies in their effort to attain and maintain the 8-hour ozone standard. The average over counties within ten percent of the standard shows that the proposed rule would also help those counties to maintain the standard. All of these metrics show a decrease in 2020 and a larger decrease in 2030, indicating in four different ways the overall improvement in ozone air quality.

Table 2.1-2: Average Change in Projected Future Year 8-hour Ozone Design Value

Average[a]	Number of Eastern Counties	change in 2020 design value[b] (ppb)	change in 2030 design value[b] (ppb)
All	525	-0.5	-0.7
All, population-weighted	525	-0.7	-0.8
Violating counties[c]	270	-0.6	-0.8
Violating counties[c], population-weighted	270	-0.8	-1.0
Counties within 10 percent of the standard[d]	185	-0.4	-0.5
Counties within 10 percent of the standard[d], population-weighted	185	-0.5	-0.7

[a] averages are over counties with 2001 modeled design values
[b] assuming the nominal modeled control scenario
[c] counties whose 2001 design values exceeded the 8-hour ozone standard (>= 85 ppb)
[d] counties whose 2001 design values were less than but within 10 percent of the 8-hour ozone standard (between 77 and 85 ppb)

The impact of the proposed reductions has also been analyzed with respect to those areas that have the highest projected design values. We project that there will be 13 Eastern counties with design values at or above 85 ppb in 2030. After implementation of this proposed action, we project that 7 of these 13 counties would be at least 40% closer to a design value of less than 85 ppb, and on average all 13 counties would be 35% closer to a design value of less than 85 ppb.

2.1.4 Environmental Effects of Ozone Pollution

There are a number of public welfare effects associated with the presence of ozone in the ambient air.[34] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

The Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant".[35] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake". To a lesser extent, ozone can also diffuse directly through surface layers to the plant's interior.[36] Once sufficient levels of ozone, a highly reactive substance, (or its reaction products) reaches the interior of plant cells, it can inhibit or damage essential cellular components and functions, including enzyme activities, lipids, and cellular membranes, disrupting the plant's osmotic (i.e., water) balance and energy utilization patterns.[37, 38] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or as reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[39] With fewer resources available, the plant reallocates existing resources away from root growth and storage, above ground growth or yield, and reproductive processes, toward leaf repair and maintenance. Studies have shown that plants stressed in these ways may exhibit a general loss of vigor, which can lead to secondary impacts that modify plants' responses to other environmental factors. Specifically, plants may become more sensitive to other air pollutants, more susceptible to disease, insect attack, harsh weather (e.g., drought, frost) and other environmental stresses. Furthermore, there is some evidence that ozone can interfere with the formation of mycorrhiza, essential symbiotic fungi associated with the roots of most terrestrial plants, by reducing the amount of carbon available for transfer from the host to the symbiont.[40]

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on sensitive vegetation. Not all plants, however, are equally sensitive to ozone. Much of the variation in sensitivity between individual plants or whole species is related to the plant's ability to regulate the extent of gas exchange via leaf stomata (e.g., avoidance of O_3 uptake through closure of stomata).[41, 42, 43] Other resistance mechanisms may involve the intercellular production of detoxifying substances. Several biochemical substances capable of detoxifying ozone have been reported to occur in plants including the antioxidants ascorbate and glutathione. After injuries have occurred, plants may be capable of repairing the damage to a limited extent.[44] Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants. The next few paragraphs present additional information on ozone damage to trees, ecosystems, agronomic crops and urban ornamentals.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[45, 46] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts.[47] Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[48,49]

Because plants are at the center of the food web in many ecosystems, changes to the plant community can affect associated organisms and ecosystems (including the suitability of habitats that support threatened or endangered species and below ground organisms living in the root zone). Ozone impacts at the community and ecosystem level vary widely depending upon numerous factors, including concentration and temporal variation of tropospheric ozone, species composition, soil properties and climatic factors.[50] In most instances, responses to chronic or recurrent exposure in forest exosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[51, 52, 53] It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Laboratory and field experiments have also shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the Unites States."[54] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[55, 56, 57]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[58] This is therefore a potentially costly environmental effect. However, in the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative analysis has been conducted. Methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

2.2 Particulate Matter

In this section we review the health and welfare effects of PM. We also describe air quality monitoring and modeling data that indicate many areas across the country continue to be exposed to levels of ambient PM above the NAAQS. Emissions of HCs and NOx from the engines, vessels and equipment subject to this proposed rule contribute to these PM concentrations. Information on air quality was gathered from a variety of sources, including monitored PM concentrations, air quality modeling done for recent EPA rulemakings and other state and local air quality information.

2.2.1 Science of PM Formation

Particulate matter (PM) represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM is further described by breaking it down into size fractions. PM_{10} refers to particles generally less than or equal to 10 micrometers (µm) in diameter. $PM_{2.5}$ refers to fine particles, those particles generally less than or equal to 2.5 µm in diameter. Inhalable (or "thoracic") coarse particles refer to those particles generally greater than 2.5 µm but less than or equal to 10 µm in diameter. Ultrafine PM refers to particles with diameters generally less than 100 nanometers (0.1 µm). Larger particles (>10 µm) tend to be removed by the respiratory clearance mechanisms, whereas smaller particles are deposited deeper in the lungs.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SOx, NOx and VOCs) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology and source category. Thus, $PM_{2.5}$, may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.

The engines, vessels and equipment that would be covered by the proposed standards contribute to ambient PM levels through primary (direct) and secondary (indirect) PM. Primary PM is directly emitted into the air, and secondary PM forms in the atmosphere from gases emitted by fuel combustion and other sources. Along with primary PM, the engines, vessels and equipment controlled in this action emit HC and NOx, which react in the atmosphere to form secondary $PM_{2.5}$. Both types of directly and indirectly formed particles from Small SI engines and equipment and Marine SI engines and vessels are found principally in the fine fraction.

EPA has recently amended the PM NAAQS (71 FR 61144, October 17, 2006). The final rule, signed on September 21, 2006 and published on October 17, 2006, addressed revisions to the primary and secondary NAAQS for PM to provide increased protection of public health and welfare, respectively. The primary $PM_{2.5}$ NAAQS include a short-term (24-hour) and a long-term (annual) standard. The level of the 24-hour $PM_{2.5}$ NAAQS has been revised from 65 µg/m3 to 35 µg/m3 to provide increased protection against health effects associated with short-term exposures to fine particles. The current form of the 24-hour $PM_{2.5}$ standard was retained (e.g., based on the 98th percentile concentration averaged over three years). The level of the annual $PM_{2.5}$ NAAQS was retained at 15 µg/m3, continuing protection against health effects associated with long-term exposures. The current form of the annual $PM_{2.5}$ standard was retained as an annual arithmetic mean averaged over three years, however, the following two aspects of the spatial averaging criteria were narrowed: (1) the annual mean concentration at each site shall be within 10 percent of the spatially averaged annual mean, and (2) the daily values for each monitoring site pair shall yield a correlation coefficient of at least 0.9 for each calendar quarter. With regard to the primary PM_{10} standards, the 24-hour PM_{10} NAAQS was retained at a level of 150 $\mu g/m^3$ not to be exceeded more than once per year on average over a three-year period. Given that the available evidence does not suggest an association between long-term exposure to coarse particles at current ambient levels and health effects, EPA has revoked the annual PM_{10} standard.

With regard to the secondary PM standards, EPA has revised these standards to be identical in all respects to the revised primary standards. Specifically, EPA has revised the current 24-hour $PM_{2.5}$ secondary standard by making it identical to the revised 24-hour $PM_{2.5}$ primary standard, retained the annual $PM_{2.5}$ and 24-hour PM_{10} secondary standards, and revoked the annual PM_{10} secondary standards. This suite of secondary PM standards is intended to provide protection against PM-related public welfare effects, including visibility impairment, effects on vegetation and ecosystems, and material damage and soiling.

2.2.2 Health Effects of PM

As stated in the EPA Particulate Matter Air Quality Criteria Document (PM AQCD), available scientific findings “demonstrate well that human health outcomes are associated with ambient PM.”[5] We are relying primarily on the data and conclusions in the PM AQCD and PM staff paper, which reflects EPA’s analysis of policy-relevant science from the PM AQCD, regarding the health effects associated with particulate matter.[59,60] We also present additional recent studies published after the cut-off date for the PM AQCD.[6, 61] Taken together this information supports the conclusion that PM-related emissions from Small SI engines and equipment and Marine SI engines and vessels are associated with adverse health effects.

2.2.2.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases (PM AQCD, p. 8-305), hospitalization and emergency department visits for cardiopulmonary diseases (PM AQCD, p. 9-93), increased respiratory symptoms (PM AQCD, p. 9-46), decreased lung function (PM AQCD Table 8-34) and physiological changes or biomarkers for cardiac changes (PM AQCD, Section 8.3.1.3.4). In addition, the PM AQCD describes a limited body of new evidence from epidemiologic studies for potential relationships between short-term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality. (PM AQCD, Section 8.3.4).

Among the studies of effects from short-term exposure to $PM_{2.5}$, several studies specifically address the contribution of mobile sources to short-term $PM_{2.5}$ effects on daily mortality. These studies indicate that there are statistically significant associations between mortality and PM related to mobile source emissions (PM AQCD, p. 8-85). The analyses incorporate source apportionment tools into daily mortality studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death established a specific influence of mobile source-related $PM_{2.5}$ on daily mortality[62] and a concentration-response function for mobile source-associated $PM_{2.5}$ and daily mortality.[63] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. They found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient

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[5] Personal exposure includes contributions from many different types of particles, from many sources, and in many different environments. Total personal exposure to PM includes both ambient and nonambient components; and both components may contribute to adverse health effects.

[6] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by EPA, CASAC, and the public, as did the PM AQCD. The provisional assessment found that the "new" studies expand the scientific information and provide important insights on the relationship between PM exposure and health effects of PM. The provisional assessment also found that "new" studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects.

PM_{10} when compared with other sources.[64] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

2.2.2.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to elevated ambient $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases and lung cancer (PM AQCD, p. 8-307), and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease (PM AQCD, pp. 8-313, 8-314). Of specific importance to this proposal, the PM AQCD also notes that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to the observed ambient PM-related increases in lung cancer incidence and mortality (PM AQCD, p. 8-318).

The PM AQCD and PM Staff Paper emphasize the results of two long-term studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors - the inclusion of measured PM data, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis (PM AQCD, p. 8-306, Staff Paper, p.3-18).[65,66,67] These studies indicate that there are significant associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. A variety of studies have been published since the completion of the PM AQCD. One such study, an analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[68] EPA is assessing the significance of this study within the context of the broader literature.

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth (PM AQCD, Section 8.3.3.2.3). One such study, which was summarized in the 2006 Provisional Assessment, reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and measures of atherosclerosis in the Los Angeles basin.[69] The study found significant associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease. EPA is assessing the significance of this study within the context of the broader literature.

2.2.2.3 Roadway-Related Exposure and Health Studies

A recent body of studies reinforces the findings of these PM morbidity and mortality effects by looking at traffic-related exposures, PM measured along roadways, or time spent in traffic and adverse health effects. While many of these studies did not measure PM specifically, they include potential exhaust exposures which include mobile source PM because they employ indices such as roadway proximity or traffic volumes. One study with specific relevance to

$PM_{2.5}$ health effects is a study that was done in North Carolina looking at concentrations of $PM_{2.5}$ inside police cars and corresponding physiological changes in the police personnel driving the cars. The authors report significant elevations in markers of cardiac risk associated with concentrations of $PM_{2.5}$ inside police cars on North Carolina state highways.[70] A number of studies of traffic-related pollution have shown associations between fine particles and adverse respiratory outcomes in children who live near major roadways. [71,72,73] Additional information on near-roadway health effects is included in the recent Mobile Source Air Toxics rule (72 FR 8428, February 26, 2007).

2.2.3 Current and Projected PM Levels

The proposed emission reductions from this rule would assist PM nonattainment areas in reaching the standard by each area's respective attainment date and assist PM maintenance areas in maintaining the PM standards in the future. The emission reductions would also help continue to lower ambient PM levels and resulting health impacts into the future. In this section we present information on current and future attainment of the PM standards.

2.2.3.1 Current $PM_{2.5}$ Levels

A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard. In 2005, EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS based on air quality design values (using 2001-2003 or 2002-2004 measurements) and a number of other factors.[7](70 FR 943, January 5, 2005; 70 FR 19844, April 14, 2005) These areas are comprised of 208 full or partial counties with a total population exceeding 88 million.[8] As mentioned in Section 2.2.1, the 1997 $PM_{2.5}$ NAAQS were recently revised and the 2006 $PM_{2.5}$ NAAQS became effective on December 18, 2006. Nonattainment areas will be designated with respect to the new 2006 PM NAAQS in early 2010. Table 2.2-1 presents the number of counties in areas currently designated as nonattainment for the 1997 $PM_{2.5}$ NAAQS as well as the number of additional counties which have monitored data that is violating the 2006 $PM_{2.5}$ NAAQS.

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[7] The full details involved in calculating a $PM_{2.5}$ design value are given in Appendix N of 40 CFR Part 50.

[8] The $PM_{2.5}$ nonattainment areas are listed in a Memo to the Docket titled "Nonattainment Areas and Mandatory Class I Federal Areas" and contained in Docket EPA-HQ-OAR-2004-0008.

Table 2.2-1. Fine Particle Standards: Current Nonattainment Areas and Other Violating Counties

	Number of Counties	Population[1]
1997 $PM_{2.5}$ Standards: 39 areas currently designated	208	88,394,000
2006 $PM_{2.5}$ Standards: Counties with violating monitors[2]	49	18,198,676
Total	257	106,592,676

[1] Population numbers are from 2000 census data.

[2] This table provides an estimate of the counties violating the 2006 $PM_{2.5}$ NAAQS based on 2003-05 air quality data. The areas designated as nonattainment for the 2006 $PM_{2.5}$ NAAQS will be based on 3 years of air quality data from later years. Also, the county numbers in the summary table includes only the counties with monitors violating the 2006 $PM_{2.5}$ NAAQS. The monitored county violations may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most $PM_{2.5}$ nonattainment areas will be required to attain the 1997 $PM_{2.5}$ NAAQS in the 2010 to 2015 time frame and then be required to maintain the 1997 $PM_{2.5}$ NAAQS thereafter.[9] The attainment dates associated with the potential nonattainment areas based on the 2006 $PM_{2.5}$ NAAQS would likely be in the 2015 to 2020 timeframe. The emission standards being proposed in this action would become effective between 2008 and 2013. The expected $PM_{2.5}$ inventory reductions from the standards proposed in this action would be useful to states in attaining or maintaining the $PM_{2.5}$ NAAQS.

2.2.3.2 Current PM_{10} Levels

EPA designated PM_{10} nonattainment areas in 1990.[10] As of October 2006, approximately 28 million people live in the 46 areas that are designated as PM_{10} nonattainment, for either failing to meet the PM_{10} NAAQS or for contributing to poor air quality in a nearby area. There are 46 full or partial counties that make up the PM_{10} nonattainment areas.[11]

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[9] The EPA finalized $PM_{2.5}$ attainment and nonattainment areas in April 2005. The EPA finalized the PM Implementation rule in March 2007.

[10] A PM_{10} design value is the concentration that determines whether a monitoring site meets the NAAQS for PM_{10}. The full details involved in calculating a PM_{10} design value are given in Appendices H and I of 40 CFR Part 50.

[11] The PM_{10} nonattainment areas are listed in a Memo to the Docket titled "Nonattainment Areas and Mandatory Class I Federal Areas" and contained in Docket EPA-HQ-OAR-2004-0008.

2.2.3.3 Projected $PM_{2.5}$ Levels

Recent air quality modeling predicts that without additional controls there will continue to be a need for reductions in PM concentrations in the future. In the following sections we describe the recent PM air quality modeling and results of the modeling.

2.2.3.3.1 PM Modeling Methodology

Recently PM air quality analyses were performed for the PM NAAQS final rule, which was promulgated by EPA in 2006. The Community Multiscale Air Quality (CMAQ) model was used as the tool for simulating base and future year concentrations of PM, visibility and deposition in support of the PM NAAQS air quality assessments. The PM NAAQS analysis included all federal rules up to and including the Clean Air Interstate Rule (CAIR) and all final mobile source rule controls as of October 2006. Details on the PM air quality modeling are provided in the RIA for the final PM NAAQS rule, included in the docket for this proposed rule.

2.2.3.3.2 Areas at Risk of Future $PM_{2.5}$ Violations

Air quality modeling performed for the final PM NAAQS indicates that in the absence of additional local, regional or national controls, there will likely continue to be counties that will not attain some combination of the annual 2006 $PM_{2.5}$ standard (15 µg/m^3) and the daily 2006 $PM_{2.5}$ standard (35 µg/m^3). The PM NAAQS analysis provides estimates of future $PM_{2.5}$ levels across the country. For example, in 2015 based on emission controls currently adopted or expected to be in place[12], we project that 53 million people will live in 52 counties with projected $PM_{2.5}$ design values at and above the 2006 standard, see Table 2.2-2.[13] The proposed rule would provide emission reductions that will help areas to attain the $PM_{2.5}$ NAAQS. Table 2.2-2 also lists the 54 counties, where 27 million people are projected to live, with 2015 projected design values that do not violate the $PM_{2.5}$ NAAQS but are within ten percent of it. The proposed rule may help ensure that these counties continue to maintain their attainment status.

Table 2.2-2 Counties with 2015 Projected $PM_{2.5}$ Design Values Above and within 10% of the 2006 $PM_{2.5}$ Standard

State	County	2015 Projected Annual $PM_{2.5}$ Design Value (µg/m^3)[a]	2015 Projected Daily $PM_{2.5}$ Design Value (µg/m^3)[a]	2015 Population[b]
Alabama	Jefferson Co	**15.9**	**36.9**	669,850
California	Alameda Co	**13.3**	**59.4**	1,628,698
California	Butte Co	**13.4**	**50.7**	242,166

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[12] Counties forecast to remain in nonattainment may need to adopt additional local or regional controls to attain the standards by dates set pursuant to the Clean Air Act. The emissions reductions associated with this proposed rule would help these areas attain the PM standards by their statutory date.

[13] Note that this analysis identifies only counties projected to have a violating monitor; the number of counties to be designated and the associated population would likely exceed these estimates.

California	Colusa Co	9.5	33.5	23,066
California	Contra Costa Co	**12.6**	**61.3**	1,155,323
California	Fresno Co	**20.1**	**73.0**	960,934
California	Imperial Co	**14.8**	**45.7**	173,482
California	Inyo Co	**6.1**	**38.1**	19,349
California	Kern Co	**21.3**	**81.4**	804,940
California	Kings Co	**17.2**	**70.6**	161,607
California	Los Angeles Co	**23.7**	**62.2**	9,910,805
California	Merced Co	**15.8**	**54.4**	250,152
California	Orange Co	**20.0**	**41.1**	3,467,120
California	Placer Co	**11.4**	**38.1**	403,624
California	Riverside Co	**27.8**	**73.5**	2,015,955
California	Sacramento Co	**12.2**	**49.8**	1,488,456
California	San Bernardino Co	**24.6**	**65.7**	2,157,926
California	San Diego Co	**15.8**	**40.7**	3,489,368
California	San Francisco Co	**11.3**	**52.5**	765,846
California	San Joaquin Co	**15.4**	**51.1**	675,362
California	San Luis Obispo Co	**9.4**	**35.8**	304,079
California	San Mateo Co	**10.5**	**41.9**	785,949
California	Santa Clara Co	**10.7**	**48.5**	1,899,727
California	Solano Co	**11.7**	**57.7**	529,784
California	Sonoma Co	**10.0**	**38.9**	569,486
California	Stanislaus Co	**16.6**	**61.9**	547,041
California	Sutter Co	**11.2**	**39.3**	99,716
California	Tulare Co	**21.2**	**77.2**	441,185
California	Ventura Co	**14.1**	**38.8**	923,205
California	Yolo Co	10.2	33.0	206,388
Connecticut	Fairfield Co	11.0	31.6	893,629
Georgia	Bibb Co	13.7	27.0	160,468
Georgia	Clayton Co	13.9	28.7	280,476
Georgia	DeKalb Co	13.6	31.5	715,947
Georgia	Floyd Co	14.0	30.9	97,674
Georgia	Fulton Co	**15.5**	**32.2**	877,365
Georgia	Muscogee Co	13.4	34.2	197,634
Georgia	Wilkinson Co	13.6	29.3	11,259
Idaho	Ada Co	8.9	32.2	397,456
Idaho	Bannock Co	**9.1**	**40.2**	88,033
Idaho	Canyon Co	9.2	32.6	154,137
Idaho	Power Co	**10.5**	**36.6**	8,932
Idaho	Shoshone Co	**12.4**	**36.2**	15,646
Illinois	Cook Co	**15.5**	**37.1**	5,362,931
Illinois	Madison Co	**15.2**	**35.5**	271,854
Illinois	St. Clair Co	14.6	30.4	251,612
Illinois	Will Co	13.2	32.0	634,068
Indiana	Clark Co	13.6	31.1	112,523
Indiana	Lake Co	**13.4**	**40.8**	490,795
Indiana	Marion Co	13.5	33.1	889,645
Kentucky	Jefferson Co	13.8	33.4	710,231
Maryland	Anne Arundel Co	11.1	33.2	574,322
Maryland	Baltimore city	13.0	35.5	596,076
Maryland	Baltimore Co	11.3	32.6	810,172
Massachusetts	Hampden Co	11.6	32.9	452,055
Michigan	Kalamazoo Co	12.8	32.7	257,817
Michigan	Kent Co	12.0	31.9	654,449

Michigan	Oakland Co	13.0	33.2	1,355,670
Michigan	St. Clair Co	12.5	32.5	185,970
Michigan	Wayne Co	**17.4**	**39.0**	1,921,253
Montana	Lincoln Co	**15.0**	**42.4**	19,875
Montana	Missoula Co	10.6	32.1	118,303
New Jersey	Camden Co	11.1	32.1	512,135
New Jersey	Hudson Co	12.0	32.8	604,036
New Jersey	Union Co	12.2	32.8	525,096
New York	Bronx Co	12.8	33.2	1,283,316
New York	New York Co	14.0	33.2	1,551,641
Ohio	Cuyahoga Co	**15.4**	**40.0**	1,325,507
Ohio	Franklin Co	13.7	33.5	1,181,578
Ohio	Hamilton Co	14.3	34.2	841,858
Ohio	Jefferson Co	14.2	34.2	68,909
Ohio	Lucas Co	12.5	32.2	443,230
Ohio	Scioto Co	**15.6**	**34.3**	81,013
Ohio	Trumbull Co	12.1	34.2	227,546
Oregon	Jackson Co	**10.9**	**37.6**	250,169
Oregon	Klamath Co	**10.1**	**39.1**	69,423
Oregon	Lane Co	**12.9**	**53.6**	387,237
Oregon	Washington Co	9.0	32.0	639,839
Pennsylvania	Allegheny Co	**16.5**	**53.4**	1,245,917
Pennsylvania	Beaver Co	12.1	33.2	184,648
Pennsylvania	Berks Co	**12.0**	**35.5**	396,410
Pennsylvania	Dauphin Co	11.0	33.3	272,748
Pennsylvania	Lancaster Co	12.2	33.7	535,622
Pennsylvania	Lehigh Co	10.5	34.7	328,523
Pennsylvania	Mercer Co	11.0	31.6	123,577
Pennsylvania	Northampton Co	10.9	35.0	286,838
Pennsylvania	Philadelphia Co	13.3	35.2	1,372,037
Pennsylvania	York Co	**12.3**	**35.9**	417,408
Tennessee	Knox Co	13.6	29.6	448,931
Utah	Box Elder Co	**8.6**	**39.0**	49,878
Utah	Cache Co	**12.5**	**51.9**	114,729
Utah	Salt Lake Co	**12.6**	**49.3**	1,133,410
Utah	Utah Co	**9.3**	**36.7**	508,106
Utah	Weber Co	**9.1**	**36.2**	229,807
Washington	Clark Co	9.2	34.3	479,002
Washington	King Co	10.8	34.0	2,013,808
Washington	Pierce Co	**11.1**	**43.0**	879,363
Washington	Snohomish Co	**11.3**	**40.1**	782,319
Washington	Thurston Co	8.9	34.9	264,364
Washington	Yakima Co	9.6	34.9	261,452
West Virginia	Berkeley Co	12.0	32.7	99,349
West Virginia	Hancock Co	13.4	32.7	30,857
West Virginia	Kanawha Co	13.9	28.9	196,498
Wisconsin	Milwaukee Co	12.1	32.1	908,336
Wisconsin	Waukesha Co	11.8	32.4	441,482
Wyoming	Sheridan Co	10.5	31.8	28,623
Number of Violating Counties		52		
Population of Violating Counties				53,468,515
Number of Counties within 10%		54		
Population of Counties within 10%				26,896,926

[a] Bolded concentrations indicate levels above the annual $PM_{2.5}$ standard.

[b] Populations are based on 2000 census projections.

2.2.4 Environmental Effects of PM Pollution

In this section we discuss some of the public welfare effects of PM and its precursors, including NOx, such as visibility impairment, acid deposition, eutrophication, nitrification and fertilization, materials damage, and deposition of PM.

2.2.4.1 Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[74] Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.[75] Local visibility impairment may take the form of a localized plume, a band or layer of discoloration appearing well above the terrain as a result from complex local meteorological conditions. Alternatively, local visibility impairment may manifest as an urban haze, sometimes referred to as a "brown cloud." This urban haze is largely caused by emissions from multiple sources in the urban areas and is not typically attributable to only one nearby source or to long-range transport. The second type of visibility impairment, regional haze, usually results from multiple pollution sources spread over a large geographic region. Regional haze can impair visibility over large regions and across states.

Visibility is important because it directly affects people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, both in where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the 2004 PM AQCD as well as the 2005 PM Staff Paper.[76,77]

Fine particles are the major cause of reduced visibility in parts of the United States. To address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which would act in conjunction with the establishment of a regional haze program. In setting this secondary standard, EPA concluded that $PM_{2.5}$ causes adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. The secondary (welfare-based) $PM_{2.5}$ NAAQS was established as equal to the suite of primary (health-based) NAAQS. Furthermore, section 169 of the Act provides additional authority to remedy existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas labeled as mandatory class I federal areas (62 FR 38680-81, July 18, 1997).[14][15] In July 1999 the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory class I federal areas. Visibility can be said to be

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[14] These areas are defined in section 162 of the Act as those national parks exceeding 6,000 acres , wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

[15] The mandatory class I federal areas are listed in a Memo to the Docket titled "Nonattainment Areas and Mandatory Class I Federal Areas" and contained in Docket EPA-HQ-OAR-2004-0008.

impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.

EPA has determined that emissions from nonroad engines significantly contribute to air pollution that may be reasonably anticipated to endanger public health and welfare for visibility effects in particular (67 FR 68242, November 8, 2002). The hydrocarbon emissions from the Small SI engines and equipment subject to this proposed rule are PM-precursors and contribute to these visibility effects. This is evident in the PM and visibility modeling recently completed for the PM NAAQS and the CAIR. Small SI engines and equipment and Marine SI engines and vessels were included in the PM NAAQS and CAIR PM and visibility modeling which projected visibility problems persisting in the future.[78,79] In this section we present current information and projected estimates about both visibility impairment related to ambient $PM_{2.5}$ levels across the country and visibility impairment in mandatory class I federal areas. We conclude that visibility will continue to be impaired in the future and the projected emission reductions from this proposed action would help improve visibility conditions across the country and in mandatory class I federal areas.

2.2.4.1.1 Current Visibility Impairment

The need for reductions in the levels of $PM_{2.5}$ is widespread. Currently, high ambient $PM_{2.5}$ levels are measured throughout the country. Fine particles may remain suspended for days or weeks and travel hundreds to thousands of kilometers, and thus fine particles emitted or created in one county may contribute to ambient concentrations in a neighboring region.[80]

As mentioned above, the secondary $PM_{2.5}$ standards were set as equal to the suite of primary $PM_{2.5}$ standards. Recently designated $PM_{2.5}$ nonattainment areas indicate that, as of October 2006, almost 90 million people live in 208 counties that are in nonattainment for the $PM_{2.5}$ NAAQS. Thus, at least these populations (plus others who travel to these areas) would likely be experiencing visibility impairment. Emissions of PM precursors, such as hydrocarbons, from Small SI engines and equipment and Marine SI engines and vessels contribute to this impairment.

2.2.4.1.2 Current Visibility Impairment at Mandatory Class I Federal Areas

Detailed information about current and historical visibility conditions in mandatory class I federal areas is summarized in the EPA Report to Congress and the 2002 EPA Trends Report.[81,82] The conclusions draw upon the Interagency Monitoring of Protected Visual Environments (IMPROVE) network data. One of the objectives of the IMPROVE monitoring network program is to provide regional haze monitoring representing all mandatory class I federal areas where practical. The National Park Service report also describes the state of national park visibility conditions and discusses the need for improvement.[83]

The regional haze rule requires states to establish goals for each affected mandatory class I federal area to improve visibility on the haziest days (20% most impaired days) and ensure no degradation occurs on the cleanest days (20% least impaired days). Although there have been general trends toward improved visibility, progress is still needed on the haziest days.

Specifically, as discussed in the 2002 EPA Trends Report,without the effects of pollution a natural visual range in the United States is approximately 75 to 150 km in the East and 200 to 300 km in the West. In 2001, the mean visual range for the worst days was 29 km in the East and 98 km in the West.[84]

2.2.4.1.3 Future Visibility Impairment

Recent modeling for the final PM NAAQS rule was used to project $PM_{2.5}$ levels in the U.S. in 2015. The results suggest that $PM_{2.5}$ levels above the 2006 NAAQS will persist in the future. We predicted that in 2015, there will be 52 counties with a population of 53 million where $PM_{2.5}$ levels will exceed the 2006 $PM_{2.5}$ NAAQS. Thus, in the future, a percentage of the population may continue to experience visibility impairment in areas where they live, work and recreate.

The emissions from Small SI engines and equipment and Marine SI engines and vessels contribute to visibility impairment. These emissions occur in and around areas with $PM_{2.5}$ levels above the $PM_{2.5}$ NAAQS. Thus, the emissions from these sources contribute to the current and anticipated visibility impairment and the proposed emission reductions would help improve future visibility impairment.

2.2.4.1.4 Future Visibility Impairment at Mandatory Class I Federal Areas

Achieving the $PM_{2.5}$ NAAQS will help improve visibility across the country, but it will not be sufficient to meet the statutory goal of no manmade impairment in the mandatory class I federal areas (64 FR 35722, July 1, 1999 and 62 FR 38680, July 18, 1997). In setting the NAAQS, EPA discussed how the NAAQS in combination with the regional haze program, is deemed to improve visibility consistent with the goals of the Act.[85] In the East, there are and will continue to be areas with $PM_{2.5}$ concentrations above the $PM_{2.5}$ NAAQS and where light extinction is significantly above natural background. Thus, large areas of the Eastern United States have air pollution that is causing and will continue to cause visibility problems. In the West, scenic vistas are especially important to public welfare. Although the $PM_{2.5}$ NAAQS is met in most areas outside of California, virtually the entire West is in close proximity to a scenic mandatory class I federal area protected by 169A and 169B of the CAA.

Recent modeling for the CAIR was used to project visibility conditions in mandatory class I federal areas across the country in 2015. The results for the mandatory class I federal areas suggest that these areas are predicted to continue to have visibility impairment above background on the 20% worst days in the future.

The overall goal of the regional haze program is to prevent future visibility impairment and remedy existing visibility impairment in mandatory class I federal areas. As shown by the future visibility estimates in Table 2.2-3, it is projected that there will continue to be mandatory class I federal areas with visibility levels above background in 2015. Additional emission reductions will be needed from the broad set of sources that contribute, including the engines, vessels and equipment subject to this proposed rule.[86] The reductions proposed in this action are a part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

Table 2.2-3: Current (1998-2002) Visibility, Projected (2015) Visibility, and Natural Background Levels for the 20% Worst Days at 116 IMPROVE Sites

Class I Area Name[a]	State	1998-2002 Baseline Visibility (deciviews)[b]	2015 CAIR Control Case Visibility[c] (deciviews)	Natural Background (deciviews)
Acadia	ME	22.7	21.0	11.5
Agua Tibia	CA	23.2	23.2	7.2
Alpine Lakes	WA	18.0	17.4	7.9
Anaconda - Pintler	MT	12.3	12.2	7.3
Arches	UT	12.0	12.1	7.0
Badlands	SD	17.3	16.8	7.3
Bandelier	NM	13.2	13.2	7.0
Big Bend	TX	18.4	18.3	6.9
Black Canyon of the Gunnison	CO	11.6	11.4	7.1
Bob Marshall	MT	14.2	14.0	7.4
Boundary Waters Canoe Area	MN	20.0	19.0	11.2
Bridger	WY	11.5	11.3	7.1
Brigantine	NJ	27.6	25.4	11.3
Bryce Canyon	UT	12.0	11.9	7.0
Cabinet Mountains	MT	13.8	13.4	7.4
Caney Creek	AR	25.9	24.1	11.3
Canyonlands	UT	12.0	12.0	7.0
Cape Romain	SC	25.9	23.9	11.4
Caribou	CA	14.8	14.6	7.3
Carlsbad Caverns	NM	17.6	17.9	7.0
Chassahowitzka	FL	25.7	23.0	11.5
Chiricahua NM	AZ	13.9	13.9	6.9
Chiricahua W	AZ	13.9	13.9	6.9
Craters of the Moon	ID	14.7	14.7	7.1
Desolation	CA	12.9	12.8	7.1
Dolly Sods	WV	27.6	23.9	11.3
Dome Land	CA	20.3	19.9	7.1
Eagle Cap	OR	19.6	19.0	7.3
Eagles Nest	CO	11.3	11.4	7.1
Emigrant	CA	17.6	17.4	7.1
Everglades	FL	20.3	19.2	11.2
Fitzpatrick	WY	11.5	11.3	7.1
Flat Tops	CO	11.3	11.4	7.1
Galiuro	AZ	13.9	14.1	6.9
Gates of the Mountains	MT	11.2	10.8	7.2
Gila	NM	13.5	13.5	7.0
Glacier	MT	19.5	19.1	7.6
Glacier Peak	WA	14.0	13.8	7.8
Grand Teton	WY	12.1	12.0	7.1
Great Gulf	NH	23.2	21.2	11.3
Great Sand Dunes	CO	13.1	13.0	7.1
Great Smoky Mountains	TN	29.5	26.1	11.4
Guadalupe Mountains	TX	17.6	17.5	7.0
Hells Canyon	OR	18.1	18.0	7.3
Isle Royale	MI	21.1	20.1	11.2
James River Face	VA	28.5	25.1	11.2

Jarbidge	NV	12.6	12.8	7.1
Joshua Tree	CA	19.5	20.3	7.1
Joyce Kilmer - Slickrock	NC	29.5	26.1	11.5
Kalmiopsis	OR	14.8	14.4	7.7
Kings Canyon	CA	23.5	24.1	7.1
La Garita	CO	11.6	11.5	7.1
Lassen Volcanic	CA	14.8	14.6	7.3
Lava Beds	CA	16.6	16.5	7.5
Linville Gorge	NC	27.9	24.6	11.4
Lostwood	ND	19.6	18.7	7.3
Lye Brook	VT	23.9	21.1	11.3
Mammoth Cave	KY	30.2	27.0	11.5
Marble Mountain	CA	17.1	16.8	7.7
Maroon Bells - Snowmass	CO	11.3	11.3	7.1
Mazatzal	AZ	13.1	13.5	6.9
Medicine Lake	MT	17.7	17.1	7.3
Mesa Verde	CO	12.8	12.8	7.1
Mingo	MO	27.5	25.9	11.3
Mission Mountains	MT	14.2	14.0	7.4
Mokelumne	CA	12.9	12.8	7.1
Moosehorn	ME	21.4	20.3	11.4
Mount Hood	OR	14.0	13.7	7.8
Mount Jefferson	OR	15.7	15.2	7.8
Mount Rainier	WA	18.9	19.4	7.9
Mount Washington	OR	15.7	15.2	7.9
Mount Zirkel	CO	11.7	11.8	7.1
North Cascades	WA	14.0	14.0	7.8
Okefenokee	GA	26.4	24.7	11.5
Otter Creek	WV	27.6	24.0	11.3
Pasayten	WA	14.7	14.5	7.8
Petrified Forest	AZ	13.5	13.8	7.0
Pine Mountain	AZ	13.1	13.4	6.9
Presidential Range - Dry	NH	23.2	20.9	11.3
Rawah	CO	11.7	11.7	7.1
Red Rock Lakes	WY	12.1	12.1	7.1
Redwood	CA	16.5	16.5	7.8
Rocky Mountain	CO	14.1	14.1	7.1
Roosevelt Campobello	ME	21.4	20.1	11.4
Salt Creek	NM	17.7	17.3	7.0
San Gorgonio	CA	21.5	22.1	7.1
San Jacinto	CA	21.5	21.4	7.1
San Pedro Parks	NM	11.4	11.4	7.0
Sawtooth	ID	13.6	13.5	7.2
Scapegoat	MT	14.2	14.1	7.3
Selway - Bitterroot	MT	12.3	12.1	7.3
Seney	MI	23.8	22.6	11.4
Sequoia	CA	23.5	24.1	7.1
Shenandoah	VA	27.6	23.4	11.3
Sierra Ancha	AZ	13.4	13.7	6.9
Sipsey	AL	28.7	26.1	11.4
South Warner	CA	16.6	16.5	7.3
Strawberry Mountain	OR	19.6	19.2	7.5
Superstition	AZ	14.7	15.0	6.9
Swanquarter	NC	24.6	21.9	11.2

Sycamore Canyon	AZ	16.1	16.6	7.0
Teton	WY	12.1	12.1	7.1
Theodore Roosevelt	ND	17.6	16.8	7.3
Thousand Lakes	CA	14.8	14.6	7.3
Three Sisters	OR	15.7	15.2	7.9
UL Bend	MT	14.7	14.1	7.2
Upper Buffalo	AR	25.5	24.3	11.3
Voyageurs	MN	18.4	17.6	11.1
Weminuche	CO	11.6	11.4	7.1
West Elk	CO	11.3	11.3	7.1
Wind Cave	SD	16.0	15.4	7.2
Wolf Island	GA	26.4	24.9	11.4
Yellowstone	WY	12.1	12.1	7.1
Yolla Bolly - Middle Eel	CA	17.1	16.9	7.4
Yosemite	CA	17.6	17.4	7.1
Zion	UT	13.5	13.3	7.0

[a] 116 IMPROVE sites represent 155 of the 156 Mandatory Class I Federal Areas. One isolated Mandatory Class I Federal Area (Bering Sea, an uninhabited and infrequently visited island 200 miles from the coast of Alaska), was considered to be so remote from electrical power and people that it would be impractical to collect routine aerosol samples.[87]

[b] The deciview metric describes perceived visual changes in a linear fashion over its entire range, analogous to the decibel scale for sound. A deciview of 0 represents pristine conditions. The higher the deciview value, the worse the visibility, and an improvement in visibility is a decrease in deciview value.

[c] The 2015 modeling projections are based on the Clear Air Interstate Rule analyses (EPA, 2005).

2.2.4.2 Atmospheric Deposition

Wet and dry deposition of ambient particulate matter delivers a complex mixture of metals (e.g., mercury, zinc, lead, nickel, aluminum, cadmium), organic compounds (e.g., POM, dioxins, furans) and inorganic compounds (e.g., nitrate, sulfate) to terrestrial and aquatic ecosystems. The chemical form of the compounds deposited is impacted by a variety of factors including ambient conditions (e.g., temperature, humidity, oxidant levels) and the sources of the material. Chemical and physical transformations of the particulate compounds occur in the atmosphere as well as the media onto which they deposit. These transformations in turn influence the fate, bioavailability and potential toxicity of these compounds. Atmospheric deposition has been identified as a key component of the environmental and human health hazard posed by several pollutants including mercury, dioxin and PCBs.[88]

Adverse impacts on water quality can occur when atmospheric contaminants deposit to the water surface or when material deposited on the land enters a waterbody through runoff. Potential impacts of atmospheric deposition to waterbodies include those related to both nutrient and toxic inputs. Adverse effects to human health and welfare can occur from the addition of excess particulate nitrate nutrient enrichment which contributes to toxic algae blooms and zones of depleted oxygen, which can lead to fish kills, frequently in coastal waters. Particles contaminated with heavy metals or other toxins may lead to the ingestion of contaminated fish, ingestion of contaminated water, damage to the marine ecology, and limited recreational uses. Several studies have been conducted in U.S. coastal waters and in the Great Lakes Region in which the role of ambient PM deposition and runoff is investigated.[89,90,91,92,93]

Adverse impacts on soil chemistry and plant life have been observed for areas heavily impacted by atmospheric deposition of nutrients, metals and acid species, resulting in species shifts, loss of biodiversity, forest decline and damage to forest productivity. Potential impacts also include adverse effects to human health through ingestion of contaminated vegetation or livestock (as in the case for dioxin deposition), reduction in crop yield, and limited use of land due to contamination.

2.2.4.2.1 Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when NOx and SO_2 react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles.[94] It contributes to damage of trees at high elevations and in extreme cases may cause lakes and streams to become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage.

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

A study of emission trends and acidity of water bodies in the Eastern United States by the General Accounting Office (GAO) found that from 1992 to 1999 sulfates declined in 92 percent of a representative sample of lakes, and nitrate levels increased in 48 percent of the lakes sampled.[95] The decrease in sulfates is consistent with emission trends, but the increase in nitrates is inconsistent with the stable levels of nitrogen emissions and deposition. The study suggests that the vegetation and land surrounding these lakes have lost some of their previous capacity to use nitrogen, thus allowing more of the nitrogen to flow into the lakes and increase their acidity. Recovery of acidified lakes is expected to take a number of years, even where soil and vegetation have not been “nitrogen saturated,” as EPA called the phenomenon in a 1995 study.[96] This situation places a premium on reductions of NOx from all sources, including Small SI and Marine SI engines, vessels and equipment in order to reduce the extent and severity of nitrogen saturation and acidification of lakes in the Adirondacks and throughout the United States.

The NOx reductions from this rule would help reduce acid rain and acid deposition, thereby helping to reduce acidity levels in lakes and streams throughout the country and helping accelerate the recovery of acidified lakes and streams and the revival of ecosystems adversely affected by acid deposition. Reduced acid deposition levels will also help reduce stress on forests, thereby accelerating reforestation efforts and improving timber production. Deterioration of our historic buildings and monuments, and of buildings, vehicles, and other structures exposed to acid rain and dry acid deposition also will be reduced, and the costs borne to prevent acid-related damage may also decline. While the reduction in nitrogen acid deposition will be roughly proportional to the reduction in NOx emissions, respectively, the precise impact of this proposed rule will differ across different areas.

2.2.4.2.2 Eutrophication, Nitrification and Fertilization

In recent decades, human activities have greatly accelerated nutrient impacts, such as nitrogen deposition in both aquatic and terrestrial systems. Nitrogen deposition in aquatic systems can cause excessive growth of algae and lead to degraded water quality and associated impairment of fresh water and estuarine resources for human uses.[97] Nitrogen deposition on terrestrial systems can cause fertilization and lead to ecosystem stress and species shift.

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration, and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can adversely affect fish and shellfish populations.

Deposition of nitrogen contributes to elevated nitrogen levels in waterbodies. The NO_x reductions from today's promulgated standards will help reduce the airborne nitrogen deposition that contributes to eutrophication of watersheds, particularly in aquatic systems where atmospheric deposition of nitrogen represents a significant portion of total nitrogen loadings.

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. According to the NOAA report, more than half of the nation's estuaries have moderate to high expressions of at least one of these symptoms – an indication that eutrophication is well developed in more than half of U.S. estuaries.[98]

In its Third Report to Congress on the Great Waters, EPA reported that atmospheric deposition contributes from 2 to 38 percent of the nitrogen load to certain coastal waters.[99] A review of peer reviewed literature in 1995 on the subject of air deposition suggests a typical contribution of 20 percent or higher.[100] Human-caused nitrogen loading to the Long Island Sound from the atmosphere was estimated at 14 percent by a collaboration of federal and state air and water agencies in 1997.[101] The National Exposure Research Laboratory, U.S. EPA, estimated based on prior studies that 20 to 35 percent of the nitrogen loading to the Chesapeake Bay is attributable to atmospheric deposition.[102] The mobile source portion of atmospheric NOx contribution to the Chesapeake Bay was modeled at about 30 percent of total air deposition.[103]

In U.S. terrestrial systems, the nutrient whose supply most often sets the limit of possible plant based productivity at a given site is nitrogen. By increasing available nitrogen, overall ecosystem productivity may be expected to increase for a time, and then decline as nitrogen saturation is reached. However, because not all vegetation, organisms, or ecosystems react in the same manner to increased nitrogen fertilization, those plants or organisms that are predisposed to capitalize on any increases in nitrogen availability gain an advantage over those that are not as responsive to added nutrients, leading to a change in plant community composition and diversity. Changes to plant community composition and structure within an ecosystem are of concern because plants in large part determine the food supply and habitat types available for use by other organisms. Further, in terrestrial systems, plants serve as the integrators between above-ground and below-ground environments and influence nutrient, energy and water cycles. Because of these linkages, chronic excess nutrient nitrogen additions can lead to complex, dramatic, and severe ecosystem level responses such as changes in habitat suitability, genetic diversity, community dynamics and composition, nutrient status, energy and nutrient cycling, and frequency and intensity of natural disturbance regimes such as fire.

These types of effects have been observed both experimentally and in the field. For example, experimental additions of nitrogen to a Minnesota grassland dominated by native warm-season grasses produced a shift to low-diversity mixtures dominated by coolseason grasses over a 12 year period at all but the lowest rate of nitrogen addition.[104] Similarly, the coastal sage scrub (CSS) community in California has been declining in land area and in drought deciduous shrub density over the past 60 years, and is being replaced in many areas by the more nitrogen responsive Mediterranean annual grasses. Some 25 plant species are already extinct in California, most of them annual and perennial forbs that occurred in sites now experiencing conversion to annual grassland. As CSS converts more extensively to annual grassland dominated by invasive species, loss of additional rare species may be inevitable. Though invasive species are often identified as the main threat to rare species, it is more likely that invasive species combine with other factors, such as excess N deposition, to promote increased productivity of invasive species and resulting species shifts.

Deposition of nitrogen from the engines covered in this proposal contributes to elevated nitrogen levels in bodies of water and on land. The NOx reductions proposed in this action will reduce the airborne nitrogen deposition that contributes to eutrophication of watersheds and nitrogen saturation on land.

2.2.4.2.3 Heavy Metals

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for influencing forest growth (PM AQCD, p. 4-87).[105] Investigation of trace metals near roadways and industrial facilities indicate that a substantial burden of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions (PM AQCD, p. 4-75). Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment.

Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline (PM AQCD, p. 4-76).[106] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Some trace metals absorbed into the plant and can bind to the leaf tissue (PM AQCD, p. 4-75). When these leaves fall and decompose, the heavy metals are transferred into the soil.[107,108]

The environmental sources and cycling of mercury are currently of particular concern due to the bioaccumulation and biomagnification of this metal in aquatic ecosystems and the potent toxic nature of mercury in the forms in which is it ingested by people and other animals. Mercury is unusual compared with other metals in that it largely partitions into the gas phase (in elemental form), and therefore has a longer residence time in the atmosphere than a metal found predominantly in the particle phase. This property enables a portion of emitted mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. Localized or regional impacts are also observed for mercury emitted from combustion sources. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[109,110] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[111] Overall, the National Science and Technology Council (NSTC, 1999) identifies atmospheric deposition as the primary source of mercury to aquatic systems. Forty-four states have issued health advisories for the consumption of fish contaminated by mercury; however, most of these advisories are issued in areas without a mercury point source.

Elevated levels of zinc and lead have been identified in streambed sediments, and these elevated levels have been correlated with population density and motor vehicle use.[112,113] Zinc and nickel have also been identified in urban water and soils. In addition, platinum, palladium, and rhodium, metals found in the catalysts of modern motor vehicles, have been measured at elevated levels along roadsides.[114] Plant uptake of platinum has been observed at these locations.

2.2.4.2.4 Polycyclic Organic Matter

Polycyclic organic matter (POM) is a byproduct of incomplete combustion and consists of organic compounds with more than one benzene ring and a boiling point greater than or equal to 100 degrees centigrade.[115] Polycyclic aromatic hydrocarbons (PAHs) are a class of POM that contains compounds which are known or suspected carcinogens.

Major sources of PAHs include mobile sources. PAHs in the environment may be present as a gas or adsorbed onto airborne particulate matter. Since the majority of PAHs are adsorbed onto particles less than 1.0 μm in diameter, long range transport is possible. However, studies have shown that PAH compounds adsorbed onto diesel exhaust particulate and exposed to ozone have half lives of 0.5 to 1.0 hours.[116]

Since PAHs are insoluble, the compounds generally are particle reactive and accumulate in sediments. Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan.[117,118] Analyses of PAH deposition to Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[119,120] Sediment concentrations of PAHs are high enough in some segments of Tampa Bay to pose an environmental health threat. EPA funded a study to better characterize the sources and loading rates for PAHs into Tampa Bay.[121] PAHs that enter a waterbody through gas exchange likely partition into organic rich particles and be biologically recycled, while dry deposition of aerosols containing PAHs tends to be more resistant to biological recycling.[122] Thus, dry deposition is likely the main pathway for PAH concentrations in sediments while gas/water exchange at the surface may lead to PAH distribution into the food web, leading to increased health risk concerns.

Trends in PAH deposition levels are difficult to discern because of highly variable ambient air concentrations, lack of consistency in monitoring methods, and the significant influence of local sources on deposition levels.[123] Van Metre et al. (2000) noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlates with increases in automobile use.[124]

Cousins et al. (1999) estimates that greater than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[125] An analysis of polycyclic aromatic hydrocarbon (PAH) concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[126]

2.2.4.2.5 Materials Damage and Soiling

The deposition of airborne particles can also reduce the aesthetic appeal of buildings and culturally important articles through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion.[127] Particles affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to absorb corrosive gases (principally sulfur dioxide). The rate of metal corrosion depends on a number of factors, including the deposition rate and nature of the pollutant; the influence of the metal protective corrosion film; the amount of moisture present; variability in the electrochemical reactions; the presence and concentration of other surface electrolytes; and the orientation of the metal surface.

2.3 Gaseous Air Toxics

Small SI and Marine SI emissions contribute to ambient levels of gaseous air toxics known or suspected as human or animal carcinogens, or that have non-cancer health effects. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. All of these compounds, except acetaldehyde, were identified as national or regional risk drivers in the 1999 National-Scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources. The reductions in Small SI and Marine SI emissions proposed in this rulemaking would help reduce exposure to these harmful substances.

Air toxics can cause a variety of cancer and noncancer health effects. A number of the mobile source air toxic pollutants described in this section are known or likely to pose a cancer hazard in humans. Many of these compounds also cause adverse noncancer health effects resulting from chronic,[16] subchronic,[17] or acute[18] inhalation exposures. These include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems.

Benzene: The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[128, 129, 130] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggests a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[131, 132] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[133, 134] In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[135, 136, 137, 138] EPA's IRIS program has not yet evaluated these new data.

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[16] Chronic exposure is defined in the glossary of the Integrated Risk Information (IRIS) database (http://www.epa.gov/iris) as repeated exposure by the oral, dermal, or inhalation route for more than approximately 10 of the life span in humans (more than approximately 90 days to 2 years in typically used laboratory animal species).

[17] Defined in the IRIS database as exposure to a substance spanning approximately 10 of the lifetime of an organism.

[18] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

1,3-Butadiene: EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[139, 140] The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown. However, it is virtually certain that the carcinogenic effects are mediated by genotoxic metabolites of 1,3-butadiene. Animal data suggest that females may be more sensitive than males for cancer effects; while there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 1,3-Butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[141]

Formaldehyde: Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[142] EPA's current IRIS summary provides an upper bound cancer unit risk estimate of $1.3\text{x}10^{-5}$ per $\mu g/m^3$. In other words, there is an estimated risk of about thirteen excess cancer cases in one million people exposed to 1 $\mu g/m^3$ of formaldehyde over a lifetime. EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[143, 144] NCI is currently performing an update of these studies. A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[145] In 2004, the working group of the International Agency for Research on Cancer (IARC) concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals—a higher classification than previous IARC evaluations. The agency is currently conducting a reassessment of the human hazard and dose-response associated with formaldehyde.

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[146, 147, 148] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. The risk assessment analyzed carcinogenic risk from inhaled formaldehyde using approaches that are consistent with EPA's draft guidelines for carcinogenic risk assessment. In 2001, Environment Canada relied on this cancer dose-response assessment in their assessment of formaldehyde.[149] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoetic cancers, but a continuing statistically significant excess in lung cancers was reported.[150]

Based on the developments of the last decade, in 2004, EPA also relied on this cancer unit risk estimate during the development of the plywood and composite wood products national emissions standards for hazardous air pollutants (NESHAPs).[151] In these rules, EPA concluded that the CIIT work represented the best available application of the available mechanistic and dosimetric science on the dose-response for portal of entry cancers due to formaldehyde exposures. EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes.

Acetaldehyde: Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered moderately toxic by the inhalation, oral, and intravenous routes.[152] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract.[153] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

Acrolein: Acrolein is intensely irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation and congestion. EPA determined in 2003 using the 1999 draft cancer guidelines that the human carcinogenic potential of acrolein could not be determined because the available data was inadequate. No information was available on the carcinogenic effects of acrolein in humans, and the animal data provided inadequate evidence of carcinogenicity.[154]

Polycyclic Organic Matter (POM): POM is generally defined as a large class of organic compounds which have multiple benzene rings and a boiling point greater than 100 degrees Celsius. One of these compounds, naphthalene, is discussed separately below. Polycyclic aromatic hydrocarbons (PAH) are a class of POM that contain only hydrogen and carbon atoms. A number of PAHs are known or suspected carcinogens.

Recent studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth as well as impaired cognitive development at age three.[155][156] EPA has not yet evaluated these recent studies.

Naphthalene: Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust and evaporative emissions from mobile sources. EPA recently released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[157] The draft reassessment recently completed external peer review.[158] California EPA has also released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[159] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[160]

In addition to reducing VOC, NOx, CO and $PM_{2.5}$ emissions from Small SI engines and equipment and Marine SI engines and vessels the standards being proposed today would also reduce air toxics emitted from these engines, vessels and equipment thereby helping to mitigate some of the adverse health effects associated with operation of these engines, vessels and equipment.

2.4 Carbon Monoxide

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

2.4.1 Health Effects of CO Pollution

We are relying on the data and conclusions in the EPA Air Quality Criteria Document for CO (CO Criteria Document) regarding the health effects associated with CO exposure.[161] Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood’s capacity to carry oxygen to organs and tissues.[162, 163] Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Although there are effective compensatory increases in blood flow to the brain, at some concentrations of COHb, somewhere above 20 percent, these compensations fail to maintain sufficient oxygen delivery, and metabolism declines.[164] The subsequent hypoxia in brain tissue then produces behavioral effects, including decrements in continuous performance and reaction time.[165]

Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects.[166] Persons with heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising.[167] Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks.[168]

Several epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases). Several studies in the United States and Canada have also reported an association between ambient CO exposures and frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association between ambient CO exposure and mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the CO Criteria Document review process and noted the possibility that the average ambient CO levels used as exposure indices in the epidemiology studies may be surrogates for ambient air mixes impacted by combustion sources and/or other constituent toxic components of such mixes. More research will be needed to better clarify CO's role.[169]

As noted above, CO has been linked to numerous health effects. In addition to health effects from chronic exposure to ambient CO levels, acute exposures to higher levels are also a problem. Acute exposures to CO are discussed further in Section 2.5.

2.4.2 Attainment and Maintenance of the CO NAAQS

On July 3, 1995 EPA made a finding that small land-based spark-ignition engines cause or contribute to CO nonattainment (60 FR 34581, July 3, 1995). Marine spark-ignition engines, which have relatively high per engine CO emissions, can also be a source of CO emissions in CO nonattainment areas. In the preamble for this proposed rule EPA makes a finding that recreational marine engines and vessels cause or contribute to CO nonattainment and we provide information showing CO emissions from spark-ignition marine engines and vessels in the CO nonattainment areas in 2005. Spark-ignition marine engines and vessels contribute to CO nonattainment in more than one of the CO nonattainment areas.

A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard. EPA has designated nonattainment areas for the CO NAAQS by calculating air quality design values and considering other factors.[19]

There are two CO NAAQS. The 8-hour average CO NAAQS is 9 ppm, not to be exceeded more than once per year, and the 1-hour average CO NAAQS is 35 ppm, not to be exceeded more than once per year. As of October 26, 2006, there are approximately 15 million people living in 6 areas (which include 10 counties) that are designated as nonattainment for CO, see Table 2.4-1. The emission reductions proposed in this action would help areas to attain and maintain the CO NAAQS.

Table 2.4-1: Classified Carbon Monoxide Nonattainment Areas as of October 2006[a]

Area	Classification	Population (1000s)
Las Vegas, NV	serious	479
Los Angeles South Coast Air Basin	serious	14,594
El Paso, TX	moderate <= 12.7 ppm	62
Missoula, MT	moderate <= 12.7 ppm	52
Reno, NV	moderate <= 12.7 ppm	179
Total		15,365

[a] This table does not include Salem, OR which is an unclassified CO nonattainment area.

In addition to the CO nonattainment areas, there are areas that have not been designated as nonattainment where air quality monitoring may indicate a need for CO control. For example,

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[19] The full details involved in calculating a CO design value are given in 40 CFR Part 50.8.

areas like Birmingham, AL and Calexico, CA have not been designated as nonattainment although monitors in these areas have recorded multiple exceedances since 1995.[170]

There are also over 54 million people living in CO maintenance areas, see Table 2.4-2.[20] Carbon monoxide maintenance areas may remain at risk for high CO episodes especially in geographic areas with unusually challenging meteorological and topographical conditions and in areas with high population growth and increasing vehicle miles traveled.

Table 2.4-2: Carbon Monoxide Maintenance Areas as of October 2006

	Number of Areas	Number of Counties	Population (1000s)
Serious	5	11	5,902
Moderate > 12.7ppm	4	19	17,576
Moderate <= 12.7ppm	30	61	23,319
Unclassified	33	41	7,544
Total	72	132	54,341

A 2003 NAS report found that in geographical areas that have achieved attainment of the NAAQS, it might still be possible for ambient concentrations of CO to sporadically exceed the standard under unfavorable conditions such as strong winter inversions. Areas like Alaska are prone to winter inversions due to their topographic and meteorologic conditions. The report further suggests that additional reductions in CO are prudent to further reduce the risk of violations in regions with problematic topography and temporal variability in meteorology.[171] The reductions in CO emissions from this proposed rule could assist areas in maintaining the CO standard.

As discussed in the preamble, Small SI engines and equipment and Marine SI engines and vessels do contribute to CO nonattainment. The CO emission benefits from this rule would help states in their strategy to attain the CO NAAQS. Maintenance of the CO NAAQS is also challenging and many areas would be able to use the emissions reductions from this proposed rule to assist in maintaining the CO NAAQS into the future.

2.5 Acute Exposure to Air Pollutants

Emissions from Small SI engines and equipment and Marine SI engines and vessels contribute to ambient concentrations of ozone, CO, air toxics and PM and acute exposures to CO and PM. As mentioned in Section II.B.4 of the preamble for this proposal, elevated exposures to

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[20] The CO nonattainment and maintenance areas are listed in a Memo to the Docket titled “Nonattainment Areas and Mandatory Class I Federal Areas” and contained in Docket EPA-HQ-OAR-2004-0008.

CO from Marine SI engines and vessels have been well documented. As mentioned in Sections II.B.2 and II.B.4 of the preamble, elevated exposures to CO and PM can occur as a result of operating Small SI engines and equipment. The standards being proposed in this action can help reduce acute exposures to CO and PM from Marine SI engines and vessels and Small SI engines and equipment.

2.5.1 Exposure to CO from Marine SI Engines and Vessels

In recent years, a substantial number of carbon monoxide (CO) poisonings and deaths have occurred on and around recreational boats across the nation. The actual number of deaths attributable to CO poisoning while boating is difficult to estimate because CO-related deaths in the water may be labeled as drowning. An interagency team consisting of the National Park Service, the U.S. Department of Interior, and the National Institute for Occupational Safety and Health maintains a record of published CO-related fatal and nonfatal poisonings.[172] Between 1984 and 2004, 113 CO-related deaths and 458 non-fatal CO poisonings have been identified based on hospital records, press accounts, and other information. Deaths have been attributed to exhaust from both onboard generators and propulsion engines. Houseboats, cabin cruisers, and ski boats are the most common types of boats associated with CO poisoning cases. These incidents have prompted other federal agencies, including the United States Coast Guard and National Park Service, to issue advisory statements and other interventions to boaters to avoid activities that could lead to excessive CO exposure.[173]

CO concentrations can be extremely elevated within several meters of the exhaust port. Engineers and industrial hygienists from CDC/NIOSH and other state and federal agencies have conducted field studies of CO concentrations on and around houseboats. In one study of houseboat concentrations, CO concentrations immediately at the point of generator exhaust discharge on one houseboat averaged 0.5% (5,000 ppm), and ranged from 0.0% to 1.28% (12,800 ppm).[174] With both propulsion and generators running, time-averaged concentrations on the swim deck were 0.2 - 169 ppm at different locations on one boat's swim platform, 17-570 ppm on another's, and 0-108 on another. Other studies also show the potential for high concentrations with extreme peaks in CO concentrations in locations where boaters and swimmers can be exposed during typical boating activities, such as standing on a swim deck or swimming near a boat.

2.5.2 Exposure to CO and PM from Small SI Engines and Equipment

A large segment of the population uses small, gasoline-powered spark-ignition (SI) lawn and garden equipment on a regular basis. Emissions from many of the Small SI engines powering this equipment may lead to elevated air pollution exposures for a number of gaseous and particulate compounds, especially for individuals such as landscapers, whose occupations require the daily use of these engines and equipment.

Emission studies with lawn and garden equipment suggest a potential for high exposures during the Small SI engine operation.[175,176] Studies investigating air pollutant exposures during small engine use did report elevated personal exposure measurements related to lawn and garden equipment use.[177,178] Bunger et al. reported elevated CO personal measurements related to chainsaw use, with short-term concentrations exceeding 400 ppm for certain cutting activities. This study evaluated personal exposures during the use of uncontrolled chainsaws. Baldauf at al. evaluated the use of lawnmowers, chainsaws and string trimmers meeting US EPA Phase 2 standards. In this study, short-term exposures during lawnmower and chainsaw use exceeded 120 ppm of CO, while string trimmer use resulted in some short-term exposures approaching 100 ppm of CO. This study also indicated that short-term $PM_{2.5}$ exposures could exceed 100 µg/m^3. Pollutant exposures were highly dependent on the operator's orientation to the engine and wind direction, as well as the activities being conducted.

These studies indicate that emissions from some lawn and garden equipment meeting EPA's current Phase 2 standards may result in exposures to certain pollutants at levels of concern for adverse health effects. The potential for elevated exposure to CO and $PM_{2.5}$ for operators of Small SI engines and equipment would be reduced by this proposed rule.

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CHAPTER 3: Emission Inventory

This chapter presents our analysis of the emission impact of the proposed rule for spark ignition (SI) small nonroad engines (≤25 horsepower (hp) or ≤19 kilowatts (kW) used in land-based or auxiliary marine applications (hereafter collectively termed small nonroad SI engines) and Marine SI engines. The control requirements include exhaust and evaporative emission standards for small non-handheld SI engines (Class I <225 cubic centimeters (cc) and Class II ≥225 cc), an evaporative emission standards for small handheld SI engines (Classes III-V), and exhaust and evaporative emission standards for all Marine SI engines.

Section 3.1 presents an overview of methodology used to develop the emission inventories for the small nonroad and marine engines that are subject to the proposed rulemaking. Section 3.2 identifies the specific modeling inputs that were used to develop the baseline scenario emission inventories. The resulting baseline emission inventories are also presented in that section. Section 3.3 then describes the contribution of the small nonroad and Marine SI engines to national baseline inventories. Section 3.4 describes the development of the controlled inventories, specifically the changes made to the baseline modeling inputs to incorporate the new standards. The control inventories are also presented in this section. Section 3.5 follows with the projected emission reductions resulting from the proposed rule. Section 3.6 describes the emission inventories used in the air quality modeling described in Chapter 2. This discussion includes a description of the changes in the inputs and resulting emission inventories between the preliminary baseline and control scenarios used for the air quality modeling and the more refined final baseline and control scenarios reflected in the actual proposal.

In Sections 3.2, 3.4 and 3.5, the estimates of baseline, controlled, and emission reduction inventories, respectively, for criteria pollutants from small nonroad and Marine SI engines are reported for the 50-state geographic area (including the District of Columbia). These inventories reflect the emissions from the engines subject to the proposed Phase 3 standards. As such, they exclude the emissions from engines that are regulated by the State of California as provided for by section 209 of the Clean Air Act.

More specifically, California is prevented from regulating nonroad engines with less than 175 horsepower that are used in farm and construction equipment. Therefore, those engines are subject to federal regulation and included in our 50-state inventories. By contrast, we do not include the emissions from California marine engines in our inventories. California has also been granted a waiver under the Clean Air Act to regulate exhaust emissions form all Marine SI engines and evaporative emissions from outboard and personal watercraft SI engines. That State also has indicted its intent to adopt the proposed Phase III standards for evaporative emissions from stern drive engines. Therefore, are excluded in our 50-state inventories.

In Section 3.3, 50-state inventories are used to compare the nationwide importance of these sources to other source categories, i.e., stationary, area, and other mobile sources. Finally, Section 3.6 presents inventories for 37 of the most eastern states in the nation that were included in the air quality modeling domain for this proposal. Unlike the 50-state inventories in the other sections, these inventories include all small nonroad SI and marine engines. The 37-state control scenarios assume federal standards apply only to those engines that are not subject to California emission regulations as described earlier.

Inventories are generally presented for the following pollutants: exhaust and evaporative total hydrocarbons (THC), oxides of nitrogen (NO_x), particulate matter ($PM_{2.5}$ and PM_{10}), and carbon monoxide (CO). The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling as noted below. The proposed requirements would also reduce hazardous air pollutants such as benzene, formaldeyde, acetaldehyde, 1,3-butadiene, acrolein, napthalene, and 15 other compounds grouped together as polycyclic organic matter (POM).

The hydrocarbon inventories in Sections 3.3 and 3.5 for the nationwide comparison and air quality modeling, respectively, are presented as volatile organic compounds (VOC) rather than THC. This is a broader class of hydrocarbon compounds that is important for air quality modeling purposes. The additional compounds that comprise VOC are reactive oxygenated species represented by aldehydes (RCHO) and alcohols (RCOH), and less reactive species represented by methane (CH_4) and ethane (CH_3CH_3).

Finally, none of the controlled inventory estimates include the potential uses of the averaging, banking, and trading (ABT) program for engine manufacturers, since these are flexibilities that would be difficult to predict and model. More information regarding these provisions can be found in the preamble for this proposal that is published in the Federal Register.

3.1 Overview of Small Nonroad and Marine SI Engine Emissions Inventory Development

This section describes how the baseline emission inventories were modeled for the small nonroad and Marine SI engines affected by the proposed rule. Section 3.1 focuses on exhaust and evaporative hydrocarbons, and exhaust $NO_{x,}$ PM, and CO.

The primary emission inventories associated with the small nonroad and Marine SI engine proposed rule, which are summarized in Sections 3.2 through 3.5, were generated using a modified version of our NONROAD2005 model. More specifically we started with the most recent public version of the model, i.e., NONROAD2005a, which was released in February 2006. A copy of that model and the accompanying technical reports that detail of the modeling inputs (e.g., populations, activity, etc.) are available in the docket for this proposal.[1] They can also be accessed on our website at: http://www.epa.gov/otaq/nonrdmdl.htm.

The NONROAD2005a model was modified to incorporate new emission test data and other improvements for this rulemaking. This special version is named NONROAD2005c. A copy of the model and most of the accompanying documentation are available in the docket.[2,3,4] The documentation for evaporative emission changes is in Chapter 5. The modifications we made to NONROAD2005a to reflect the baseline and control scenarios related to the proposed rule are fully described in Sections 3.2 and 3.4, respectively.

The nonroad model estimates emission inventories of important air emissions from a diverse universe of nonroad equipment. The model's scope includes all off-highway sources with the exception of locomotives, aircraft and commercial marine vessels. The model can distinguish emissions on the basis of equipment type, horsepower, and technology group. For the engines subject to the proposal, the nonroad model evaluates numerous equipment types with each type containing multiple horsepower categories and technology groups. A central feature of the model is the projection of future or past emissions between 1970 and 2050.

The chemical species NOx, PM, and CO are exhaust emissions, i.e., pollutants emitted directly as exhaust from combustion of gasoline fuel in the engine. Hydrocarbon species, e.g., THC and VOC, consist of both exhaust and evaporative emissions. The exhaust component represents hydrocarbons emitted as products of combustion, which can also include emissions vented from the crankcase. The evaporative hydrocarbon component includes compounds from unburned fuel that are emitted either while the engine being operated or when the equipment is not in use. The various categories of evaporative emissions that are included in the nonroad model are:

Diurnal. These emissions result from changes in temperature during the day. As the day gets warmer there is a concomitant rise in the temperature of the liquid fuel in the fuel tank. This causes the vapor pressure inside the tank to increase, forcing vaporized fuel to escape into the atmosphere. For modeling purposes, this category also includes diffusion losses that come from fuel vapor exiting the orifice of a vented fuel tank cap regardless of temperature.

Permeation. These emissions occur when fuel molecules transfuse through plastic or rubber fuel-related components (fuel lines and fuel tanks) into the atmosphere.

Hot Soak. These emissions occur after the engine is shut off and the engine's residual heat causes fuel vapors from the fuel tank or fuel metering device to be released into the atmosphere.

Running Loss. Similar in form to diurnal losses, these emissions are caused from the engine's heat during equipment operation.

Vapor Displacement or Refueling Loss. These are vapors displaced from the fuel tank when liquid fuel is being added during a refueling event.

Liquid Spillage. This refers to the liquid fuel that is spilled when equipment is refueled either from a portable fuel container or fuel pump, which subsequently evaporates into the atmosphere.

Equipment fueled by compressed natural gas, liquified petroleum gas, or diesel fuel are assumed to have zero evaporative emissions. Consequently, all evaporative emissions are from gasoline or gasoline blends, i.e., ethanol and gasoline.

The control scenario analyzed in Section 3.4 reflects the proposed standards for exhaust hydrocarbons, CO, and NOx from small nonhandheld nonroad and Marine SI engines.[1] New standards to control evaporative emissions from hose permeation and tank permeation from these engine classes and handheld equipment are also included. Further, the proposal also would establish new standards for running loss and diffusion emissions from small nonhandheld nonroad SI engines and diurnal emissions from Marine SI engines. Finally, we expect that the technology necessary to achieve the proposed exhaust emission standards will indirectly lower exhaust PM. All of these effects are reflected in the controlled emission inventories presented in this chapter.

3.2 Baseline Emission Inventory Estimates

This section describes more specifically how we developed the baseline exhaust and evaporative inventories for small nonroad and Marine SI engines. The resulting baseline inventories are also presented. Section 3.2.1 provides this information for exhaust and evaporative emissions.

The inventory estimates presented throughout this section include only equipment that would be subject to the proposed standards. For small nonroad SI equipment, California’s Air Resources Board (ARB) has promulgated standards that are roughly equivalent in stringency overall to our proposed national standards, although some of the specific requirements and test procedures are different. However, the Clean Air Act prohibits California from regulating engines used in farm and construction equipment with maximum power levels below 175 hp or 130 kW. Therefore, the requirements contained in this proposal for small nonroad SI engines will apply in California to the above farm and construction equipment power levels. As a result, these engines are included in the inventories presented in this chapter.

For Marine SI engines, ARB also has its own exhaust emission standards that are roughly equivalent overall to our proposed national standards. In addition, ARB has stated its intend to develop evaporative emissions standards for boats in California. Therefore, exhaust and evaporative inventory estimates contained in this proposal are modeled for 49 states (excluding California) for Marine SI engines.

3.2.1 Baseline Exhaust and Evaporative Emissions Estimates for THC, NOx, $PM_{2.5}$, PM_{10}, and CO

The baseline exhaust and evaporative emission inventories for small nonroad and Marine SI engines include the effects of all existing applicable federal emission standards. We

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[1] The CO standard applies to small nonhandheld SI engines used in auxiliary marine applications.

generated these inventories by starting with the NONROAD2005a emissions model, which was released to the public in February 2005. That model was then modified to incorporate new emission test data and other improvements for this rulemaking. This special version of the model is named NONROAD2005c. The modifications to the base model are described below.

3.2.1.1 Changes from NONROAD2005a to NONROAD2005c

As already mentioned, a number of improvements to the most publically available nonroad emissions inventory model were made to develop the NONROAD2005c, which is used in this proposed rulemaking. These revisions were based on recent testing programs, other information, and model enhancements. The changes are summarized below for Small SI and Marine SI engines. Many of the most important revisions are discussed in greater detail in the following sections.

3.2.1.1.1 Revisions for Small SI Engines

The modifications that we made to the NONROAD2005a model for Small SI engines that are most relevant to the proposal are summarized below:

1. Revised fuel tank and hose permeation emission factors;
2. Explicitly separated fuel tank diffusion losses to diurnal emission estimates;
3. Updated exhaust emission factors and deterioration rates, and technology-type sales fractions for Phase 2 engines;
4. Adjusted equipment populations to properly account for the application of federal emission requirements to engines in California; and
5. Added the ability to specifically model the effects of ethanol blends on fuel tank and hose permeation.

3.2.1.1.2 Revisions for Recreation Marine SI Engines

The modifications that we made to the NONROAD2005a model for Marine SI engines that are most relevant to the proposal are summarized below:

1. Revised brake-specific fuel consumption factors;
2. Revised PM emission factors for 2-stroke technology engines;
3. Revised fuel tank and hose permeation emission factors and temperature effects;
4. Updated modeling inputs for high performance sterndrive and inboard (SD/I) engines; and
5. Added the ability to specifically model the effects of ethanol blends on fuel tank and hose permeation.

3.2.1.2 Baseline Exhaust Emission Calculations

3.2.1.2.1 Small SI Exhaust Calculations

We revised the Phase 2 exhaust emission factors in the NONROAD2005a inventory model to reflect new information and our better understanding of the in-use emissions of these engines, as discussed further below.

The nonroad model estimates exhaust emissions in a given year by applying an appropriate emission factor based on the engines age or hours of use.[5] This reflects the fact that an engine's exhaust emissions performance degrades over its lifetime due to normal use or misuse (i.e., tampering or neglect). More specifically, the emission factor is a combination of a "zero-hour" emission level (ZHL) and a deterioration factor (DF). The ZHL represents the emission rate for recently manufactured engines, i.e., engines with few operating hours. The DF to the degree of emissions degradation per unit of activity. Nonroad engine activity is expressed in terms of hours of use or fraction of its median life. This later term refers to the age at which 50 percent of the engines sold in a given year ceased to function and have been scrapped. The following formula describes the basic form of the calculation:

$$EF_{aged} = ZHL \times DF$$

where: EF_{aged} is the emission factor for an aged engine
ZML is the zero hour emission factor for a new engine
DF is the deterioration factor

The form of the DF for nonroad SI engines is as follows:

$$DF = 1 + A \times (\text{Age Factor})^{b} \quad \text{for Age Factor} \le 1$$
$$DF = 1 + A \quad \text{for Age Factor} > 1$$

where: $$\text{Age Factor} = \frac{[\text{Cumulative Hours} \times \text{Load Factor}]}{\text{Median Life at Full Load, in Hours}}$$

$A,\ ^{b}$ = constants for a given technology type; $b \le 1$.

The constants A and b can be varied to approximate a wide range of deterioration patterns. "A" can be varied to reflect differences in maximum deterioration. For example, setting A equal to 2.0 would result in emissions at the engine's median life being three times the emissions when new. The shape of the deterioration function is determined by the second constant, b. This constant can be set at any level between zero and 1.0; currently, the NONROAD model sets b equal to either 0.5 or 1.0. The first case results in a curvilinear deterioration rate in which most of the deterioration occurs in the early part of an engine's life. The second case results in a linear deterioration pattern in which the rate of deterioration is constant throughout the median life of an engine. In both cases, we previously decided to cap deterioration at the end of an engine's median life, under the assumption that an engine can only deteriorate to a certain point beyond which it becomes inoperable. For spark ignition engines at or below 25 horsepower, which are the subject of this proposal, the nonroad model sets the constant b equal to 0.5. The emission factor inputs for Phase 2 small nonroad SI engines used in this analysis are shown in Table 3.2-1

Table 3.2-1: Phase 2 Modeling Emission Factors for Small SI Engines(g/kW-hr)

Class/ Technology	HC ZML	HC "A"	NOx ZML	NOx "A"	CO ZML	CO "A"	PM10 ZML*	PM10 "A"*
Class I - SV	10.30	1.753	2.57	0.000	386.53	0.070	0.35	1.753
Class I - OHV	8.73	1.753	3.28	0.000	392.93	0.070	0.05	1.753
Class II	5.58	1.095	3.71	0.000	472.80	0.080	0.08	1.095

* The nonroad model calculates PM2.5 as 92 percent of PM10.

Some of the values shown in Table 3.2-1 have been updated from the NONROAD2005a inventory model based on data collected by EPA on in-use engines as well as manufacturer-supplied certification data. The ZHL emission factors for Class I engines were updated based on testing performed by EPA on 16 in-use walk-behind lawnmowers. The Class I side-valve engine A values were revised to be the same as the Class I overhead engine A values based on the same in-use testing of lawnmowers which showed similar in-use deterioration characteristics between overhead valve and sidevalve Class I engines. The Class I and Class II engine A values for CO emissions were revised to better reflect the level of deterioration seen in both the in-use lawnmower testing noted above as well as certification data provided by manufacturers to EPA. Finally, based on data collected from another test program of in-use lawnmowers, the assumption that there was no deterioration of Class I and II emissions after the median life was reached was revised to reflect further continued emissions deterioration after that point.

Also, the model was modified to acknowledge the continued use of side-valve engine designs in Class I nonhandheld engines meeting Phase 2 standards. In the rulemaking that established those regulatory requirements, side-valve technology was assumed to be superceded by overhead valve designs and was modeled accordingly. In reality, side-valve technology has continued to be used in small nonroad SI engines. The resulting technology mixture is shown in Table 3.2-2. The estimated sales fractions by engine class and technology are based on sales information provided by engine manufacturers to EPA for the 2005 model year. A full description of the emission modeling information for Phase 2 engines and the basis for the estimates can be found in the docket for this rule.

Table 3.2-2: Phase 3 Small Nonroad SI Engine Technology Classes

Engine Class	Technology Class	Percent Sales (%)
Class I	Side Valve	60
Class I	Overhead Valve	40
Class II	Overhead Valve	100

3.2.1.2.2 Marine SI Exhaust Calculations

The NONROAD2005a model included a number of recent updates to the emission rates and technology mix of Marine SI engines.[6] These updates were largely based on data submitted to EPA by marine engine manufacturers as part of the certification process and on new test data collected by EPA.[7] However, NONROAD2005a does not include high-performance SD/I marine engines. High-performance marine engines are niche product and were not included in the data set used to develop the engine populations for the NONROAD2005a model.

Manufacturers have recently commented that approximately 1,500 high-performance engines are produced in the U.S. per year. These engines range from 500 to 1500 horsepower and are used in both racing and non-racing applications. Based on conversations with individual high-performance engine manufacturers, we estimate that about two thirds of these engines are sold for use in the U.S. with an average power of about 650 horsepower. These engines are designed to sacrifice service life for power, but with rebuilds, generally are used for 7-8 years (we use 8 years for our modeling). Based on these estimates and the growth rate in the NONROAD2005a model, we estimate a 1998 population of SD/I engines >600 horsepower of 7500 units. One manufacturer stated that they performed a survey on the annual use of these engines for warranty purposes and the result was an average annual use of about 30 hours per year. We also updated the baseline emission factors for high performance marine engines based on the emission data presented in Chapter 4. Note that no changes were made to the PM emission factors because no new data was available. Table 3.2-3 presents the updated emission factors for high-performance SD/I marine engines.

Table 3.2-3: Emission Factors for High-Performance Marine Engines [g/kW-hr]

Pollutant	Carbureted Engines (MS4C, Bin 12)	Fuel-Injected Engines (MS4D, Bin 12)
HC	13.8	13.8
CO	253	207
NOx	8.4	6.8
PM	0.08	0.08
BSFC	400	362

3.2.1.3 Baseline Evaporative Emission Calculations

Chapter 5 presents a great deal of information on evaporative emission rates from fuel systems used in nonroad equipment. Much of this information was incorporated into the NONROAD2005a model.[8] However, we have continued to collect evaporative emission data and incorporate the new information into our evaporative emission inventory calculations. These updates are described below.

3.2.1.3.1 Fuel Ethanol Content

Currently, about 30 percent of fuel sold in the U.S. contains ethanol. With the recent establishment of the Energy Policy Act of 2005,[9] this percentage is expected to increase. The significance of the use of ethanol in fuel, for the inventory calculations, is that ethanol in fuel can affect the evaporative emissions from nonroad equipment. Fuel blends containing ethanol typically increase the permeation rate for most materials used in gasoline fuel systems. This is discussed in more detail below.

Title XV, section 1501, of the Energy Policy Act requires that the total volume of renewable fuel increase from 4.0 to 7.5 billion gallons per year from 2006 to 2012, and the Energy Information Administration (EIA) predicts that production will actually reach 9.6 billion gallons per year by then. Based on these figures and projected gasoline sales from the Energy Information Administration,[10,11,12] we estimate that about two-thirds of gasoline sold in 2012 and later will contain ethanol. Table 3.2-4 presents our estimates for ethanol blended fuels into the future. The blend market shares shown in the last column of this table assume 10 percent for ethanol content of blended gasoline in all areas except California, where it is 5.7 volume percent.

Table 3.2-4: Estimated Fraction of Gasoline Containing Ethanol

Calendar Year	U.S. Gasoline Sales [10^9 gal.]	U.S. Ethanol Sales [10^9 gal.]	Fraction of Gas with Ethanol
2000	129.9	1.6	13.5%
2001	132.0	1.8	14.5%
2002	135.6	2.1	17.0%
2003	137.0	2.8	22.2%
2004	139.6	3.4	26.3%
2005	139.9	3.8	29.7%
2006	141.3	4.1	31.6%
2007	143.0	5.2	39.2%
2008	145.4	6.0	44.9%
2009	148.1	6.9	50.4%
2010	150.9	7.9	56.4%
2011	153.3	8.8	62.2%
2012	155.6	9.6	67.1%

* ethanol fraction projected to be constant after last year of Energy Policy Act phase-in (2012)

3.2.1.3.2 Hose Permeation

We developed hose permeation emission factors based on the permeation data and hose requirements presented in Chapter 5. Because permeation is a function of surface area and because hose lengths and inner diameters are defining parameters, hose permeation rates are based on $g/m^2/day$. These emission factors incorporate a more complete set of data than those in the NONROAD2005a model. In addition, distinctions are now made between permeation rates for liquid fuel versus fuel vapor exposure and between permeation rates for gasoline versus ethanol-blend fuels. The updated hose emission factors are discussed below and presented in Table 3.2-5.

Fuel hoses in Small SI applications vary greatly in construction depending on the individual specifications of the engine and equipment manufacturers. However most fuel hose used on non-handheld equipment meets the SAE J30 R7 hose requirements which includes a permeation requirement of 550 g/m^2/day on Fuel C at 23°C.[13] Chapter 5 presents data on several hose constructions that range from 190 to 450 g/m^2/day on Fuel C. As discussed in Chapter 5, permeation is typically lower on gasoline than on Fuel C. At the same time, blending ethanol into the fuel increases permeation. Based on data presented in Chapter 5, we estimate that non-handheld fuel hose permeation rates range from 27 to 180 g/m^2/day on gasoline and 80-309 g/m^2/day on gasoline blended with 10 percent ethanol (E10). Of the data presented in Chapter 5, the lowest two permeation rates for SAE J30 R7 hose were from an unknown fuel hose construction and from a hose (used in some Small SI applications) that was specially constructed of fuel resistant materials to facilitate painting. Dropping the unknown hose construction (which is not known to be used in Small SI applications), we get average permeation rates of 122 g/m^2/day on gasoline and 222 g/m^2/day on E10 at 23˚C.

Chapter 5 also presents permeation data on nine samples of fuel lines used in handheld equipment tested using E10 fuel. The permeation rates for these samples ranged from 165 to 455 g/m^2/day at 23˚C with an average of 255 g/m^2/day. All of the hose samples, except one were made of NBR rubber, with the exception being a NBR/PVC blend. To determine an emission factor for handheld fuel lines on gasoline, we used the ratio of permeation rates for NBR rubber samples on E10 versus gasoline. The resulting permeation rate for handheld hose on gasoline was estimated to be 140 g/m^2/day at 23˚C.

Fuel hose for portable marine fuel tanks is not subject to any established recommended practice. For this reason, we consider fuel hose used on portable marine fuel tanks to be equivalent to the hose used in Small SI applications. The supply hose for each portable marine fuel tank is modeled to include a primer bulb with the same permeation rate as the hose.

Recommended practices for marine hose on SD/I vessels include a permeation rate of 100 g/m^2/day on Fuel C and 300 g/m^2/day on fuel CM15 (15 percent methanol).[14,15] Accordingly, these vessels have fuel hose with lower permeation. Rather than using the recommended permeation rate limits for this hose, we base the permeation emission factors for this hose on the data presented in Chapter 5 on gasoline with ethanol which is more representative of in-use fuels. Chapter 5 also includes data on commercially available low permeation fuel hose which is used by some manufacturers. However, we do not include this in the baseline emission factor calculation because its use is primarily in anticipation of upcoming permeation standards and would therefore not be expected to remain in the baseline without enactment of this proposed rule.

For other vessels with installed fuel tanks (OB and PWC), we based the permeation emission factors on the test data in Chapter 5 on marine hose not certified to Coast Guard Class I requirements.

The Coast Guard specifications for fill neck hose call for a permeation limit of 300 g/m^2/day on Fuel C and 600 on Fuel CM15. However, fill neck hose are not usually exposed to liquid fuel. Therefore, we used the vapor line data presented in Chapter 5 for both fill neck and vent line permeation rates. Hose permeation rates for both gasoline and E10 are presented in Table 3.2.-5.

Table 3.2-5: Hose Permeation Emission Factors at 23˚C [g/m^2/day]

Hose Type	Gasoline	E10
Handheld equipment fuel hose	140	255
Non-handheld equipment fuel hose	122	222
Portable fuel tank supply hose*	122	222
Installed system OB/PWC fuel lines	42	125
Installed system SD/I fuel lines	22	40
Fill necks and vent lines (vapor exposure)	2.5	4.9

* this permeation rate is used for primer bulbs as well

The above permeation rates do not include any effects of deterioration. Over time, the fuel can draw some of the plasticizers out of the rubber in the hose, making it more brittle and subject to cracking. This is especially true for higher permeation fuel hoses which are generally less fuel resistant. Exposure to ozone over time can also deteriorate the hose. This deterioration would presumably increase the permeation rate over time. However, we do not have any data to quantify this effect and are not including deterioration in this analysis at this time. Lower permeation fuel hose, such as that designed to meet the proposed standard would likely have much lower deterioration due to the use of more fuel resistant materials. Therefore this analysis may underestimate the inventory and benefits associated with the proposed fuel permeation standards.

3.2.1.3.3 Hose Lengths

The hose lengths used in NONROAD2005a are based primarily on confidential information supplied by equipment manufacturers. Hose lengths for handheld equipment are based on survey data provided by the Outdoor Power Equipment Institute.[16] Recently, we received comment from a boatbuilder using outboard motors that the hose lengths in our calculations were too short.[17] Because our existing data set did not include outboard boats with installed fuel tanks, we updated the hose lengths for these vessels based on the data supplied by this boat builder. In addition, the vent line lengths in the NONROAD2005a were divided by two to account for a vapor gradient throughout the fuel line caused by diurnal breathing and diffusion. This factor has been removed in lieu of the new emission factors for vent lines based on vapor exposure. Table 3.2-6 presents the updated hose lengths for outboard boats with installed fuel tanks.

Table 3.2-6: Updated Hose Lengths for Outboard Boats with Installed Fuel Systems

Engine Power Category	Fill Neck Length [m]	Fuel Supply Hose Length [m]	Vent Hose Length [m]
18.7-29.8 kW	1.8	1.8	1.5
29.9-37.3 kW	2.4	2.4	1.8
37.4-74.6 kW	3.1	3.1	2.1
74.7-130.5 kW	3.7	3.7	2.4
130.6+ kW	4.3	4.3	2.7

3.2.1.3.4 Tank Permeation

For fuel tanks, the NONROAD2005a model does not include a fuel ethanol effect on permeation. Data in Chapter 5 suggest that even polyethylene fuel tanks see a small increase in permeation on E10 compared to gasoline. This increase is much larger for nylon fuel tanks like those used in handheld equipment with structurally-integrated fuel tanks. Table 3.2-7 presents the updated emission factors on E10 fuel and compares them to the emission factors based on gasoline permeation rates. The primary difference between the permeation rates for installed marine tanks, compared to smaller HDPE fuel tanks, is largely due to the wall thickness of the different constructions rather than material permeation properties. Permeation rate is a function of wall thickness, so as tank thickness doubles, permeation rate halves. The model considers permeation from metal fuel tanks to be zero.

Table 3.2-7: Tank Permeation Emission Factors at 29˚C [g/m^2/day]

Tank Type	Gasoline	E10
Nylon handheld fuel tanks	1.25	2.5
Small SI HDPE <0.25 gallons	6.5	7.2
Small SI HDPE ≥0.25 gallons	9.7	10.7
Portable and PWC HDPE fuel tanks	9.9	10.9
Installed non-metal marine fuel tanks	8.0	8.8
Metal tanks	0	0

3.2.1.3.5 Diffusion

The NONROAD2005a model includes an adjustment factor to diurnal emissions to account for diffusion. The data used to create this adjustment factor is included in Chapter 5. This adjustment factor is applied to all Small SI equipment in the NONROAD2005a model. However, we believe that handheld equipment are all produced with either sealed fuel tanks or slosh/spill resistant fuel caps. Therefore, we do not include diffusion emissions for handheld equipment in this analysis.

3.2.1.3.6 Modeling of Nonlinear Ethanol Blend Permeation Effects

Based on the limited available test data it appears that the effect of alcohol-gasoline blends on permeation is nonlinear, tending to increase permeation at lower alcohol concentrations up to about 20 percent ethanol, but then decreasing permeation at higher alcohol concentrations.[18]

Starting with the zero and 10 percent ethanol points described above, a simple exponential curve was selected to connect the zero and 10 percent points continuing up to the 20 percent ethanol level. Then to get a nonlinear decreasing curve above 20 percent a simple decreasing exponential curve was used. Since effects above 85 percent are especially uncertain, and no such fuels are foreseen for use in nonroad equipment, the effect above 85 percent was set equal to the E85 effect. The equations used are shown here, and an example curve based on these equations is shown in Figure 3.2-1.

Hose and Tank Permeation for 0 - 20 percent ethanol volume percent:

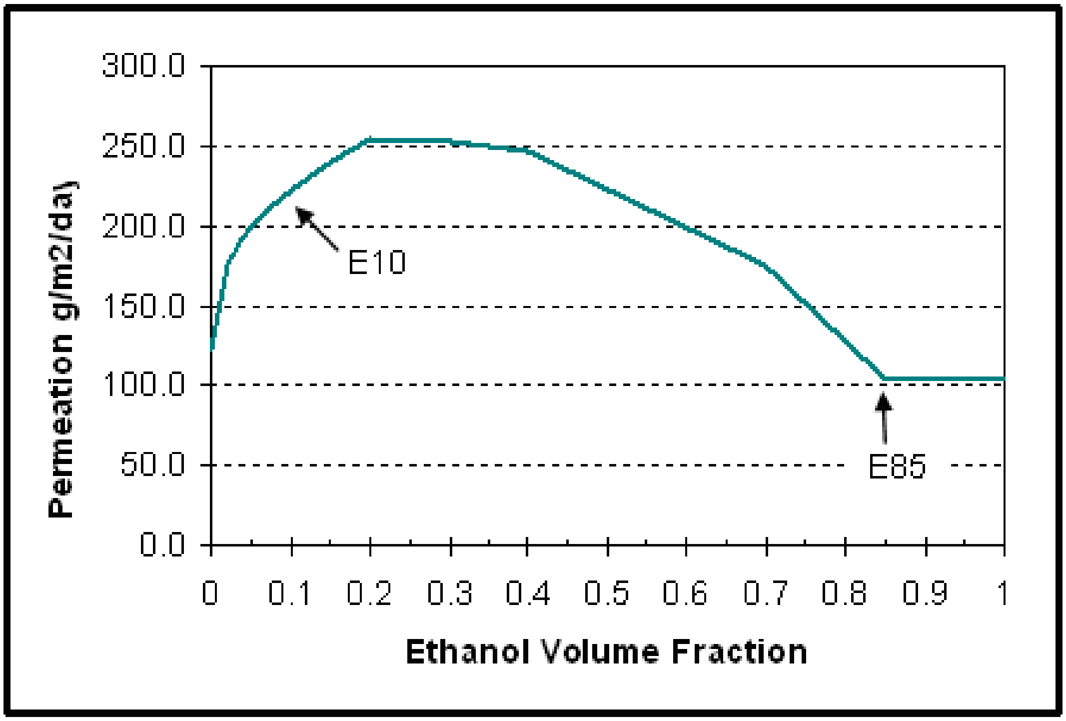
$$\text{Permeation EF} = \text{GasEF} + \text{GasEF} \times (\text{E10fac} - 1) \times [\, (\text{EthVfrac} / 0.10)\ \hat{}\ 0.4\,]$$

Hose and Tank Permeation for ethanol volume percent greater than 20 percent:

$$\begin{aligned}\text{Permeation EF} = {} & \text{GasEF} \times \{\, 1 + (\text{E10fac} - 1) \times [\, (20 / 10)\ \hat{}\ 0.4\,]\, \} \\ & \times \{\, 1 - [\, (\text{MIN}(\text{EthVfrac}, 0.85) - 0.20\,) / 0.80\,]\ \hat{}\ (1 / 0.4\,)\, \}\end{aligned}$$

where:
Permeation EF = Permeation emission factor for modeled fuel (grams per meter^2 per day)
GasEF = Gasoline hose permeation emission factor from input EF data files (grams per meter^2 per day)
E10fac = permeation emission adjustment factor for E10 relative to gasoline. This is the ratio of the E10 to gasoline permeation emission factors (unitless)
EthVfrac = Volume fraction ethanol in the fuel being modeled. E10 = 0.10
0.4 = exponent chosen to yield a reasonable shape of curve.

Figure 3.2-1: Ethanol Blend Hose Permeation Example Curve



Note that all ethanol blends currently modeled with NONROAD or NMIM are less than or equal to E10, so no parts of this curve above E10 are used. Also note that the value of E10fac used in the modeling of the control case is 2.0 for all the tank and hose permeation sources listed above in Tables 3.2-6 and 3.2-7.

3.2.1.3.7 Modeling Effect of Ethanol Blend Market Share on Permeation

The effect of ethanol blend market share is modeled linearly. In most areas the ethanol blend market share is either zero or 100 percent, but in areas where it is between those two market shares, or when doing a nationwide model run, the effect is calculated as a simple proportion. For instance a 30 percent market share of E10 would be modeled using a permeation rate 30 percent of the way between the E0 permeation rate and the E10 permeation rate.

3.2.1.4 Baseline Exhaust and Evaporative Inventory Results for THC, NOx, $PM_{2.5}$, PM_{10}, and CO

Table 3.2-8 presents the 50-state baseline emission inventories, respectively, for small nonroad SI engines. Table 3.2-9 provides the same information for Marine SI engines.

Table 3.2-8: Baseline 50-State Annual Exhaust and Evaporative Emissions for Small Nonroad Spark-Ignition Engines (short tons)

Year	THC	NOx	PM2.5	PM10	CO
2001	1,099,402	101,928	23,163	25,177	16,108,103
2002	1,074,137	101,261	23,382	25,416	15,560,774
2003	1,039,522	99,649	23,480	25,522	14,941,296
2004	978,760	97,929	23,483	25,525	14,382,759
2005	905,814	95,779	23,417	25,453	13,784,367
2006	849,619	94,550	23,498	25,541	13,369,719
2007	794,827	92,988	23,804	25,874	12,919,586
2008	748,034	90,638	24,335	26,451	12,285,206
2009	715,943	89,272	24,882	27,045	11,775,265
2010	700,482	88,968	25,402	27,611	11,492,162
2011	698,481	89,543	25,888	28,139	11,426,366
2012	700,981	90,440	26,364	28,657	11,438,836
2013	706,486	91,607	26,832	29,165	11,517,029
2014	714,968	92,973	27,291	29,664	11,645,064
2015	724,695	94,432	27,747	30,160	11,797,078
2016	735,292	95,959	28,202	30,654	11,965,466
2017	746,447	97,519	28,655	31,146	12,143,564
2018	758,021	99,101	29,107	31,638	12,328,523
2019	769,929	100,700	29,558	32,128	12,519,136
2020	781,985	102,310	30,009	32,618	12,712,775
2021	794,072	103,922	30,460	33,109	12,907,487
2022	806,192	105,533	30,911	33,599	13,102,999
2023	818,336	107,145	31,362	34,089	13,299,184
2024	830,496	108,759	31,813	34,579	13,495,942
2025	842,686	110,379	32,265	35,070	13,693,641
2026	855,022	112,019	32,718	35,563	13,893,823
2027	867,389	113,666	33,173	36,057	14,094,990
2028	879,769	115,314	33,627	36,551	14,296,561
2029	892,157	116,964	34,081	37,045	14,498,417
2030	904,553	118,615	34,535	37,538	14,700,521
2031	916,953	120,267	34,990	38,032	14,902,797
2032	929,357	121,919	35,444	38,526	15,105,180
2033	941,764	123,571	35,898	39,020	15,307,643
2034	954,175	125,223	36,353	39,514	15,510,182
2035	966,587	126,875	36,807	40,008	15,712,789
2036	979,003	128,527	37,261	40,502	15,915,457
2037	991,420	130,179	37,716	40,995	16,118,191
2038	1,003,840	131,832	38,170	41,489	16,320,977
2039	1,016,261	133,484	38,625	41,983	16,523,816
2040	1,028,684	135,136	39,079	42,477	16,726,708

Table 3.2-9: Baseline 50-State Annual Exhaust and Evaporative Emissions for Marine Spark-Ignition Engines (Short Tons)

Year	THC	NOx	PM2.5	PM10	CO
2001	935,494	41,514	15,625	16,984	2,584,786
2002	909,607	43,401	15,092	16,404	2,552,368
2003	877,441	45,661	14,417	15,670	2,510,927
2004	841,151	48,164	13,679	14,869	2,469,934
2005	801,985	50,675	12,886	14,007	2,423,497
2006	762,092	53,207	12,090	13,142	2,375,768
2007	724,443	55,750	11,311	12,295	2,328,182
2008	687,350	58,296	10,553	11,470	2,280,928
2009	651,744	60,797	9,824	10,678	2,235,187
2010	618,843	63,228	9,149	9,945	2,191,484
2011	588,283	65,613	8,525	9,266	2,149,407
2012	561,699	67,843	7,983	8,678	2,112,511
2013	538,510	69,883	7,534	8,189	2,081,945
2014	518,615	71,789	7,144	7,766	2,054,769
2015	502,307	73,583	6,823	7,416	2,031,684
2016	488,502	75,245	6,549	7,118	2,011,569
2017	477,287	76,781	6,324	6,874	1,995,319
2018	469,041	78,169	6,156	6,691	1,983,611
2019	462,146	79,469	6,012	6,535	1,974,297
2020	457,338	80,655	5,908	6,422	1,968,663
2021	453,687	81,768	5,826	6,333	1,965,024
2022	451,360	82,796	5,768	6,270	1,963,888
2023	449,882	83,756	5,726	6,224	1,964,657
2024	449,089	84,663	5,696	6,191	1,967,014
2025	449,054	85,517	5,680	6,174	1,971,025
2026	449,611	86,327	5,675	6,168	1,976,557
2027	450,640	87,096	5,678	6,172	1,983,392
2028	451,987	87,828	5,687	6,182	1,991,331
2029	453,610	88,537	5,701	6,197	1,999,984
2030	455,480	89,225	5,719	6,217	2,009,248
2031	457,536	89,896	5,741	6,240	2,019,028
2032	459,725	90,554	5,765	6,266	2,029,227
2033	462,071	91,197	5,792	6,296	2,039,870
2034	464,529	91,828	5,821	6,327	2,050,883
2035	467,079	92,448	5,851	6,360	2,062,245
2036	469,685	93,060	5,883	6,394	2,073,873
2037	472,348	93,664	5,915	6,429	2,085,737
2038	475,055	94,261	5,948	6,465	2,097,797
2039	477,796	94,853	5,982	6,502	2,110,011
2040	480,560	95,440	6,016	6,539	2,122,336

3.2.2 Baseline Hazardous Air Pollutant Estimates

The analysis of toxic air pollutants from small nonroad and Marine SI engines focuses on seven major pollutants: benzene, formaldehyde, acetaldehyde, 1,3-butadiene, acrolein, naphthalene, and 15 other compounds grouped together as polycyclic organic matter (POM) for this analysis.[2] All of these compounds, except acetaldehyde, were identified as national or regional cancer or noncancer "risk" drivers in the 1999 National Scale Air Toxics Assessment (NATA)[19] and have significant inventory contributions from mobile sources. That is, for a significant portion of the population, these compounds pose a significant portion of the total cancer or noncancer risk from breathing outdoor air toxics. The health effects of these hazardous pollutants are specifically discussed in Section 2.3. Many of these compounds are also part of the THC inventories. An exception is formaldehyde, which is not measured by the analytic technique used to measure THC, and part of the mass of other aldehydes as well. However, all are included in the VOC inventories presented in this chapter.

The baseline inventories for each of the toxic air pollutants described above are based on the work performed for EPA's mobile source air toxic (MSAT) final rulemaking.[20] The hazardous air pollutant inventories for all nonroad equipment except aircraft, locomotives, and commercial marine vessels in MSAT were developed using EPA's National Mobile Inventory Model (NMIM). This model is an analytical framework that links a county-level database to our highway and nonroad models and collates the output into a single database table. The resulting estimates for small nonroad and Marine SI engines account for local differences in fuel characteristics and temperatures.

The modeling results reflect the future use of renewable fuels as specified in the Energy Policy Act of 2005. Emissions were modeled for each county in the continental U.S. for 1999, 2010, 2015, 2020, and 2030. For this proposal, a special NMIM simulation was also performed using the MSAT methodology for 2001 (our base year). The analysis for this additional year is also included in the MSAT documentation for completeness.

To estimate the baseline air toxics inventories for this proposal, we started with the MSAT baseline case (no air toxics control) results for the Source Category Codes (SCCs) that contain the affected small nonroad and Marine SI engines.[3] Those inventories were produced by the NMIM model using NONROAD2005a (the latest public release), so they do not reflect the emission modeling improvements we made for the proposed rule. Therefore, we corrected the MSAT air toxics inventories to mirror the results from our improved NONROAD2005c model.

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[2] The 15 POMs summarized in this chapter are acenaphthene, acenapthylene, anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylkene, beno(k)fluoranthene, chrysene, dibenzo(a,h)anthracene,fluoranthene, fluorene, ideno(1,2,3,c,c)-pyrene, phenanthrene, and pyrene.

[3] MSAT controls only affect the benzene content of nonroad gasoline fuel. Therefore, if the MSAT control case was used, only the benzene inventory for the nonroad engines affected by this proposal would be significantly affected.

This adjustment was done to avoid the need to run the NMIM/MSAT model, which is quite resource intensive, using the new NONROAD2005c model.

The hazardous air pollutant inventory for each exhaust and evaporative gaseous hydrocarbon species is estimated in NMIM as a fraction of VOC emissions, except for POMs, which are found in both the gas and particle phase. For each POM hydrocarbon species, the toxics inventory is estimated as a ratio to PM. Therefore, in order to correct the MSAT results to mirror the improved model results, we multiplied each MSAT hazardous air pollutant inventory for the applicable nonroad SCCs by the ratio of the VOC or PM emission results, as appropriate, from the new NONROAD2005c model to the respective NMIM NONROAD2005a model results.

Tables 3.2-10 presents the 50-state baseline inventories, respectively, for toxic air emissions from small nonroad SI engines. Tables 3.2-11 provides the same information for Marine SI engines.

Table 3.2-10: Baseline 50-State Air Toxic Emissions for Small Nonroad Spark-Ignition Engines (short tons)

Year	Benzene	1,3 Butadiene	Formaldehyde	Acetaldehyde	Acrolein	Napthalene	POM
2001	33,534	5,165	8,035	2,826	462	418	93
2020	22,923	3,169	5,182	2,429	270	409	107
2030	26,502	3,663	5,991	2,805	312	475	123

Table 3.2-11: Baseline 50-State Air Toxic Emissions for Marine Spark-Ignition Engines (short tons)

Year	Benzene	1,3 Butadiene	Formaldehyde	Acetaldehyde	Acrolein	Napthalene	POM
2001	21,590	1,790	1,846	1,354	179	32	30
2020	9,144	694	606	666	47	32	15
2030	9,073	670	583	649	45	34	15

3.3 Contribution of Small Nonroad and Marine SI Engines to National Emissions Inventories

This section describes the nationwide contribution of small nonroad and Marine SI engines to the emissions of other source categories. Information is presented for the pollutants that are directly controlled by the proposed standards, i.e., VOC, NO_x, and CO, and those that are indirectly reduced by some of the requisite control technology, i.e., $PM_{2.5}$ and PM_{10}. The VOC inventories includes both exhaust and evaporative hydrocarbon emissions.

3.3.1 National Emission Inventory Development

The national inventories are presented for 2001, 2015, and 2020 for the contiguous 48-states of the U.S. and the District of Columbia.[21] The stationary, area, motorcycle, aircraft, locomotive, commercial marine inventories were taken directly from EPA's most recent air quality modeling for the PM NAAQS. The gaseous emission inventories for highway diesel vehicles and the 2001 calendar year PM emission estimates for highway diesel vehicles were also taken directly from that work. The emission inventories for on highway gasoline vehicles were taken from work performed for our Mobile Source Air Toxics (MSAT) rulemaking analysis. These inventories account for the future use of renewable fuels as required by the Energy Policy Act of 2005. Finally, the nonroad engine baseline inventories were estimated using the modified version of NONROAD2005a that was developed for this proposal, as discussed further in Section 3.2.1.

3.3.1.1 VOC Emissions Contribution

Table 3.3-1 provides the contribution of small nonroad SI engines, Marine SI engines and other source categories to total VOC emissions. The emissions from nonroad Small SI (<19kW) and Marine SI engines are 28 percent of the mobile source inventory and 13 percent of the total manmade VOC emissions in 2001. These percentages decrease slightly to 27 percent and 10 percent, respectively, by 2020.

3.3.1.2 NOx Emissions Contribution

Table 3.3-2 provides the contribution of nonroad small nonroad SI engines, Marine SI engines and other source categories to total NOx emissions. The emissions from small nonroad and Marine SI engines are 1 percent of the mobile source inventory and 1 percent of the total manmade NOx emissions in 2001. These percentages increase to 4 percent and 2 percent, respectively, by 2020.

3.3.1.3 PM Emissions Contribution

Table 3.3-3 and 3.3-4 provide the contribution of small nonroad SI engines, Marine SI engines and other source categories to total $PM_{2.5}$ and PM_{10} emissions, respectively. Both particle size categories from small nonroad and Marine SI engines are about 9 percent of the mobile source inventory and approximately 2 percent of the total manmade $PM_{2.5}$ emissions in 2001. These percentages stay about the same at about 10 percent and 2 percent, respectively, by 2020.

3.3.1.4 CO Emissions Contribution

Table 3.3-5 provides the contribution of small nonroad SI engines, Marine SI engines and other source categories to total CO emissions. The emissions from small nonroad and

Marine SI engines are 24 percent of the mobile source inventory and 22 percent of the total manmade CO emissions in 2001. These percentages decrease to 22 percent and increase to 27 percent, respectively, by 2020.

Table 3.3-1: 50-State Annual VOC Baseline Emission Levels for Mobile and Other Source Categories

Category	2OO1 short tons	% of mobile source	% of total	2015 short tons	% of mobile source	% of total	2020 short tons	% of mobile source	% of total
Small Handheld Nonroad SI	503,772	6.3%	2.9%	204,425	3.9%	1.5%	221,027	4.4%	1.6%
Small Nonhandheld Nonroad SI	699,516	8.8%	4.0%	582,107	11.1%	4.2%	627,909	12.5%	4.7%
Marine SI	1,035,768	13.0%	5.9%	552,888	10.5%	4.0%	502,803	10.0%	3.7%
SI Recreational Vehicles	497,207	6.3%	2.8%	593,624	11.3%	4.3%	443,407	8.8%	3.3%
Large Nonroad SI (>25hp)	132,820	1.7%	0.75%	20,012	0.4%	0.15%	12,220	0.2%	0.09%
Portable Fuel Containers*	244,545	3.1%	1.39%	238,055	4.5%	1.73%	254,479	5.1%	1.89%
Land-Based Nonroad Diesel	188,884	2.4%	1.07%	95,934	1.8%	0.70%	76,047	1.5%	0.56%
Marine Diesel	1,472	0.02%	0.01%	1,636	0.03%	0.01%	1,623	0.03%	0.01%
Commercial Marine	33,577	0.42%	0.19%	39,956	0.76%	0.29%	43,876	0.87%	0.33%
Locomotive	39,279	0.49%	0.22%	35,423	0.67%	0.26%	34,407	0.69%	0.26%
Aircraft	22,084	0.28%	0.13%	25,426	0.48%	0.18%	27,644	0.55%	0.20%
Total Off Highway	3,398,924	42.8%	19.3%	2,389,485	45.5%	17.3%	2,245,442	44.8%	16.6%
Total Highway	4,540,133	57.2%	25.8%	2,865,967	54.5%	20.8%	2,769,812	55.2%	20.5%
Total Mobile Sources	7,939,058	100.0%	45.0%	5,255,453	100.0%	38.2%	5,015,254	100.0%	37.2%
Stationary Point and Area Sources	9,692,344	-	55.0%	8,519,026	-	61.8%	8,475,443	-	62.8%
Total Man-Made Sources	17,631,402	-	100.0%	13,774,479	-	100.0%	13,490,697	-	100.0%

Table 3.3-2: 50-State Annual NOx Baseline Emission Levels for Mobile and Other Source Categories

Category	2001 short tons	% of mobile source	% of total	2015 short tons	% of mobile source	% of total	2020 short tons	% of mobile source	% of total
Small Handheld Nonroad SI	2,678	0.0%	0.0%	3,647	0.1%	0.0%	3,945	0.1%	0.0%
Small Nonhandheld Nonroad SI	111,641	0.9%	0.5%	102,382	1.8%	0.9%	110,936	2.3%	1.0%
Marine SI	44,732	0.4%	0.2%	79,288	1.4%	0.7%	86,908	1.8%	0.8%
SI Recreational Vehicles	5,948	0.0%	0.0%	15,287	0.3%	0.1%	18,224	0.4%	0.2%
Large Nonroad SI (>25hp)	325,636	2.7%	1.51%	63,747	1.1%	0.54%	46,888	1.0%	0.43%
Land-Based Nonroad Diesel	1,548,236	12.7%	7.18%	969,065	16.7%	8.15%	678,377	14.4%	6.26%
Marine Diesel	39,301	0.32%	0.18%	47,282	0.82%	0.40%	48,557	1.03%	0.45%
Commercial Marine	930,886	7.63%	4.32%	953,398	16.47%	8.02%	989,930	20.95%	9.14%
Locomotive	999,455	8.19%	4.64%	646,647	11.17%	5.44%	627,659	13.28%	5.79%
Aircraft	83,764	0.69%	0.39%	95,330	1.65%	0.80%	105,133	2.23%	0.97%
Total Off Highway	4,092,277	33.5%	19.0%	2,976,071	51.4%	25.0%	2,716,559	57.5%	25.1%
Total Highway	8,105,316	66.5%	37.6%	2,811,495	48.6%	23.6%	2,008,237	42.5%	18.5%
Total Mobile Sources	12,197,593	100.0%	56.6%	5,787,566	100.0%	48.7%	4,724,796	100.0%	43.6%
Stationary Point and Area Sources	9,355,659	-	43.4%	6,107,354	-	51.3%	6,111,866	-	56.4%
Total Man-Made Sources	21,553,252	-	100.0%	11,894,919	-	100.0%	10,836,662	-	100.0%

Table 3.3-3: 50-State Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

Category	2001 short tons	% of mobile source	% of total	2015 short tons	% of mobile source	% of total	2020 short tons	% of mobile source	% of total
Small Handheld Nonroad SI	20,587	4.6%	0.9%	24,015	8.8%	1.2%	25,947	10.9%	1.3%
Small Nonhandheld Nonroad SI	4,879	1.1%	0.2%	6,403	2.4%	0.3%	6,957	2.9%	0.3%
Marine SI	16,837	3.7%	0.7%	7,352	2.7%	0.4%	6,367	2.7%	0.3%
SI Recreational Vehicles	12,301	2.7%	0.5%	15,864	5.8%	0.8%	11,773	4.9%	0.6%
Large Nonroad SI (>25hp)	1,610	0.4%	0.07%	2,207	0.8%	0.11%	2,421	1.0%	0.12%
Land-Based Nonroad Diesel	164,180	36.4%	6.80%	75,788	27.9%	3.68%	46,075	19.3%	2.24%
Marine Diesel	1,066	0.24%	0.04%	774	0.28%	0.04%	760	0.32%	0.04%
Commercial Marine	39,829	8.82%	1.65%	46,567	17.12%	2.26%	52,517	21.97%	2.55%
Locomotive	24,418	5.41%	1.01%	16,967	6.24%	0.82%	16,034	6.71%	0.78%
Aircraft	5,664	1.25%	0.23%	6,544	2.41%	0.32%	7,044	2.95%	0.34%
Total Off Highway	291,371	64.5%	12.1%	202,483	74.4%	9.8%	175,896	73.6%	8.6%
Total Highway	160,229	35.5%	6.6%	69,551	25.6%	3.4%	63,154	26.4%	3.1%
Total Mobile Sources	451,600	100.0%	18.7%	272,034	100.0%	13.2%	239,050	100.0%	11.6%
Stationary Point and Area Sources	1,963,264	-	81.3%	1,786,151	-	86.8%	1,817,722	-	88.4%
Total Man-Made Sources	2,414,864	-	100.0%	2,058,185	-	100.0%	2,056,773	-	100.0%

Table 3.3-4: 50-State Annual PM_{10} Baseline Emission Levels for Mobile and Other Source Categories

Category	2001 short tons	% of mobile source	% of total	2015 short tons	% of mobile source	% of total	2020 short tons	% of mobile source	% of total
Small Handheld Nonroad SI	22,378	4.3%	0.8%	26,104	7.6%	1.0%	28,204	9.0%	1.1%
Small Nonhandheld Nonroad SI	5,303	1.0%	0.2%	6,960	2.0%	0.3%	7,562	2.4%	0.3%
Marine SI	18,301	3.5%	0.6%	7,991	2.3%	0.3%	6,920	2.2%	0.3%
SI Recreational Vehicles	13,370	2.6%	0.5%	17,244	5.0%	0.7%	12,796	4.1%	0.5%
Large Nonroad SI (>25hp)	1,630	0.3%	0.06%	2,228	0.6%	0.09%	2,441	0.8%	0.09%
Land-Based Nonroad Diesel	169,258	32.5%	5.76%	78,132	22.7%	3.03%	47,500	15.1%	1.84%
Marine Diesel	1,099	0.21%	0.04%	798	0.23%	0.03%	784	0.25%	0.03%
Commercial Marine	41,409	7.96%	1.41%	48,448	14.07%	1.88%	54,649	17.40%	2.11%
Locomotive	25,173	4.84%	0.86%	17,521	5.09%	0.68%	16,535	5.26%	0.64%
Aircraft	6,490	1.25%	0.22%	7,539	2.19%	0.29%	8,108	2.58%	0.31%
Total Off Highway	304,412	58.5%	10.4%	212,964	61.8%	8.3%	185,500	59.1%	7.2%
Total Highway	216,032	41.5%	7.3%	131,415	38.2%	5.1%	128,605	40.9%	5.0%
Total Mobile Sources	520,444	100.0%	17.7%	344,379	100.0%	13.3%	314,105	100.0%	12.2%
Stationary Point and Area Sources	2,418,848	-	82.3%	2,236,080	-	86.7%	2,269,828	-	87.8%
Total Man-Made Sources	2,939,292	-	100.0%	2,580,459	-	100.0%	2,583,932	-	100.0%

Table 3.3-5: 50-State Annual CO Baseline Emission Levels for Mobile and Other Source Categories

Category	2001 short tons	% of mobile source	% of total	2015 short tons	% of mobile source	% of total	2020 short tons	% of mobile source	% of total
Small Handheld Nonroad SI	1,101,646	1.3%	1.1%	948,479	1.8%	1.6%	1,024,684	2.0%	1.7%
Small Nonhandheld Nonroad SI	16,980,598	19.4%	17.6%	12,274,519	23.7%	20.3%	13,227,534	25.3%	21.7%
Marine SI	2,785,192	3.2%	2.9%	2,189,207	4.2%	3.6%	2,121,300	4.1%	3.5%
SI Recreational Vehicles	1,220,580	1.4%	1.3%	1,982,847	3.8%	3.3%	1,903,316	3.6%	3.1%
Large Nonroad SI (>25hp)	1,787,054	2.0%	1.85%	455,196	0.9%	0.75%	302,751	0.6%	0.50%
Land-Based Nonroad Diesel	893,320	1.0%	0.93%	483,358	0.9%	0.80%	310,258	0.6%	0.51%
Marine Diesel	6,293	0.01%	0.01%	8,705	0.02%	0.01%	9,565	0.02%	0.02%
Commercial Marine	123,806	0.14%	0.13%	147,449	0.28%	0.24%	158,517	0.30%	0.26%
Locomotive	99,292	0.11%	0.10%	112,747	0.22%	0.19%	117,785	0.23%	0.19%
Aircraft	263,232	0.30%	0.27%	305,998	0.59%	0.51%	327,720	0.63%	0.54%
Total Off Highway	25,261,013	28.9%	26.2%	18,908,505	36.5%	31.2%	19,503,428	37.3%	32.0%
Total Highway	62,083,222	71.1%	64.4%	32,912,028	63.5%	54.4%	32,752,093	62.7%	53.8%
Total Mobile Sources	87,344,234	100.0%	90.6%	51,820,533	100.0%	85.6%	52,255,521	100.0%	85.8%
Stationary Point and Area Sources	9,014,249	-	9.4%	8,734,963	-	14.4%	8,641,678	-	14.2%
Total Man-Made Sources	96,358,483	-	100.0%	60,555,496	-	100.0%	60,897,199	-	100.0%

3.4 Controlled Nonroad Small Spark-Ignition and Marine Engine Emission Inventory Development

This section describes how the controlled emission inventories were developed for the small nonroad and Marine SI engines that are subject to the proposal. The resulting controlled emission inventories are also presented. Section 3.4.1 provides this information for exhaust and evaporative emissions.

Once again, the inventory estimates presented throughout this section only include equipment that would be subject to the proposed standards. Specifically for California, this includes small nonroad SI engines used in farm and construction equipment with maximum power levels below 175 hp or 130 kW. For Marine SI engines, our analysis assumes that the proposed standards have no effect because that state already has equivalent exhaust emission standards and is expected to adopt equivalent evaporative hydrocarbon requirements.

3.4.1 Controlled Exhaust and Evaporative Emissions Estimates for THC, NOx, $PM_{2.5}$, PM_{10}, and CO

The controlled exhaust and evaporative emission inventories for small nonroad and Marine SI engines include the effects of the proposed requirements and all existing applicable federal emission standards. We generated these inventories by modifying NONROAD2005c to account for the engine and equipment controls associated with the proposed standards. (See the baseline emission inventory discussion in Section 3.2 for the changes we made to the publically available NONROAD2005a model to develop NONROAD2005c.) The modifications that were made to estimate the controlled emissions inventories are described below.

3.4.1.1 Controlled Exhaust Emission Standards, Zero-Hour Emission Factors and Deterioration Rates

3.4.1.1.1 Small SI Exhaust Emission Calculations

The proposed Phase 3 emission standards and implementation schedule are shown in Table 3.4-1. While the standards are proposed to take effect in 2011 for Class II engines and 2012 for Class I engines, we proposing a number of flexibilities for engine and equipment manufacturers that will allow the continued production and use of engines meeting the Phase 2 standards in limited numbers over the first four years of the Phase 3 program. The implementation schedule shown in the table is used for modeling purposes only. It is based on our assumption that engine and equipment manufacturers take full advantage of the flexibilities being proposed.

Table 3.4-1: Phase 3 Emission Standards and Estimated Implementation Schedule for Class I and II Small SI Engines[a] (g/kW-hr or Percent)

Engine Class	Requirement	2011	2012	2013	2014	2015+
Class I	HC+NOx	--	10	10	10	10
	CO (marine generator sets only)	--	5	5	5	5
	Estimated Sales Percentage	--	95	95	100	100
Class II	HC+NOx	8	8	8	8	8
	CO (marine generator sets only)	5	5	5	5	5
	Estimated Sales Percentage	83	83	93	93	100

[a] Reflects maximum use of proposed compliance flexibilities by engine and equipment manufacturers. Used for modeling purposes only.

The modeled emission factors corresponding to the proposed Phase 3 standards are shown in Table 3.4-2. (See Section 3.2.1.2.1 for a discussion of how the model uses zero hour emission levels (ZML) and deterioration rates (A values.) We developed these new emission factors based on testing of catalyst-equipped engines both in the laboratory and in-use. A full description of the emission factor information for Phase 3 engines and the basis for the estimates can be found in the docket for this rule.

Table 3.2-2: Phase 3 Modeling Emission Factors for Small SI Engines (g/kW-hr)

Class/ Technology	HC ZML	HC "A"	NOx ZML	NOx "A"	CO ZML	CO "A"	PM10 ZML*	PM10 "A"*
Class I - SV	5.60	0.797	1.47	0.302	319.76	0.070	0.24	1.753
Class I - OHV	5.09	0.797	1.91	0.302	325.06	0.070	0.05	1.753
Class II	4.25	0.797	1.35	0.302	391.13	0.080	0.08	1.095

* The nonroad model calculates PM2.5 as 92 percent of PM10.

We left the proportion of sales in each technology classification unchanged from those used for Phase 2 engines. The technology mix was previously shown Table 3.2-2.

Finally, as discussed in more detail in Chapter 6, were developed a new brake-specific fuel consumption (BSFC) estimate for Class II engines to reflect the expected fuel consumption benefit associated with the use of additional electronic fuel injection technology on Phase 3 compliant engines. The resulting BFSC for Phase 3 Class II engines is 0.727 pounds per horsepower-hour (lb/hp-hr).

3.4.1.1.2 Marine SI Exhaust Emission Calculations

For the control case, we developed new technology classifications for engines meeting the proposed standards. For outboards and personal watercraft, we no longer will attempt to determine the technology mix between low emitting technology options (such as DI 2-stroke versus 4 stroke). The new technology classifications for these engines are simply tied to the standard. These new technology classifications are titled MO09 and MP09 for outboards and personal watercraft, respectively. In determining the combined HC+NOx emission factor, we used the proposed emission standards with a 10 percent compliance margin (with deterioration factor applied). To determine the NOx emission factors, we used certification data to determine the sales weighted average NOx for low emission technologies in each power bin. HC was then determined as the difference between the HC+NOx and the NOx emission factors. Because we are proposing the same standards for OB and PWC and because they use similar engines, we use the same HC+NOx emission factors and deterioration factors for both engine types.

Because the proposed CO standard primarily acts as a cap on CO, the CO emission factors were determined based on the emission factors for existing low emission engines in each power bin. Fuel consumption factors were calculated in the same manner. Therefore, some differences are seen between the projected CO and BSFC factors for OB and PWC. No changes were made to the PM emission factors. Also, the existing deterioration factors for 4-stroke carbureted engines were applied to the control case (1.05 for HC, NOx, and CO). Table 3.4-3 presents the zero-hour OB/PWC emission factors for the control case.

Table 3.4-3: Control Case Emission Factors for OB/PWC (g/kW-hr)

Power Bin	HC	NOx	CO		BSFC	
			OB	PWC	OB	PWC
0-2.2 kW	18.8	4.8	542	640	563	563
2.3-4.5 kW	17.4	3.6	357	538	560	560
4.6-8.2 kW	16.7	5.6	292	243	555	555
8.3-11.9 kW	14.4	6.8	248	231	552	552
12.0-18.6 kW	15.3	4.3	205	218	543	543
18.7-29.8 kW	11.9	5.7	180	206	528	528
29.9-37.3 kW	9.1	5.9	171	206	507	507
37.4-55.9 kW	8.3	5.4	173	206	471	486
55.9-74.6 kW	8.3	5.4	173	206	471	486
74.7-130.5 kW	8.7	5.0	152	202	415	394
130.6+ kW	10.0	3.7	139	178	387	380

For sterndrive and inboards, we developed a new engine classification similar to the OB/PWC discussion above. MS4A applies to SD/I engines meeting the proposed standard through the use of aftertreatment. HC and NOx emission factors are based on test data presented in Chapter 4 for SD/I engines equipped with catalysts. CO emission factors are based on meeting the proposed standard at the end of useful life (with the deterioration factor applied). No emission reductions are modeled for PM. The fuel consumption factor for fuel-injected 4-stroke SD/I engines is applied to the control case. Deterioration factors for catalyst-equipped engines are the same as those used in the NONROAD2005a model for catalyst-equipped large SI engines. Table 3.4-4 presents the zero-hour emission factors and the accompanying deterioration factors for the control case.

Table 3.4-4: Control Case EFs (g/kW-hr) and DFs for SD/I

Engine Category	HC		NOx		CO		BSFC
	EF	DF	EF	DF	EF	DF	
All (MS4A)	1.80	1.64	1.60	1.15	55.0	1.36	345

3.4.1.2 Controlled Evaporative Emission Rates

Below, we present the effect of the proposed evaporative emission standards on hose permeation, tank permeation, diurnal, and running loss emission inventories.

3.4.1.2.1 Hose Permeation

Similar to the baseline case, hose permeation rates are based on g/m^2/day and are modeled as a function of temperature. The fuel hose test procedures are based on Fuel CE10 as a test fuel. Based on data presented in Chapter 5, we would expect in-use emissions on gasoline-based E10 to be about half of the measured level on Fuel CE10. In addition, we believe that hose designed to meet the proposed 15 g/m^2/day standard on 10 percent ethanol fuel will permeate at least 50 percent less when gasoline is used. Therefore, we model permeation from hoses designed to meet 15 g/m^2/day on Fuel CE10 to be 7.5 g/m^2/day on E10 and 3.75 g/m^2/day on gasoline at 23°C. Consistent with the baseline emission case, we weight the gasoline and E10 emission factors by our estimates of gasoline sales with and without ethanol added.

Fill neck and vent hose containing vapor rather than liquid fuel are not subject to the proposed standards. Neither is hose on handheld equipment with winter use applications (e.g. handheld Class V chainsaws). No emission reductions are modeled for these hose types.

3.4.1.2.2 Tank Permeation

Similar to the baseline case, fuel tank permeation rates are based on units of g/m^2/day and are modeled as a function of temperature. We believe that fuel tanks using alternative materials to meet the proposed 1.5 g/m^2/day standard on 10 percent ethanol fuel will typically permeate at least 50 percent less when gasoline is used. Therefore, we model permeation from fuel tanks to be 1.5 g/m^2/day on fuel E10 and 0.75 g/gal/day at 29°C, regardless of fuel used.

Two exceptions to the above discussion are nylon tanks used on handheld equipment and metal tanks. For these fuel tanks, we do not include any emissions reductions from baseline.

3.4.1.2.3 Diurnal

We are not proposing a diurnal emission requirement for Small SI equipment. Therefore, we do not model direct reductions in diurnal emissions. However, we are proposing a limit on diffusion emissions. As a result, we set the diffusion multiplier to 1.0 for all non-handheld Small SI equipment for the control case. Note that this multiplier was already set to 1.0 for handheld equipment in the baseline case. This is equivalent to applying a 32 percent reduction to the diurnal emission factors.

In the control case for marine, we model portable fuel tanks as having 90 percent lower diurnal emissions than an open vent system. Also, we set the diffusion multiplier to 1.0 because the tanks would be sealed. Presumably, the diurnal temperature cycles would build some pressure in the fuel tank causing hydrocarbons to be released when the tank is opened. Therefore, we do not model these tanks as having zero diurnal emissions. For PWC, we use the baseline scenario of sealed systems with a 1.0 psi pressure relief valve. For installed fuel tanks, we model a 60 percent reduction due to a carbon canister in the fuel line with passive purge. This reduction is based on data presented in Chapter 5. As in the baseline case, no diffusion is modeled for PWC and installed fuel tanks.

3.4.1.2.4 Running Loss

For Class I engines, we believe that the proposed running loss control requirement will be met by routing vapor from the fuel take to the engine air intake system. Therefore, all vapor generated in the fuel tank should be consumed by the engine, thereby eliminating running loss emissions. However, there may be some inefficiencies in the system such as vapor escaping out the intake at idle. Therefore, we model the running loss emission reduction as only 90 percent. For Class II equipment, we believe that some equipment will inherently meet the proposed standard because they will have low enough temperature fluctuation in the fuel tanks during operation to certify by design. Based on the data presented in Chapter 5 on fuel tank temperatures during operation, we estimate an 80 percent reduction in running loss for Class II equipment.

3.4.1.3 Controlled Exhaust and Evaporative Inventory Results for THC, NOx, $PM_{2.5}$, PM_{10}, CO and SO_2

Tables 3.4-5 presents the 50-state controlled emission inventories, respectively, for small nonroad SI engines. Tables 3.4-6 provides the same information for Marine SI engines.

Table 3.4-5: Controlled 50-State Annual Exhaust and Evaporative Emissions for Small Nonroad Spark-Ignition Engines (short tons)

Year	THC	NOx	PM2.5	PM10	CO
2001	1,099,402	101,928	23,163	25,177	16,108,103
2002	1,074,137	101,261	23,382	25,416	15,560,774
2003	1,039,522	99,649	23,480	25,522	14,941,296
2004	978,760	97,929	23,483	25,525	14,382,759
2005	905,814	95,779	23,417	25,453	13,784,367
2006	849,619	94,550	23,498	25,541	13,369,719
2007	794,827	92,988	23,804	25,874	12,919,586
2008	743,099	90,638	24,335	26,451	12,285,206
2009	705,099	89,272	24,882	27,045	11,775,265
2010	683,397	88,968	25,402	27,611	11,492,162
2011	653,532	80,103	25,888	28,139	11,091,811
2012	605,062	72,135	26,037	28,301	10,733,334
2013	562,800	65,271	26,172	28,447	10,467,631
2014	535,060	61,428	26,344	28,635	10,363,567
2015	519,198	58,117	26,647	28,965	10,317,051
2016	509,608	56,053	26,985	29,332	10,334,605
2017	506,270	55,149	27,353	29,732	10,408,287
2018	507,491	54,869	27,751	30,164	10,515,612
2019	511,030	54,946	28,159	30,607	10,642,994
2020	515,956	55,241	28,574	31,058	10,782,258
2021	522,022	55,772	28,993	31,515	10,932,278
2022	528,733	56,409	29,416	31,974	11,087,748
2023	535,947	57,121	29,842	32,437	11,247,239
2024	543,403	57,866	30,270	32,902	11,408,690
2025	550,981	58,643	30,699	33,368	11,572,096
2026	558,690	59,447	31,128	33,835	11,738,240
2027	566,466	60,268	31,559	34,303	11,905,720
2028	574,280	61,097	31,989	34,770	12,073,845
2029	582,125	61,934	32,419	35,238	12,242,505
2030	590,000	62,778	32,849	35,706	12,411,661
2031	597,896	63,627	33,280	36,173	12,581,170
2032	605,803	64,479	33,710	36,641	12,750,877
2033	613,723	65,333	34,140	37,109	12,920,739
2034	621,652	66,188	34,571	37,577	13,090,731
2035	629,588	67,045	35,001	38,044	13,260,842
2036	637,536	67,905	35,431	38,512	13,431,126
2037	645,494	68,767	35,862	38,980	13,601,583
2038	653,458	69,631	36,292	39,448	13,772,142
2039	661,426	70,496	36,722	39,915	13,942,788
2040	669,399	71,361	37,153	40,383	14,113,517

Table 3.4-6: Controlled 50-State Annual Exhaust and Evaporative Emissions for Marine Spark-Ignition Engines (short tons)

Year	THC	NOx	PM2.5	PM10	CO
2001	935,494	41,514	15,625	16,984	2,584,786
2002	909,607	43,401	15,092	16,404	2,552,368
2003	877,441	45,661	14,417	15,670	2,510,927
2004	841,151	48,164	13,679	14,869	2,469,934
2005	801,985	50,675	12,886	14,007	2,423,497
2006	762,092	53,207	12,090	13,142	2,375,768
2007	724,443	55,750	11,311	12,295	2,328,182
2008	687,350	58,296	10,553	11,470	2,280,928
2009	634,175	58,835	9,508	10,335	2,214,580
2010	582,548	59,308	8,520	9,261	2,150,304
2011	532,769	59,541	7,584	8,243	2,086,638
2012	485,231	59,635	6,733	7,319	2,028,270
2013	441,421	59,547	5,978	6,497	1,976,179
2014	401,152	59,336	5,286	5,746	1,927,610
2015	364,619	59,024	4,666	5,072	1,883,241
2016	330,888	58,595	4,099	4,455	1,842,019
2017	300,138	58,051	3,588	3,900	1,804,951
2018	272,927	57,378	3,143	3,416	1,772,827
2019	249,343	56,577	2,767	3,007	1,743,893
2020	228,847	55,656	2,448	2,661	1,718,956
2021	210,304	54,638	2,164	2,352	1,696,117
2022	194,021	53,570	1,920	2,087	1,676,245
2023	180,805	52,527	1,729	1,880	1,659,281
2024	169,904	51,497	1,577	1,714	1,644,771
2025	160,668	50,466	1,452	1,578	1,632,439
2026	152,898	49,451	1,348	1,465	1,622,175
2027	146,673	48,468	1,267	1,377	1,614,086
2028	141,435	47,561	1,200	1,304	1,608,064
2029	137,294	47,142	1,148	1,248	1,606,899
2030	134,028	46,859	1,107	1,203	1,607,678
2031	131,342	46,691	1,073	1,166	1,610,007
2032	129,305	46,590	1,046	1,137	1,613,454
2033	127,751	46,531	1,025	1,114	1,617,823
2034	126,621	46,503	1,010	1,097	1,622,954
2035	125,891	46,508	999	1,086	1,628,820
2036	125,434	46,536	992	1,079	1,635,236
2037	125,187	46,587	988	1,074	1,642,153
2038	125,113	46,659	986	1,071	1,649,518
2039	125,179	46,755	985	1,070	1,657,283
2040	125,343	46,874	985	1,071	1,665,392

3.4.2 Controlled Hazardous Air Pollutant Estimates

The proposed hydrocarbon emission standards for small nonroad and Marine SI engines will also reduce toxic air pollutants. To calculate the controlled toxic air emission inventories, we used the same methodology that was used for the baseline inventories along with the results of the controlled emission inventories for VOC or PM, as appropriate. The methodology is described in Section 3.2.

Controlled inventories were calculated for the seven major types of air toxic emissions: benzene, formaldeyde, acetaldehyde, 1,3-butadiene, acrolein, napthalene, and 15 other compounds grouped together as polycyclic organic matter (POM) for this analysis.[4] Table 3.4-7 presents the 50-state controlled inventories, respectively, small nonroad SI engines. Table 3.4-8 provide the same information for Marine SI engines.

Table 3.4-7: Controlled 50-State Air Toxic Emissions for Small Nonroad Spark-Ignition Engines (short tons)

Year	Benzene	1,3 Butadiene	Formalde-hyde	Acetalde-hyde	Acrolein	Naptha-lene	POM
2001	33,534	5,165	8,035	2,826	462	418	93
2020	16,018	2,214	3,621	1,697	189	286	102
2030	18,341	2,535	4,146	1,941	216	329	118

Table 3.4-8: Controlled 50-State Air Toxic Emissions for Marine Spark-Ignition Engines (short tons)

Year	Benzene	1,3 Butadiene	Formalde-hyde	Acetalde-hyde	Acrolein	Naptha-lene	POM
2001	21,590	1,790	1,846	1,354	179	32	30
2020	4,890	371	324	356	25	17	7
2030	3,117	230	200	223	15	12	4

3.5 Projected Emissions Reductions from the Proposed Rule

This section presents the projected total emission reductions associated with the proposed rule. We calculated the reductions by subtracting the baseline inventories from Section 3.2 by the controlled inventories from Section 3.4.

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[4] The 15 POMs summarized in this chapter are acenaphthene, acenapthylene, anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylkene, beno(k)fluoranthene, chrysene, dibenzo(a,h)anthracene,fluoranthene, fluorene, ideno(1,2,3,c,c)-pyrene, phenanthrene, and pyrene.

3.5.1 Results for THC, NOx, $PM_{2.5}$, PM_{10}, and CO

Tables 3.5-1 presents the 50-state exhaust and evaporative emission inventories and percent reductions, respectively, for small nonroad SI engines. Tables 3.5-2 provides the same information for Marine SI engines. Tables 3.5-3 summarizes the combined emission reductions for the proposal. The earliest proposed Phase 3 standards for small nonroad SI engines begin in 2008. Similar proposed standards affect Marine SI engines one year later. Therefore the emission reductions are shown beginning in 2008 for small nonroad SI engines and 2009 for Marine SI engines. Figures 3.5-1 though 3.5-6 show the combined baseline, controlled, and by contrast the reduction emission inventories over time for small nonroad and Marine SI engines.

Table 3.5-1: Total 50-State Annual Exhaust and Evaporative Emission Reductions for Small SI Spark-Ignition Engines (short tons)

Year	THC		NOx		PM2.5		PM10		CO	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2008	4,935	1	0	0	0	0	0	0	0	0
2009	10,844	2	0	0	0	0	0	0	0	0
2010	17,085	2	0	0	0	0	0	0	0	0
2011	44,949	6	9,440	11	0	0	0	0	334,555	3
2012	95,920	14	18,305	20	327	1	356	1	705,503	6
2013	143,686	20	26,336	29	661	2	718	2	1,049,398	9
2014	179,908	25	31,545	34	947	3	1,029	3	1,281,497	11
2015	205,497	28	36,315	38	1,100	4	1,195	4	1,480,027	13
2016	225,684	31	39,906	42	1,216	4	1,322	4	1,630,861	14
2017	240,176	32	42,370	43	1,301	5	1,414	5	1,735,277	14
2018	250,529	33	44,232	45	1,356	5	1,474	5	1,812,911	15
2019	258,899	34	45,754	45	1,399	5	1,521	5	1,876,142	15
2020	266,030	34	47,069	46	1,435	5	1,560	5	1,930,518	15
2021	272,051	34	48,150	46	1,466	5	1,594	5	1,975,208	15
2022	277,458	34	49,124	47	1,495	5	1,624	5	2,015,250	15
2023	282,389	35	50,024	47	1,520	5	1,652	5	2,051,946	15
2024	287,093	35	50,893	47	1,543	5	1,677	5	2,087,252	15
2025	291,705	35	51,737	47	1,566	5	1,702	5	2,121,545	15
2026	296,331	35	52,572	47	1,590	5	1,728	5	2,155,582	16
2027	300,923	35	53,398	47	1,614	5	1,754	5	2,189,270	16
2028	305,489	35	54,217	47	1,638	5	1,780	5	2,222,715	16
2029	310,032	35	55,030	47	1,662	5	1,807	5	2,255,912	16
2030	314,553	35	55,837	47	1,686	5	1,833	5	2,288,860	16
2031	319,057	35	56,640	47	1,710	5	1,859	5	2,321,627	16
2032	323,554	35	57,440	47	1,734	5	1,885	5	2,354,303	16
2033	328,042	35	58,238	47	1,758	5	1,911	5	2,386,904	16
2034	332,523	35	59,035	47	1,782	5	1,937	5	2,419,451	16
2035	336,999	35	59,830	47	1,806	5	1,963	5	2,451,948	16
2036	341,467	35	60,623	47	1,830	5	1,989	5	2,484,331	16
2037	345,926	35	61,412	47	1,854	5	2,015	5	2,516,608	16
2038	350,382	35	62,201	47	1,878	5	2,042	5	2,548,836	16
2039	354,835	35	62,988	47	1,902	5	2,068	5	2,581,029	16
2040	359,285	35	63,775	47	1,926	5	2,094	5	2,613,191	16

Table 3.5-2: Total 50-State Annual Exhaust and Evaporative Emission Reductions for Marine SI Spark-Ignition Engines (short tons)

Year	THC		NOx		PM2.5		PM10		CO	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2009	17,569	3	1,962	3	315	3	343	3	20,607	1
2010	36,295	6	3,920	6	629	7	683	7	41,179	2
2011	55,514	9	6,072	9	941	11	1,023	11	62,769	3
2012	76,468	14	8,208	12	1,250	16	1,359	16	84,241	4
2013	97,088	18	10,336	15	1,556	21	1,692	21	105,767	5
2014	117,463	23	12,453	17	1,858	26	2,019	26	127,160	6
2015	137,688	27	14,558	20	2,157	32	2,344	32	148,443	7
2016	157,614	32	16,650	22	2,450	37	2,663	37	169,550	8
2017	177,149	37	18,730	24	2,737	43	2,975	43	190,368	10
2018	196,113	42	20,792	27	3,013	49	3,275	49	210,784	11
2019	212,803	46	22,892	29	3,246	54	3,528	54	230,404	12
2020	228,491	50	24,999	31	3,461	59	3,762	59	249,707	13
2021	243,383	54	27,131	33	3,662	63	3,981	63	268,906	14
2022	257,338	57	29,226	35	3,849	67	4,183	67	287,643	15
2023	269,076	60	31,228	37	3,997	70	4,344	70	305,376	16
2024	279,185	62	33,166	39	4,119	72	4,477	72	322,243	16
2025	288,385	64	35,051	41	4,228	74	4,596	74	338,585	17
2026	296,713	66	36,877	43	4,327	76	4,703	76	354,383	18
2027	303,966	67	38,628	44	4,411	78	4,795	78	369,306	19
2028	310,552	69	40,267	46	4,487	79	4,877	79	383,267	19
2029	316,315	70	41,395	47	4,553	80	4,949	80	393,085	20
2030	321,452	71	42,366	47	4,613	81	5,014	81	401,570	20
2031	326,194	71	43,206	48	4,668	81	5,074	81	409,021	20
2032	330,420	72	43,964	49	4,719	82	5,130	82	415,773	20
2033	334,319	72	44,666	49	4,767	82	5,181	82	422,048	21
2034	337,908	73	45,325	49	4,811	83	5,230	83	427,929	21
2035	341,188	73	45,940	50	4,852	83	5,274	83	433,425	21
2036	344,251	73	46,524	50	4,890	83	5,315	83	438,637	21
2037	347,161	73	47,077	50	4,927	83	5,355	83	443,584	21
2038	349,942	74	47,602	51	4,962	83	5,394	83	448,279	21
2039	352,617	74	48,098	51	4,997	84	5,431	84	452,729	21
2040	355,217	74	48,567	51	5,031	84	5,468	84	456,943	22

Table 3.5-3: Total 50-State Annual Exhaust and Evaporative Emission Reductions for Small Nonroad and Marine SI Spark-Ignition Engines (short tons)

Year	THC		NOx		PM2.5		PM10		CO	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2008	4,935	0	0	0	0	0	0	0	0	0
2009	28,413	2	1,962	1	315	1	343	1	20,607	0
2010	53,380	4	3,920	3	629	2	683	2	41,179	0
2011	100,463	8	15,512	10	941	3	1,023	3	397,324	3
2012	172,387	14	26,513	17	1,578	5	1,715	5	789,744	6
2013	240,774	19	36,672	23	2,217	6	2,410	6	1,155,165	8
2014	297,371	24	43,998	27	2,805	8	3,049	8	1,408,656	10
2015	343,185	28	50,874	30	3,256	9	3,539	9	1,628,471	12
2016	383,298	31	56,556	33	3,666	11	3,985	11	1,800,412	13
2017	417,325	34	61,099	35	4,038	12	4,389	12	1,925,645	14
2018	446,643	36	65,024	37	4,369	12	4,749	12	2,023,696	14
2019	471,702	38	68,646	38	4,645	13	5,049	13	2,106,545	15
2020	494,520	40	72,069	39	4,896	14	5,322	14	2,180,225	15
2021	515,434	41	75,281	41	5,129	14	5,575	14	2,244,115	15
2022	534,797	43	78,350	42	5,343	15	5,808	15	2,302,893	15
2023	551,465	43	81,252	43	5,516	15	5,996	15	2,357,322	15
2024	566,279	44	84,059	43	5,662	15	6,154	15	2,409,495	16
2025	580,091	45	86,788	44	5,794	15	6,298	15	2,460,130	16
2026	593,044	45	89,448	45	5,917	15	6,431	15	2,509,965	16
2027	604,889	46	92,025	46	6,025	16	6,549	16	2,558,576	16
2028	616,041	46	94,484	47	6,125	16	6,658	16	2,605,982	16
2029	626,348	47	96,425	47	6,215	16	6,755	16	2,648,997	16
2030	636,005	47	98,203	47	6,299	16	6,847	16	2,690,429	16
2031	645,251	47	99,845	48	6,379	16	6,933	16	2,730,649	16
2032	653,974	47	101,403	48	6,454	16	7,015	16	2,770,076	16
2033	662,361	47	102,904	48	6,525	16	7,092	16	2,808,952	16
2034	670,431	47	104,360	48	6,593	16	7,167	16	2,847,380	16
2035	678,187	47	105,770	48	6,658	16	7,237	16	2,885,372	16
2036	685,717	47	107,146	48	6,720	16	7,305	16	2,922,968	16
2037	693,087	47	108,489	48	6,781	16	7,371	16	2,960,192	16
2038	700,324	47	109,803	49	6,841	16	7,436	16	2,997,115	16
2039	707,452	47	111,087	49	6,899	15	7,499	15	3,033,757	16
2040	714,503	47	112,342	49	6,957	15	7,562	15	3,070,134	16

Note: annualized tons (2008-2038) for HC and NOx are 374,500 and 55,800 at a 7% discount and 431,800 and 64,800 at a 3% discount.

Figure 3.5-1: 50-State Annual THC Exhaust and Evaporative Emissions for Small SI and Marine SI

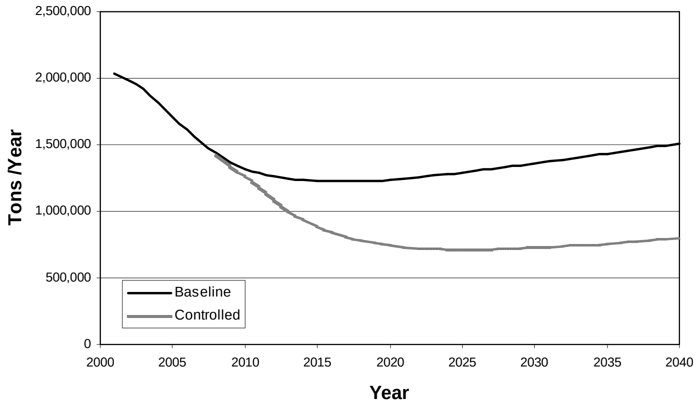


Figure 3.5-2: 50-State Annual NOx Exhaust Emissions for Small SI and Marine SI

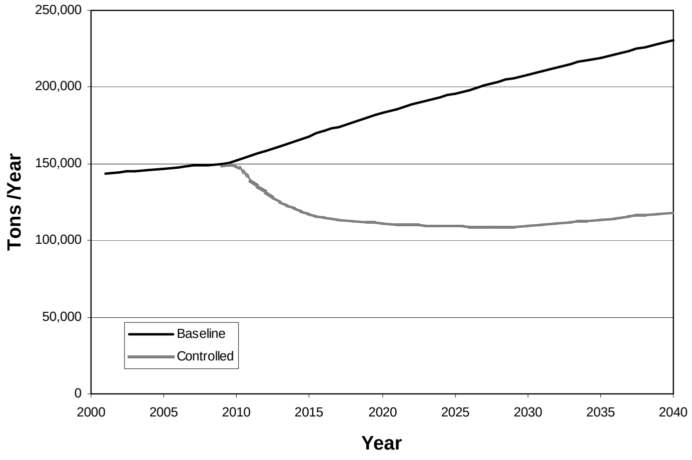


Figure 3.5-3: 50-State Annual PM2.5 Exhaust Emissions for Small SI and Marine SI

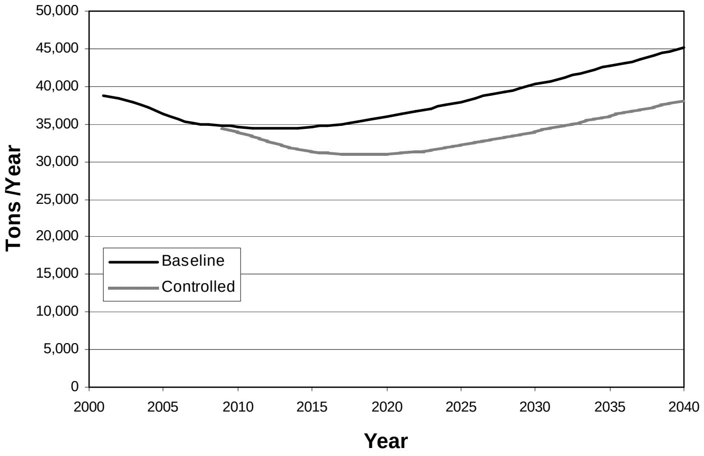


Figure 3.5-4: 50-State Annual PM10 Emissions for Small SI and Marine SI Engines

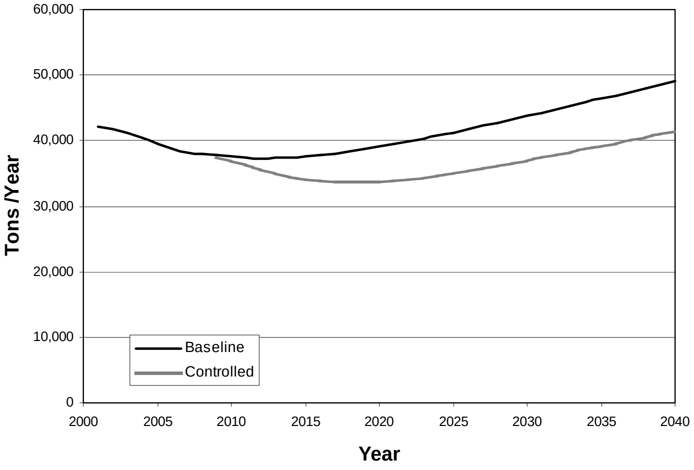
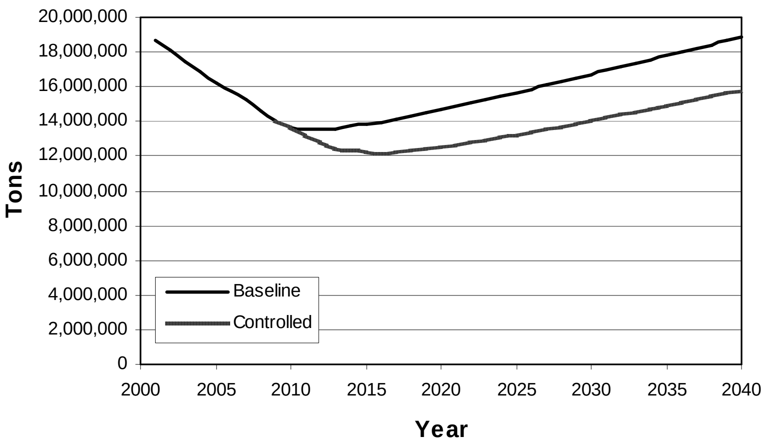


Figure 3.4-5: 50-State Annual CO Emissions from Small SI and Marine SI Engines



3.5.2 Results for Hazardous Air Pollutants

Tables 3.5-4 presents the 50-state exhaust and evaporative air toxics emission inventory and percent reductions, respectively, for small nonroad SI engines that are expected to accompany the proposed standards. Table 3.5-5 provides the same information for Marine SI engines. Tables 3.5-6 summarizes the combined hazardous air pollutant reductions for the proposal. These results are displayed for 2020 and 2030, when most or all of the engines subject to the proposed standards are represented in the respective fleets.

Table 3.5-4: 50-State Air Toxic Emission Reductions for Small Nonroad Spark-Ignition Engines (short tons)

Year	Benzene		1,3 Butadiene		Formaldehyde		Acetaldehyde		Acrolein		Napthalene		POM	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2020	6,906	30	955	30	1,561	30	732	30	81	30	123	30	5	4
2030	8,160	31	1,128	31	1,845	31	864	31	96	31	146	31	6	5

Table 3.5-5: 50-State Air Toxic Emission Reductions for Marine Spark-Ignition Engines (short tons)

Year	Benzene		1,3 Butadiene		Formaldehyde		Acetaldehyde		Acrolein		Napthalene		POM	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2020	4,254	47	323	47	282	47	310	47	22	47	15	47	8	54
2030	5,955	66	440	66	382	66	426	66	30	66	23	66	11	75

Table 3.5-6: 50-State Air Toxic Emission Reductions for Small Nonroad and Marine Spark-Ignition Engines (short tons)

Year	Benzene		1,3 Butadiene		Formaldehyde		Acetaldehyde		Acrolein		Napthalene		POM	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2020	11,160	35	1,278	33	1,843	32	1,041	34	103	33	138	31	13	10
2030	14,116	40	1,567	36	2,227	34	1,290	37	126	35	169	33	17	12

3.6 Emission Inventories Used for Air Quality Modeling

This section describes the methodology we used to develop the emission inventories for the air quality modeling. The inventories represent emissions for the summer ozone season (i.e., June, July, and August) in calendar years 2001, 2015, 2020, and 2030. Emissions were estimated are for 37 of the most eastern states, which is the geographic area of the air quality modeling domain.

The emission inputs for the air quality modeling are required early in the analytical process to ensure there is adequate time to complete the analysis and incorporate the results into the rulemaking process. Given that lead time requirement, air quality modeling is often based analytical methods that may be superceded or on a control scenario that does not specifically match the final set of emission standards. Indeed, for this proposed rulemaking both instances have occurred. Therefore, this section also describes the changes to our emission inventory models, modeling inputs, and resulting emission inventories between the preliminary baseline and control scenarios used for the air quality modeling, and the updated final baseline and control scenarios for the proposed rule.

3.6.1 Methodology for Air Quality Modeling

The air quality modeling for the proposal is in large part taken from the work performed for EPA's Clean Air Interstate Rule (CAIR) for stationary sources.[22] This approach was adopted to be consistent with, what was then, EPA's most recent ozone-related rulemaking and to conserve resources by taking advantage of the existing inventory preparation (i.e., input files) and results. The CAIR modeling domain consists of 37 states in the eastern U.S. and the District of Columbia. Emission inventories were developed for the following pollutants: VOC, NOx, PM2.5, PM10, CO, SOx, and NH3. Air quality results were generated for the summer ozone season (i.e., June, July, and August) and the CAIR calendar years 2001, 2015, and 2020. We also modeled calendar year 2030 specifically for this proposal as described below.

The special 2030 calendar year model simulation was performed by preparing CAIR-like emission inventories for all source categories. For non-mobile sources, we simply carried forward the inventories from 2020. For mobile sources, we prepared highway and off- highway inventories for 2030 using the same methodology that was used to prepare the CAIR inventories for the previous calendar years.

The emissions inventory methodology and results for the nonroad sources and the results for small nonroad and Marine SI engines are in the docket for this proposed rule.[23,24,25,26]

3.6.2 Baseline Scenario Emission Inventories

Our preliminary baseline emission inventories without the proposed controls for small nonroad and Marine SI engines were the same as the CAIR rule's "control" scenario. A special version of the draft NONROAD2004 model was used to generate the nonroad engine inventories for that rule. That version of the model is referred to as NONROAD2004n. It is identical to the draft NONROAD2004 model, which was the most recent publically available nonroad model at the time, except for a modification to allow a separate diesel fuel sulfur value for marine equipment (an unremarkable feature relative to the proposed rule). NONROAD2004n was executed within the framework of EPA's National Mobile Source Inventory Model (NMIM) that links a county-level database to model and collates the output into a single database table. The resulting estimates for nonroad and Marine SI engines account for local differences in fuel characteristics and temperatures. NONROAD2004n is discussed in more detail later in this section.

Table 3.6-1 presents the preliminary 37-state baseline inventories for VOC, NOx, PM2.5, PM10, and CO during the 3-month summer ozone season that were used in the air quality modeling for small nonroad and Marine SI engines.[5] These values are an aggregation of the county-level NMIM results.

Table 3.6-1 37-State Preliminary Baseline Scenario Emissions for Air Quality Modeling

Application	Year	VOC	PM_{10}	$PM_{2.5}$	NOx	CO
Small Nonroad SI Subject to the Proposal	2001	264,951	6,738	6,199	37,466	4,795,058
	2020	156,401	7,968	7,330	31,477	6,660,408
	2030	179,717	9,114	8,385	36,084	7,691,956
Marine SI	2001	264,951	18,397	16,925	18,576	927,890
	2020	162,488	13,930	12,815	33,061	904,964
	2030	157,380	14,534	13,371	36,332	949,504

The final baseline inventories for the proposal were estimated with a special version of the NONROAD2005a model, which is the newest public release of our nonroad model. This special version is named NONROAD2005c. Generally, we revised the model to incorporate new test results for nonhandheld Small SI engines that comply with the existing Phase 2 standards. Also, the model was modified to acknowledge the continued use of side-valve engine designs in Class I nonhandheld engines meeting those standards. In the Phase 2 rulemaking for small nonroad SI engines, side-valve technology was assumed to be superceded by overhead valve designs and was modeled accordingly. In reality, side-valve technology has continued to be used in small nonroad SI engines. The revisions we made to develop this new version is also described in Section 3.2.

Table 3.6-2 compares the preliminary and final 37-state baseline scenario inventories for

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[5] Inventories for SOx and NH4 are not important for the purposes of this discussion and can be found in the docket along with information on the other pollutants presented here. See reference 26.

small nonroad and Marine SI engines. This information is presented primarily for information purposes, since it is the percentage difference between a model's baseline and control scenario that is used for comparing the inventories from the final proposal to those used in the air quality modeling as discussed further in Section 3.6.3. As shown, the difference in the baseline scenarios between the two models ranges from about -2 percent for VOC in 2020 to about 50 percent for PM2.5 in 2020 for the combined Small SI engine and Marine SI engine categories.

Table 3.6-2: Comparison of 37-State Baseline Scenario Emissions for Preliminary Air Quality Modeling and Final Proposal

Applications	Year	VOC [short tons]			NO_x [short tons]			$PM_{2.5}$ [short tons]		
		Final	Preliminary	**Difference**	Final	Preliminary	**Difference**	Final	Preliminary	**Difference**
Small Nonroad SI Subject to the Proposal	2020	219,404	156,401	**63,003**	26,947	31,477	**(4,530)**	7,946	7,330	**616**
	2030	253,162	179,717	**73,445**	31,101	36,084	**(4,983)**	9,141	8,385	**756**
Marine SI	2020	230,222	162,488	**67,734**	40,949	33,061	**7,888**	3,108	12,815	**(9,707)**
	2030	228,081	157,380	**70,701**	44,949	36,332	**8,617**	3,008	13,371	**(10,363)**
Total	2020	449,626	318,889	**(4,731)**	67,896	64,538	**(12,418)**	11,054	20,146	**10,323**
	2030	481,243	337,096	**2,744**	76,050	72,415	**(13,600)**	12,149	21,756	**11,119**

Table 3.6-2 (Cont'd)
Comparison of 37-State Baseline Scenario Emissions for Preliminary Air Quality Modeling and Final Proposal

Applications	Year	PM_{10} [short tons]			CO [short tons]		
		Final	Preliminary	**Difference**	Final	Preliminary	**Difference**
Small Nonroad SI Subject to the Proposal	2020	8,637	7,968	**669**	3,832,891	6,660,408	**(2,827,517)**
	2030	9,936	9,114	**822**	4,414,165	7,691,956	**(3,277,791)**
Marine SI	2020	3,378	13,930	**(10,552)**	1,040,807	904,964	**135,843**
	2030	3,270	14,534	**(11,264)**	1,061,971	949,504	**112,467**
Total	2020	12,015	21,898	**(9,883)**	4,873,698	7,565,372	**(2,691,674)**
	2030	13,206	23,648	**(10,442)**	5,476,136	8,641,460	**(3,165,324)**

These baseline inventory differences are obviously due to the differences in NONROAD2004n and the special version of the model that we developed for the final proposal, i.e., NONROAD2005c, as well as the inputs to the models. As already mentioned, NONROAD2004n is equivalent to publically available draft NONROAD model with a revision that is insignificant for the purposes of the proposal as described above. The most substantial changes between the two models occurred between publically available NONROAD2004 and the publically available NONROAD2005a. The principle revisions that are relevant to this proposal generally include:

1) All new evaporative emission categories for fuel tank permeation, hose permeation, hot soak, and running losses;
2) Added capability to model emissions using daily values for temperature and gasoline volatility at the national and state level;
3) Revised methodology for calculating diurnal evaporative emissions;
4) Added the effect of evaporative emission standards for recreational vehicles and large spark-ignition engines; and
5) Updated geographic allocation factors to distribute national equipment populations to state and local jurisdictions; and

The additional changes we made from NONROAD2005a to develop NONR2005c for the proposal are important, but less significant. These revisions are described in detail in Section 3.2.

3.6.3 Control Scenario Emission Inventories

At the time we were ready to develop the control scenario for the air quality analysis, our modeling techniques and emission inputs significantly improved beyond NONROAD2004a model, which was used to generate the CAIR-related base case. So we created a special version of NONROAD2004a to better estimate the exhaust and evaporative refueling emissions for small nonroad and Marine SI engines. The special version of the model was designated as NONROAD2004n2. We also created special spreadsheet models to expand and improve our estimates of the other evaporative emissions from these engines, i.e., diurnal (including effusion), running loss, hot soak, and hose and tank permeation.

The principle changes that were incorporated into NONROAD2004n2 for exhaust and refueling emissions are:

1. Updated the estimated sales fractions by engine class and technology to account for the continued sales of Class I Small SI engines using side-valve technology (we assumed these engines would be replaced with overhead-valve technology in the Phase 2 standard rulemaking);
2. Revised emission factors and deterioration rates for Class I Small SI engines subject to Phase 2 standards based on preliminary testing;
3. Updated Marine SI engine population distributions by horsepower category; and
4. Updated Marine SI engine emission factors for hydrocarbons, CO, and NOx.

The principle changes that were incorporated into the spreadsheet models for the other evaporative emissions are:

1. Added all new evaporative emission categories for fuel tank and hose permeation; and
2. Updated the methodology for diurnal evaporative emissions.

These new tools were utilized to derive the preliminary control inventories for the air quality modeling. More specifically, we constructed alternative baseline and control scenarios for small nonroad and Marine SI engines with the NONROAD2004n2 model for exhaust and evaporative refueling emissions, and the new spreadsheet models for the other evaporative emissions. The <u>percent</u> <u>change</u> in emissions from the alternative baseline to the alternative control inventory for each pollutant was then applied to the respective CAIR-related preliminary baseline inventories to generate the preliminary control scenario inventories for the proposed rule. This approach was taken to preserve the existing air quality modeling input files, while still reflecting the full scope of the emission reductions from the proposed rule. This methodology has been documented in detail and a copy of the NONROAD2004n2 model and evaporative emission spreadsheets have been placed in the docket for this proposal.

For this proposal, the specific emission standards and associated control requirements were not fully identified when the air quality modeling was performed. As a result, we modeled a variety of preliminary control scenarios with the improved inventory tools described above to accommodate a range of possible regulatory outcomes. The air quality modeling outcomes for the preliminary scenario that most closely matches the <u>percent</u> <u>change</u> in emissions associated with the final control scenario will be used in Chapter 8 to estimate the health and welfare benefits of the proposal. Using the percentage reduction in emissions to select the appropriate preliminary control scenario matches the methodology that was originally used to develop the preliminary air quality control scenario itself, as described in the preceding paragraph.

Before selecting the preliminary air quality control scenario for our benefits assessment in Chapter 8, we would like to reiterate that the final control scenario inventories for the proposal were estimated with a special version of the NONROAD2005a model, just as we used for the final baseline scenario inventories. It should be noted that NONROAD2005a incorporates and expands upon the modeling improvements described above for NONROADn2 and the evaporative spreadsheet models, which were used to generate the percentage reduction factors associated with the alternative baseline and control scenarios. Of course, the special version reflects further modeling improvements for the proposal. Section 3.6.2 generally describes the changes we made to the NONROAD2005a base model. A more detailed discussion of the special version of the model is also contained in Section 3.2.

Table 3.6-3 compares the percentage emission reductions that are associated with the final control scenario and preliminary air quality control scenario that most closely matches the final scenario for the 37-state modeling domain. The inventories are not shown for 2001 or 2015 because the proposed requirements either have no effect on the inventories, i.e., 2001, or have not yet significantly "rolled over" into the fleet of equipment, i.e., 2015. Also, results are presented only for the two most important pollutants relative to this rule for selection purposes, i.e., VOC and NOx. As shown, the emission reductions are, on average, very close to the final control scenario based on the selection criteria. Therefore, this case is selected as the most representative preliminary control scenario relative to the air quality results associated with the proposal.

Table 3.6-4 directly compares the emission inventories (i.e., tons) for the selected preliminary control scenario to the final control scenario. As previously described, this information is presented primarily for information purposes, since it is the percentage difference between a model's baseline and control scenario that is used for comparing the inventories from the final proposal to those used in the air quality modeling. As shown, the difference in the control scenarios for the two models ranges from about -27 percent for CO in 2030 to about 50 percent for VOC in 2030 for the combined Small SI engine and Marine SI engine categories.

As with the baseline scenarios, the differences in the preliminary and final control scenarios inventories are due to the differences in models and inputs used in the analysis. Unlike the baseline scenario discussion, however, the comparison of these differences is substantially complicated by the use of not just two, but three different modeling platforms, i.e., NONROAD2004n (used for the CAIR-related base case), NONROADn2 and the spreadsheet models (used for the percent reduction factors), and the special version of NONROAD2005a (used for the final control scenario). Generally, the greatest differences result from using the NONROAD2004n model for the preliminary baseline scenario (from which the preliminary control scenario inventories were directly calculated) and the special version of NONROAD2005a model. The differences between these two models is described in Section 3.6.2. We expect that any new air quality modeling that may be needed for the final rule would be based on a single, consistent modeling platform.

Table 3.6-3: Comparison of 37-State Emission Reductions for Small Nonroad and Marine SI Engines for Emission Benefit Analysis Purposes (Tons or Percent Reduction/Year)

Pollutant	Year	Preliminary Proposal (Air Quality Modeling)				Final Proposal			
		Base (tons)	Control (tons)	Reduction (tons)	**Percent Reduction (%)**	Base (tons)	Control (tons)	Reduction (tons)	**Percent Reductio (%)**
VOC	2020	318,889	168,589	150,300	**47**	446,626	252,287	197,339	**44**
	2030	337,096	147,664	189,432	**56**	481,243	223,834	257,409	**54**
NOx	2020	64,538	41,331	23,207	**36**	67,586	42,802	24,754	**37**
	2030	72,415	40,341	32,074	**44**	76,049	40,503	35,546	**47**

Table 3.6-4: Comparison of 37-State Control Scenario Emissions for Preliminary Air Quality Modeling Scenario and Final Proposal (Tons/Year)

Applications	Year	VOC [short tons]			NO_x [short tons]			$PM_{2.5}$ [short tons]		
		Final	Preliminary	Difference	Final	Preliminary	Difference	Final	Preliminary	Difference
Small Nonroad SI Subject to the Proposal	2020	138,406	92,605	45,801	14,416	15,240	(824)	7,507	7,330	177
	2030	157,626	105,348	52,278	16,306	17,107	(801)	8,627	8,384	243
Marine SI	2020	113,881	75,984	37,897	28,386	26,091	2,295	1,287	3,412	(2,125)
	2030	66,208	42,316	23,892	24,197	17,107	7,090	582	756	(174)
Total	2020	252,287	168,589	83,698	42,802	41,331	1,471	8,794	10,742	(1,948)
	2030	223,834	147,664	76,170	40,503	34,214	6,289	9,209	9,140	69

Table 3.6-4 (Cont'd)
Comparison of 37-State Control Scenario Emissions for Preliminary (Nominal) Air Quality Modeling and Final Proposal

Applications	Year	PM_{10} [short tons]			CO [short tons]		
		Final	Preliminary	Difference	Final	Preliminary	Difference
Small Nonroad SI Subject to the Proposal	2020	8,160	7,967	193	3,231,266	4,868,575	(1,637,309)
	2030	9,377	9,113	264	3,703,736	5,593,529	(2,316,989)
Marine SI	2020	1,399	3,709	(2,310)	908,162	726,853	181,309
	2030	633	821	(188)	848,425	675,398	173,027
Total	2020	9,559	11,676	(2,117)	4,139,428	5,595,428	(1,456,000)
	2030	10,010	9,934	76	4,552,161	6,268,927	(1,716,766)

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CHAPTER 4: Feasibility of Exhaust Emission Control

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

The proposed exhaust emission standards for Small SI engines and Marine SI engines are summarized in the Executive Summary. This chapter begins with a current state of technology for spark-ignition (SI) engines and the emission control technologies expected to be available for manufacturer and continues with a presentation of available emissions data on baseline emissions and on emission reductions achieved through the application of emission control technology. In addition, this chapter provides a description new proposed test procedures including not-to-exceed requirements.

4.1 General Description of Spark-Ignition Engine Technology

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

4.1.1 Basics of Engine Cycles

Spark ignition engines may be of two-stroke or four-stroke which refers to the number of piston strokes per combustion cycle. Handheld Small SI equipment typically use two-stroke engines while larger non-handheld equipment use four-stroke engines. Outboard and personal watercraft (OB/PWC) engines, until the advent of recent environmental regulations, were generally two-stroke engines. They are now a mix of two- and four-stroke engines. Sterndrive and inboard (SD/I) engines are primarily SI four-stroke engines.

4.1.1.1 Two-Stroke Engines

“Two-stroke” refers to the number of piston strokes per combustion cycle. These two strokes, compression and expansion, occur in one revolution of the crankshaft. During the expansion stroke the piston moves downward. As the piston nears its lowest position, the intake and exhaust ports are opened. While these ports are open, a fresh charge of fuel and air is pushed into the cylinder which, in turn, helps force the burned gases from the previous cycle out of the exhaust port. During the compression stroke, the intake and exhaust ports close and the fresh charge is compressed. As the piston approaches it’s highest position, a spark-plug ignites the fresh charge to generate combustion. The force from the combustion acts on the piston to move it downward, thereby causing the expansion stroke and generating power.

In traditional two-stroke engine designs, the engines are crankcase-scavenged and carbureted with intake and exhaust ports on the cylinder walls. The advantage of this engine design is simplicity (low number of moving parts) and a high power to weight ratio of the engine. In this design, the carburetor meters fuel into the intake air which is then routed to the crankcase. The motion of the drive shaft then pressurizes the charge. Oil is typically blended into the fuel to provide cylinder and reciprocating assembly lubrication. When the piston lowers, it exposes the intake port on the side of the cylinder wall which allows the pressurized fuel/air charge to enter the cylinder. At the same time, the exhaust port is exposed allowing burned gases to escape the cylinder. Because both ports are open at the same time, some of the fresh charge can exit the exhaust port. These fuel losses are known as “short-circuiting” or “scavenging” losses and can result in 25 percent or more of the fuel passing through the cylinder unburned. As the piston moves up, the intake and exhaust ports are covered and combustion is initiated.

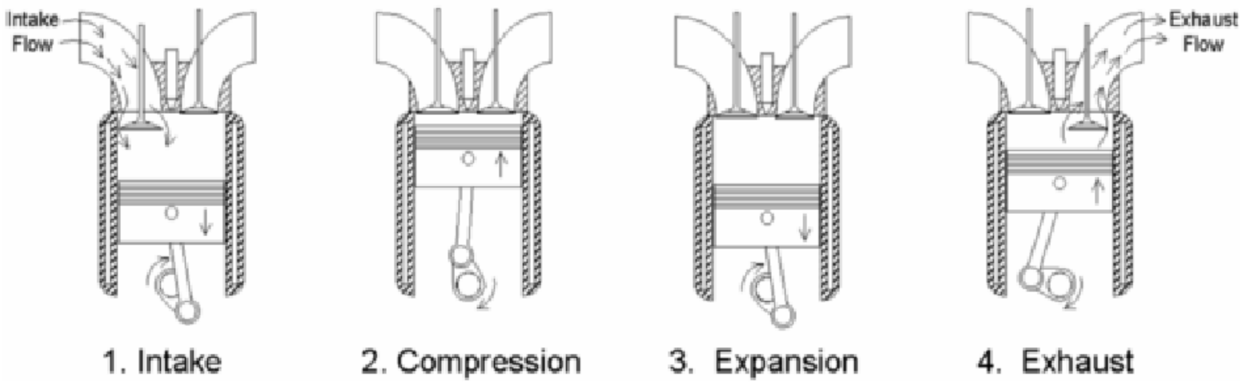
An emerging technology for reducing emissions and scavenging losses from two-stroke engines is direct-injection. This is used primarily on larger outboard and personal watercraft engines (37 kW and up) to meet exhaust emission standards. In a direct-injected engine, charge air is used to scavenge the exhaust gases. Once the exhaust valve closes, fuel is injected into the charge air and ignited with a spark-plug. Because the exhaust valve is closed during most or all of the injection event, short-circuiting losses are minimized. Also, because the fuel is not used to lubricate the crankcase, oil does not need to be blended into the fuel. As a result, much less oil is used.

4.1.1.2 Four-Stroke Engines

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

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

Figure 4.1-1: 4-Stroke Cycle



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

During the compression stroke, the intake valve closes and the momentum of the crankshaft moves the piston up the cylinder from BDC to TDC, compressing the air and fuel mixture. As the piston nears TDC, at the very end of the compression stroke, the air and fuel mixture is ignited by a spark plug and the air and fuel mixture begins to burn. As the air and fuel mixture burns, pressures and temperatures increase and the products of combustion expand in the cylinder, which causes the piston to move back down the cylinder, transmitting power to the crankshaft during the expansion or power stroke. Near the bottom of the expansion stroke, an exhaust valve opens and as the piston moves back up the cylinder, exhaust gases are pushed out through the exhaust valve to the exhaust manifold to complete the exhaust stroke, finishing a complete four-stroke cycle.

4.1.2 Exhaust Emissions from Nonroad SI Engines

Hydrocarbon (HC) and CO emissions are products of incomplete combustion. The level of CO exhaust emissions is primarily a function of the air-to-fuel ratio at which an engine is operated. Hydrocarbon emissions formation mechanisms are somewhat more complex, and appear to be primarily related to:

1. Quenching of the air/fuel mixture at the walls of the combustion chamber
2. Filling of crevice volumes with the air/fuel mixture that remains unburned due to flame quenching at the entrance to the crevice

3. Lubricant absorption and desorption of fuel compounds
4. Partial combustion during an operating cycle or even complete misfiring of the air/fuel mixture during the cycle
5. Entrainment and incomplete combustion of lubricant

As a result, a number of design and operational variables have an impact on HC emissions, including air-to-fuel ratio; combustion chamber design and geometry; homogeneity of the air/fuel charge; intake port geometry and the degree of induced air/fuel charge motion; ignition energy, dwell, and timing; the effectiveness of the cooling system; and oil consumption.

NOx emissions from SI engines are primarily emissions of nitric oxide (NO). Nitrogen in the intake air reacts with oxygen at high temperatures primarily via the Zeldovich mechanism to form NO. Thus variables that impact combustion temperatures can have a significant impact on NO formation and NOx exhaust emissions. These include air-to-fuel ratio, spark timing and the quantity of residual exhaust gases carried over between engine firing cycles (either intentional, such as EGR, or unintentional, such as poor cylinder scavenging).

Particulate matter (PM) emissions from SI engines consists primarily of semi-volatile organic compounds from the engine lubricant together with elemental-carbon soot formed from pyrolysis of fuel and lubricant during combustion.

4.1.2.1 Air-to-fuel ratio

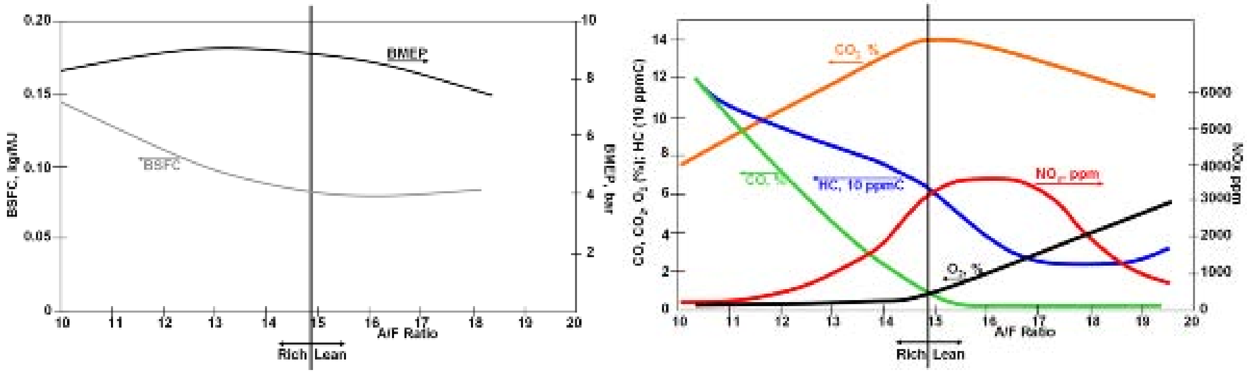
The calibration of engine air-to-fuel ratio affects torque and power output, fuel consumption (often indicated as Brake Specific Fuel Consumption or BSFC), engine temperatures, and emissions for SI engines. The effects of changing the air-to-fuel ratio on emissions, fuel consumption and torque (indicated as Brake Mean Effective Pressure or BMEP, which is torque corrected for engine volumetric displacement) are shown in Figure 3-1.[1]

In the past, manufacturers have calibrated fuel systems of nonroad SI engines for rich operation. This was done in part to reduce the risk of lean misfire due to imperfect mixing of the fuel and air and variations in the air-fuel mixture from cylinder to cylinder. Rich operation at between approximately 12.5:1 and 13:1 air-to-fuel ratio also generally increased engine torque output (figure 4.1-1) and prevented lean air-to-fuel ratio excursions during application of transient loads to the engine. Rich operation also has been used to reduce piston, combustion chamber, cylinder and exhaust port temperatures, thus reducing the thermal load on the cooling system, a particularly important issue with air-cooled engines. Operation at air-to-fuel ratios richer than approximately 13:1 or 13.5:1 can limit the effectiveness of, or pose design challenges for, post-combustion catalytic exhaust emission controls for HC and CO emissions but work well for catalytic reduction of NOx. At the same time, because a rich mixture lacks sufficient oxygen for complete combustion, it results in increased fuel consumption rates and higher HC and CO emissions.

As can be seen from the figure, the best fuel consumption rates occur when the engine is running lean of the stoichiometric air-to-fuel ratio (approximately 14.6:1 air-to-fuel ratio for typical gasolines), but lean operational limits are bounded by the onset of abnormal combustion (e.g., lean misfire and combustion knock), the ability to pick up load, and exhaust port temperatures (particularly with air-cooled engines). Many air-cooled engines are limited by heat-rejection to operation that starts approximately at stoichiometry for light loads, and is rich of stoichiometry as load is increased.

With the use of more advanced fuel systems, manufacturers would be able to improve control of the air-fuel mixture in the cylinder. This improved control allows for leaner operation that is closer to a stoichimetric air-to-fuel ratio without increasing the risk of abnormal combustion. This can be enhanced through careful selection of intake port geometry and combustion chamber shape to induce turbulence into the air/fuel cylinder charge. The leaner air-to-fuel ratios (e.g., operating just rich of stoichiometry) resulting from advanced fuel systems and intake charge turbulence can significantly reduce HC and CO emissions and fuel consumption, and can provide more oxygen in the exhaust for improved catalytic control of HC and CO. Leaner air-to-fuel ratios, however, can increase NOx emissions due to higher combustion temperatures, particularly for engines that are not equipped with exhaust catalysts. More advanced fuel systems would allow tailoring of the air to fuel ratio to allow good transient response and to add enrichment at higher load conditions for engine and catalyst protection and to reduce engine-out NOx emissions. High-load enrichment is particularly important for air-cooled engines, since high-load operation at leaner air-to-fuel ratios could also increase hydrocarbon emissions and PM emissions if the higher cylinder temperatures encountered result in a significant increase in cylinder-bore distortion and lubricating oil consumption.

Figure 4.1-2: Effects of Air-to-Fuel Ratio on Torque Output, Fuel Consumption and Emissions for Naturally Aspirated Spark Ignition Engines.



4.1.2.2 Spark-timing

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

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

4.1.3 Marinization

Gasoline sterndrive and inboard (SD/I) engines are generally derived from land-based counterparts. Engine marinizers buy automotive engine blocks and modify them for use on boats. Because of the good power/weight ratio of gasoline engines, most SD/I engines are not modified to produce more power than the base engines were originally designed to produce. In some airboat applications, aircraft engines are used.

4.1.3.1 Typical SD/I marinization process

Marine SI engines are typically built from base engines designed for use in cars and trucks. Currently, the vast majority of base engines are General Motor (GM) engines that range in size from a 3.0 L in-line four cylinder engine to an 8.1 liter V8 engine and range in power from about 100 to 300 kW. These engines are sold without front accessory drives or intake and exhaust manifolds. Also, no carbureted versions of these engines are offered; they are either sold with electronic fuel injection, or no fuel system at all. Relatively small numbers of custom blocks and Mazda rotary engines are also used.

Marinizers convert the base engines into marine engines in the following ways:

- Choose and optimize the fuel management system.
- Configure a marine cooling system.
- Add intake and exhaust manifolds, and accessory drives and units.

Fuel and air management: Historically, Marine SI engines have been carbureted. Today this technology seems to be going away but is still offered as cheaper alternative to electronic fuel injection. Less than half of new engines are sold with carburetors. GM does not offer carburetors or their associated intake manifolds because they are not used in the higher volume, automotive applications. Therefore, marinizers who produce carbureted engines must purchase the fuel systems and intake manifolds elsewhere.

The 3.0 L and 4.3 L base engines are offered with throttle body fuel injection systems as an option. All of the larger engines are offered with multi-port fuel injection as an option.

Although GM offers a base marine calibration for its electronic control module, it also offers software allowing marinizers to perform their own engine calibrations. For most engines sold, the marinizers will alter the calibrations to optimize engine operation. Except for some small market niches, the marinizers do not calibrate the engines for more power.

Cooling system: Marine SI engines are generally packaged in small compartments without much air flow for cooling. In addition, Coast Guard safety regulations require that surface temperatures be kept cool on the engine and exhaust manifold. Typically, marine exhaust systems are designed with surface temperatures below 93°C (200°F). To do this, manufacturers use ambient (raw) water to cool the engine and exhaust. Most sterndrive and inboard engines use raw water to cool the engine. This water is then used, in a water jacket, to cool the exhaust manifold. Finally, the water is dumped into the exhaust stream.

Most Marine SI engines are cooled with raw water. This means that ambient water is pumped through the engine, to the exhaust manifold, and mixed with the exhaust. The exhaust/water mixture is then dumped under water. Mixing the water with exhaust has three advantages:

- cools the exhaust and protects rubber couplings in sterndrives
- acts as a muffler to reduce noise
- helps tune the exhaust back pressure

An alternative to raw water cooling is fresh water cooling. In a fresh water system, raw water is used to cool the recirculated engine coolant (“fresh water”). The raw water is generally still used to cool the exhaust manifold and exits the engine with the exhaust. However, some systems use the engine coolant to cool the exhaust manifold.

Some gasoline engines, mostly inboards, have fresh water cooling systems which provides two advantages. 1) Engine corrosion problems are reduced, especially when the boat is used in saltwater. Fresh water systems keep saltwater, which can be corrosive, out of the engine. Because salt emulsifies at about 68°C, thermostats in fresh water systems are set around 60-62°C. 2) Marinizers can achieve much better control of the engine temperature. By reducing variables in engine operation, combustion can be better optimized.[3]

There are trade-offs with using a fresh water system. The fresh water system costs more because of the added pump and heat exchanger. Also, this system is not as efficient for cooling the engine as pumping raw water directly to the engine

Other additions: As mentioned above, marinizers add intake manifolds to carbureted engines. As part of the cooling system, marinizers must add water jacketed exhaust manifolds, pumps, and heat exchangers. SD/I engines may also have larger oil pans to help keep oil temperatures down. Because of the unique marine engine designs, marinizers also add their own front accessory drive assembly. Finally, sterndrive engines also must be coupled with the lower drive unit.

4.1.3.2 High performance SD/I marinization process

There is a niche in the SD/I market where customers are willing to sacrifice engine durability for a high power to weight ratio. Marinizers who address this niche do so by increasing the fueling of the engine, optimizing the spark-timing for power, increasing the peak engine speed (rpm), and modifying the exhaust manifold for better tuning. In some cases, the marinizers may actually increase the displacement of the engine by boring out the cylinders. Other components such as cam rails and pistons may also be modified. Superchargers may also be added. As an example, GM's largest base engine for this market is rated at 309 kW. One high performance SD/I engine with a bored cylinder, a high performance fuel injection calibration, and a supercharger achieves more than 800 kW.

4.1.4 Gaseous Fuels

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

4.2 General Description of Exhaust Emission Control Technologies

HC and CO emissions from spark-ignition engines are primarily the result of poor in-cylinder combustion. This is intensified in carbureted two-stroke engines with the very high HC emissions due to short-circuiting losses. Higher levels of NOx emissions are the result of leaner air-fuel ratios and the resulting higher combustion temperatures. Combustion chamber modifications can help reduce HC emission levels, while using improved air-fuel ratio and spark timing calibrations, as discussed in Sections 4.1.2.1 and 4.1.2.2, can further reduce HC emissions and lower CO emissions. The conversion from carburetor to electronic fuel injection will also help reduce HC and CO emissions. Exhaust gas recirculation could be used to reduce NOx emissions. The addition of secondary air into the exhaust can significantly reduce HC and CO emissions. Finally, the use catalytic converters can further reduce all three emissions.

4.2.1 Combustion chamber design

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

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

4.2.2 Fuel injection

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

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

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

Port gasoline injection: As the name suggests, port (single cylinder) or multi-port (multi-cylinder-port) fuel injection means that a fuel injector is placed in close proximity to each of the intake ports. The intake manifold, if used, flows only air. Sequentially-timed systems inject a quantity of fuel each time the intake valve opens for each cylinder, but multi-port injection systems can also be “batch fired” (all injectors pulsed simultaneously on a multicylinder engine) or continous (e.g., the Bosch CIS automotive systems of the 1970's and 80's). Port injection allows manufacturers to more precisely control the amount of fuel injected for each combustion event. This control increases the manufacturer’s ability to optimize the air-fuel ratio for emissions, performance, and fuel consumption. Because of these benefits, multi-port injection is has been widely used in automotive applications for decades.

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

A newer development to improve injector performance is air-assisted fuel injection. By injecting high pressure air along with the fuel spray, greater atomization of the fuel droplets can occur. Air-assisted fuel injection is especially helpful in improving engine performance and reducing emissions at low engine speeds. In addition, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold. On a highway 3.8-liter engine with sequential fuel injection, the air assist was shown to reduce HC emissions by 27 percent during cold-start operating conditions. At wide-open-throttle with an air-fuel ratio of 17, the HC reduction was 43 percent when compared with a standard injector.[5]

4.2.3 Exhaust gas recirculation

Exhaust gas recirculation (EGR) has been in use in cars and trucks for many years. The recirculated gas acts as a diluent in the air-fuel mixture, slowing reaction rates and absorbing heat to reduce combustion temperatures. These lower temperatures can reduce the engine-out NOx formation rate by as much as 50 percent.[6] HC is increased slightly due to lower temperatures for HC burn-up during the late expansion and exhaust strokes.

Depending on the burn rate of the engine and the amount of recirculated gases, EGR can improve fuel consumption. Although EGR slows the burn rate, it can offset this effect with some benefits for engine efficiency. EGR reduces pumping work of SI engines because the addition of nonreactive recirculated gases forces larger throttle openings for the same power output. Because the burned gas temperature is decreased, there is also less heat loss to the exhaust and cylinder walls. In effect, EGR allows more of the chemical energy in the fuel to be converted to useable work.[7]

Electronic EGR control: Many EGR systems in today’s automotive applications utilize a control valve that requires vacuum from the intake manifold to regulate EGR flow. Under part-throttle operation where EGR is needed, engine vacuum is sufficient to open the valve. However, during throttle applications near or at wide-open throttle, engine vacuum is too low to open the EGR valve. While EGR operation only during part-throttle driving conditions has been sufficient to control NOx emissions for vehicles in the past, more stringent NOx standards and emphasis on controlling off-cycle emission levels may require more precise EGR control and additional EGR during heavy throttle operation to reduce NOx emissions. Automotive manufacturers now use electronic control of EGR. By using electronic solenoids to directly open and close the EGR valve or by modulating the vacuum signal to vacuum actuated valves, the flow of EGR can be precisely controlled.

Stratified EGR: Another method of increasing the engine’s tolerance to EGR is to stratify the reicirculated gases in the cylinder. This stratification allows high amounts of dilution near the spark plug for NOx reduction while making undiluted air available to the crevices, oil films, and deposit areas so that HC emissions may be reduced. Stratification may be induced radially or laterally through control of air and mixture motion determined by the geometry of the intake ports. Research on a one cylinder engine has shown that stratified EGR will result in much lower fuel consumption at moderate speed and load (6 percent EGR at 2400 rpm, 2.5 bar BMEP) while maintaining low HC and NOx emissions when compared to homogeneous EGR.[8]

For catalyst systems with high conversion efficiencies, the benefit of using EGR becomes proportionally smaller, although it can offer cost savings by reducing catalyst rhodium loadings. Including EGR as a design variable for optimizing the engine can add significantly to the development time needed to fully calibrate the electronic controls of engines or vehicles.

4.2.4 Multiple valves and variable valve timing

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

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

Control of valve timing and lift take full advantage of the four-valve configuration for even greater improvement in combustion efficiency. Engines normally use fixed-valve timing and lift across all engine speeds. If the valve timing is optimized for low-speed torque, it may offer compromised performance under higher-speed operation. At light engine loads, for example, it is desirable to close the intake valve early to reduce pumping losses. Variable-valve timing can enhance both low-speed and high-speed performance with less compromise. Variable-valve timing can allow for increased swirl and intake charge velocity, especially during low-load operating conditions where this is most problematic. By providing a strong swirl formation in the combustion chamber, the air-fuel mixture can mix sufficiently, resulting in a faster, more complete combustion, even under lean air-fuel conditions, thereby reducing emissions. Automotive engines with valve timing have also replaced external EGR systems with “internal EGR” accomplished via variable valve overlap, generally with improved EGR rate control over external systems and improved engine-out NOx emissions.

4.2.5 Secondary air

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

Secondary air injection was first used as an emission control technique in itself without a catalyst, and still is used for this purpose in many highway motorcycles and some off-highway motorcycles to meet federal and California emission standards. For motorcycles, air is usually provided or injected by a system of check valves which uses the normal pressure pulsations in the exhaust manifold to draw in air from outside, rather than by a pump.[9]

Secondary air injection can also be used in continuous operation with rich-jetted carbureted engines to a achieve an exhaust chemistry just rich of stoichiometry to improve the efficiency of 3-way catalysts.[10,11]

4.2.6 Catalytic Aftertreatment

Over the last several years, there have been tremendous advances in exhaust aftertreatment systems. Catalyst manufacturers have increased the use of palladium (Pd), particularly for close-coupled positions in automotive catalyst applications.[12] Improvements to catalyst thermal stability and washcoat technologies, the design of higher cell densities, and the use of two-layer washcoat applications are just some of the advances made in catalyst technology.[13] Current Pd catalysts are capable of withstanding prolonged exposure to temperatures approaching 1100°C.[14] The light-off temperature of these advanced catalysts is in the range of 250 to 270°C.

There are two types of catalytic converters commonly used: oxidation and three-way. Oxidation catalysts use platinum and/or palladium to increase the rate of reaction between oxygen in the exhaust and unburned HC and CO. Ordinarily, this reaction would proceed very slowly at temperatures typical of engine exhaust. The effectiveness of the catalyst depends on its temperature, on the air-fuel ratio of the mixture, and on the mix of HC present. Highly reactive species such as formaldehyde and olefins are oxidized more effectively than less-reactive species. Short-chain paraffins such as methane, ethane, and propane are among the least reactive HC species, and are more difficult to oxidize.

Three-way catalysts use a combination of platinum and/or palladium and rhodium. In addition to promoting oxidation of HC and CO, these metals also promote the reduction of NO to nitrogen and oxygen. In order for the NO reduction to occur efficiently, an overall rich or slightly-rich of stoichiometric air-fuel ratio is required. The NOx efficiency drops rapidly as the ai-fuel ratio becomes leaner than stoichiometric. If the air-fuel ratio can be maintained precisely at or just rich of stoichiometic, a three-way catalyst can simultaneously oxidize HC and CO and reduce NOx. The window of air-fuel ratios within which this is possible is very narrow and there is a trade-off between NOx and HC/CO control even within this window. The window can be broadened somewhat through the use of oxygen storage components, such as cerium oxide, within the catalyst washcoating. Cerium oxide also promotes CO and HC removal via steam reformation with water vapor in the exhaust, and the hydrogen liberated by these reactions promotes further NOx reduction.

Manufacturers are developing catalysts with substrates that utilize thinner walls in order to design higher cell density, low thermal mass catalysts for close-coupled applications (improves mass transfer at high engine loads and increase catalyst surface area). The cells are coated with washcoat which contain the noble metals which perform the catalysis on the exhaust pollutants. The greater the number of cells, the more surface area with washcoat that exists, meaning there is more of the catalyst available to convert emissions (or that the same catalyst surface area can be put into a smaller volume). Cell densities of 900 cells per square inch (cpsi) have already been commercialized, and research on 1200 cpsi catalysts has been progressing. Typical cell densities for conventional automotive catalysts are 400 to 600 cpsi.

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

4.2.6.1 System cost

Sales volumes of recreational vessels are small compared to automotive sales and while sales of Small SI engines <19kW are similar, the price of equipment is much less than automotive. Manufacturers therefore have a limited ability to recoup large R&D expenditures for these applications. For these reasons, we believe it is not appropriate to consider highly refined catalyst systems that are tailored specifically to nonroad applications. Catalyst manufacturers have assured us that automotive-type catalysts can easily be built to any size needed for Small SI and marine applications. We are considering catalyst packaging designs that does not require the manufactures to incur the costs of reworking the entire exhaust system and, for Marine SI engines, the lower power unit. The cost of these systems will decrease substantially when catalysts become commonplace. Chapter 6 describes the estimated costs for a nonroad catalyst systems for Small SI and Marine SI engines.

4.2.6.2 Differences in emission control system application and design by engine category

One challenge in the use of catalytic control for Small SI and Marine SI engines lies in acceptable design and packaging of the exhaust catalysts onto a wide variety of different types of equipment. This section discusses specific issues related to these applications.

4.2.6.2.1 Small SI Class I engines

Class I engines typically are equipped with integral exhaust and fuel systems and are air-cooled. Significant applications include walk-behind lawn mowers (largest segment), pressure washers, generator sets and pumps. There are both overhead valve (OHV) and side-valve (SV) engines used in Class I, but side-valve engines are the predominant type in Class

I, particularly in lawn mower applications. They currently represent about 60 percent of Class I sales. Exhaust catalyst design for Class I engines must take into account several important factors that differ from automotive applications:

1. Air-cooled engines run rich of stoichiometry to prevent overheating when under load. Because of this, CO and HC emissions can be high. Catalyst induced oxidation of a high percentage of available reactants in the exhaust in the presence of excess oxygen (i.e., lean of stoichiometric conditions) can result in highly exothermic exhaust reactions and increase heat rejection from the exhaust. For example, approximately 80 to 90 percent of the energy available from catalyst-promoted exhaust reactions is via oxidation of CO.
2. Air-cooled engines have significant HC and NOx emissions that are typically much higher on a brake-specific basis than water-cooled automotive engine types. Net heat available from HC oxidation and NOx reduction at rich of stoichiometric conditions is considerably less than that of oxidation of CO at near stoichiometric or lean of stoichiometric conditions due to the much lower concentrations of NO and HC in the exhaust relative to CO.
3. Most Class I engines do not have 12-volt DC electrical systems to power auxiliaries and instead are pull start. Electronic controls relying on 12-volt DC power would be difficult to integrate onto Class I engines without a significant cost increase.
4. Most Class I engines use inexpensive stamped mufflers with internal baffles. Mufflers are typically integrated onto the engine and may or may not be placed in the path of cooling air from the cooling fan.
5. The regulatory emission test cycles (A-cycle, B-cycle), manufacturer's durability cycles and some limited in-use operation data indicate that emissions control should focus primarily on light and part load operation for the highest volume applications (lawnmowers).

These factors would lead to exhaust catalyst designs for small engines that should differ somewhat from those of light duty gasoline vehicle exhaust catalyst designs. Design elements specific to Class I Phase 3 exhaust catalysts would include:

1. Catalyst substrate volume would be sized relatively small so as to be space-velocity limited. Catalyst volume for Class I Phase 3 engines would be approximately 18 to 50 percent of the engine cylinder displacement, depending on cell count, engine-out emission levels, and oil consumption. Catalyst substrate sizes would be compact, with typical catalyst substrate volumes of approximately 2 to 5 cubic inches. This would effectively limit mass transport to catalyst sites at moderate-to-high load conditions and reduce exothermic reactions occurring when exhaust temperature is highest. This is nearly the opposite of the case of typical automotive catalyst designs. Automotive catalyst volume is typically 50 to 100 percent of cylinder displacement, with the chief constraints on catalyst volume being packaging and cold-start light-off performance.
2. Catalyst precious metal loading (Pt-platinum, Pd-palladium, Rh-rhodium) would be kept relatively low, and formulations would favor NOx and HC selectivity over CO selectivity. We estimate that typical loading ratios for Phase 3 would be approximately in the range of 40 to 50 g/ft3 (approximately 50 percent of typical automotive loadings at

light-duty vehicle Tier 2 emission levels) and can be Pt:Rh, Pd:Rh or tri-metallic. Tri-metallic platinum group metal (PGM) loadings that replace a significant fraction of Pt with Pd would be less selective for CO oxidation and would also reduce the cost of the catalyst. Loading ratios would be similar or higher in Rh than what is typically used for automotive applications (20-25 percent of the total PGM mass in Small SI) to improve NOx selectivity, improve rich of stoichiometry HC reactions and reduce CO selectivity.

3. Catalysts would be integrated into the muffler design. Incorporating the catalyst into the muffler would reduce surface temperatures, and would provide more surface area for heat rejection. This is nearly the opposite of design practice used for automotive systems, which generally try to limit heat rejection to improve cold-start light-off performance. The muffler design for Class I Phase 3 engines would have somewhat higher surface area and somewhat larger volume than many current Class I muffler designs in order to promote exhaust heat rejection and to package the catalyst, but would be similar to some higher-end "quiet" Class I muffler designs. Appropriately positioned stamped heat-shielding and touch guards would be integrated into Class I Phase 3 catalyst-muffler designs in a manner similar to many Class I Phase 2 mufflers. A degree of heat rejection would be available via forced convection from the cooling fan, downstream of cooling for the cylinder and cylinder head. This is the case with many current muffler designs. Heat rejection to catalyst muffler surfaces to minimize "hot spots" can also be enhanced internally by turning the flow through multiple chambers and baffles that serve as sound attenuation within the muffler, similar to the designs used with catalyst-equipped lawn mowers sold in Sweden and Germany.
4. Many Class I Phase 3 catalysts would include passive secondary air injection to enhance catalyst efficiency and allow the use of smaller catalyst volumes. Incorporation of passive secondary air allows halving of catalyst substrate volume for the same catalyst efficiency over the regulatory cycle. A system for Class I Phase 3 engines would be sized small enough to provide minimal change in exhaust stoichiometry at high load conditions so as to limit heat rejection, but would be provide approximately 0.5 to 1.0 points of air-to-fuel ratio change at conditions of 50 percent of peak torque and below in order to lower HC emissions effectively in engines operating at air-to-fuel ratios similar to those of current Class I Phase 2 engines. Passive secondary air systems are preferred. Mechanical or electrical air pumps are not necessary. Passive systems include stamped or drawn venturis or ejectors integrated into the muffler, some of which may incorporate an air check-valve, depending on the application. Pulse-air injection is also a form of passive secondary air injection. Pulse air draws air into the exhaust port through a check-valve immediately following the closure of the exhaust valve. Active secondary air (air pump) systems were not considered in this analysis since they may be cost prohibitive for use in Class I applications due to the need for a mechanical accessory drive or 12-volt DC power.
5. Catalyst durability in side valve engines can be enhanced through two catalyst design ideas. First, the use of a pipe catalyst upstream of the main catalyst brick can “catch” the oil in the exhaust thereby limiting the amount seen in the catalyst and thereby catalyst poisoning. Second, the catalyst brick can be lengthened to allow poisoning to some degree yet allow for catalyst conversion for the regulatory life of the engine.
6. Class I engines are typically turned off via a simple circuit that grounds the input side of

the ignition coil. Temperature fail-safe capability could, if appropriate, be incorporated into the engine by installing a bimetal thermal switch in parallel with the ignition grounding circuit used for turning the engine off. The switch can be of the inexpensive bimetal disc type in wide-spread use in numerous consumer products (furnaces, water-heaters, ovens, hair dryers, etc.). To reduce cost, the bimetal switch could be a non-contact switch mounted to the engine immediately behind the muffler, similar to the installation of bimetal sensors currently used to actuate automatic chokes on current Phase 2 Class I lawn mower engines.

4.2.6.2.2 Small SI Class II engines

Almost all Class II engines are air-cooled. Unlike Class I engines, Class II engines are not typically equipped with integral exhaust systems and fuel tanks. Significant applications include lawn tractors (largest segment), commercial turf equipment, generator sets and pumps. Overhead valve engines have largely replaced side-valve engines in Class II, with the few remaining side-valve engines certifying to the Phase II standards using emissions credits or being used in snow thrower type applications where the HC+NOx standards do not apply. Class II engines are typically built more robustly than Class I engines. They often use cast-iron cylinder liners, may use either splash lubrication or full-pressure lubrication, employ high volume cooling fans and in some cases, use significant shrouding to direct cooling air. Exhaust catalyst design practice for Class II engines will differ depending on the level of emission control. Class II engine designs are more suitable for higher-efficiency emission control systems than most Class I engine designs. The design factors are somewhat similar to Class I:

1. Class II engines are mostly air-cooled, and thus must run rich of stoichiometry at high loads. The ability to operate at air-to-fuel ratios rich of stoichiometry at high load may be more critical for some Class II engines than for Class I engines due to the longer useful life requirements in Class II. The larger displacement Class II engines have better efficiency combustion and some engines incorporate more advanced fuel metering and spark control than is typical in Class I, in order to meet the more stringent Class II Phase 2 emission standards (12.1 g/kW-hr HC+NOx in Class II versus 16.1 g/kW-hr in Class I). The heat energy available from CO oxidation is typically somewhat less than the case in Class I because of slightly lower average emission rates.
2. Class II engines have HC and NOx emissions that are generally in more equal portions, or have the potential to be, in the total regulated HC+NOx emissions and lower CO emissions than is the case for Class I engines.
3. Most Class II engines are equipped with 12-volt DC electrical systems for starting. Electronic controls relying on 12-volt DC power could be integrated into Class II engine designs. Low-cost electronic engine management systems are extensively used in motor scooter applications in Europe and Asia. Both Kohler and Honda have introduced Class II engines in North America that use electronic engine management systems.
4. Class II engines use inexpensive stamped mufflers with internal baffles similar to Class I, but the mufflers are often not integrated onto the engine design and may be remote mounted in a manner more typical of automotive mufflers. Class II mufflers are often not placed in the direct path of cooling air from the cooling fan.

5. As with Class I, the regulatory cycles (A-cycle, B-cycle), manufacturer's durability cycles and some limited in-use operation data indicate that emissions control should focus primarily on light and part load operation for the high volume sales of garden tractor equipment.

Taking these factors into account would point towards exhaust catalyst designs that differ from those of light duty gasoline exhaust catalysts and differ in some cases from Class I systems. Elements specific to Class II Phase 3 emission control system design using carburetor fuel systems would include:

1. Catalyst substrate volume would be sized relatively small so as to be space-velocity limited. Catalyst volume for Class II Phase 3 engines would be approximately 33-50 percent of the engine cylinder displacement, depending on cell count, engine-out emission levels, oil consumption and the useful life hours to which the engine's emissions are certified. Catalyst substrate sizes would be very compact within typical mufflers used in Class II, with typical catalyst substrate volumes of approximately 8 to 10 cubic inches (based on sales weighting within useful life categories). This would effectively limit mass transport to catalyst sites at moderate-to-high load conditions and reduce exothermic reactions occurring when exhaust temperature is highest.
2. Catalyst precious metal loading would be kept relatively low, and formulations would favor NOx and HC selectivity over CO selectivity to minimize heat concerns. We estimate that typical loading ratios for Phase 3 would be approximately in the range of 30 to 50 g/ft3 (approximately 50 percent of typical automotive loadings) and could be Pt:Rh, Pd:Rh or tri-metallic. Tri-metallic PGM loadings that replace a significant fraction of Pt with Pd would be less selective for CO oxidation and would also reduce the cost of the catalyst. Loading ratios would be similar or higher in Rh than what is typically used for automotive applications (20-25 percent of the total PGM mass in Small SI).
3. Catalysts would be integrated into the muffler design. Incorporating the catalyst into the muffler would reduce surface temperatures relative to the use of a separate catalyst component. The catalyst for Class II Phase 3 engines would be integrated into mufflers that are similar in volume to today's Class II Phase 2 mufflers. Appropriately positioned stamped heat-shielding and touch guards would be integrated into Class II Phase 3 catalyst-muffler designs in a manner similar to current product. Class II engines typically have a much higher volume of cooling air available downstream of the cylinder than Class I engines. Heat rejection from the cylinder and cylinder head increases the temperature of the cooling air, but it is still sufficiently below the temperature of exhaust system components to allow its use for forced cooling. Thus a degree of heat rejection would be available via forced convective cooling of exhaust components via the cooling fan. However, this would require some additional ducting to supply cooling air to exhaust system surfaces along with careful layout of engine and exhaust components within the design of the equipment that it is used to power. Integrated catalyst-mufflers can also use exhaust energy for ejector cooling (see chapter 6). Heat rejection to catalyst muffler surfaces to minimize "hot spots" can also be enhanced internally by turning the flow through multiple chambers and baffles that serve as sound attenuation within the muffler.
4. Some applications may include secondary air injection to enhance catalyst efficiency.

> Incorporation of passive secondary air allows halving of catalyst substrate volume for the same catalyst efficiency over the regulatory cycle. In many cases, this may not be necessary due to the lower engine-out emissions of Class II engines. In cases where secondary air is used, it could either be a passive system similar to the previously described Class I systems, or an active system with an engine driven pump. Pump drive for active systems could be either 12-volt DC electric or via crankcase pulse, and pump actuation could be actively controlled using an electric solenoid or solenoid valve. The use of active systems is an option but seems unlikely. The most likely control scenario for Class II would be a combination of engine out emission control, use of a small catalyst, and no use of secondary air.

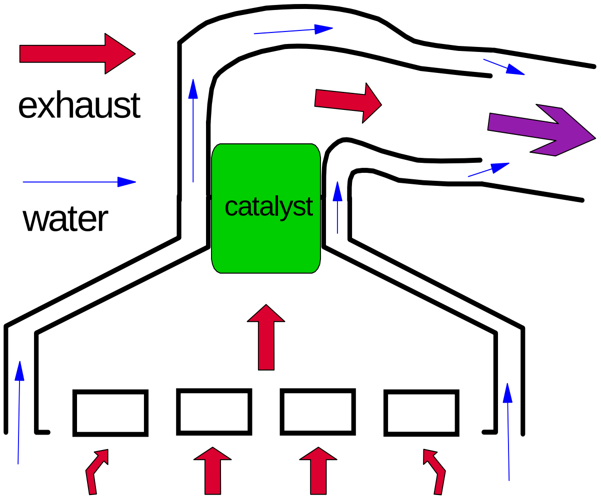
Higher catalyst efficiency, considerably lower exhaust emissions levels, and improved fuel consumption are possible with Class II engines, but heat rejection and safety considerations might necessitate the use of electronic engine management and open-loop fuel injections systems. In such a case, the design and integration of the emission control system would more closely resemble automotive applications with the use of electronic engine management and larger catalyst volumes with higher precious metal loadings.

4.2.6.2.3 Marine SI

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

As discussed later in this chapter, testing has been performed on prototype systems where small catalysts have been placed in the exhaust manifolds of SD/I engines. Figure 4.2-1 illustrates one installation design. For outboard engines, this packaging arrangement would be less straightforward because of the very short exhaust path between the cylinder exhaust ports and where the cooling water and exhaust mix. However, it may be possible to engineer a packaging solution for outboards as well similar to that shown for SD/I in Figure 4.2-1.

Figure 4.2-1: Placement of Marine Catalyst



Several marine engine manufacturers

are now producing engines with water jacketed catalysts in the exhaust. As discussed later in this chapter, one manufacturer has certified personal watercraft engines with catalysts packaged in the exhaust system. These are small oxidation catalysts used in conjunction with two-stroke engines. Two manufacturers are selling marine generators with catalysts. Also, one SD/I engine marinizer has recently added an engine with catalysts in the exhaust to its product line.

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

The matching of the catalyst to the engine may have to be compromised to fit it into the exhaust manifold. However, significant reductions are still achievable. One study on a 4.3 liter automotive engine looked at three different Pd-only catalyst displacements. The smallest of these catalysts had a displacement ratio of 0.12 to 1. The HC+NOx downstream of the catalyst was measured to be from 1.2 to 2.6 grams per mile, depending on the severity of the catalyst aging.[15] This is equivalent to about 1.5 to 3.2 g/kW-hr based on highway operation.[16] This work suggests that significant reductions are achievable with an “undersized” catalyst. As discussed later in this chapter, significant reductions in exhaust emissions have been demonstrated for catalysts packaged in SD/I exhaust systems.

4.2.6.3 Catalyst Durability

Two aspects of marine applications that could affect catalyst durability are thermal load and vibration. Because the catalyst would be coupled close to the exhaust ports, it would likely see temperatures as high as 750 to 850°C when the engine is operated at full power. The bed temperature of the catalyst would be higher due to the reactions in the catalyst. However, even at full power, the bed temperature of the catalyst most likely would not exceed the exhaust temperature by more than 50-100°C. In our laboratory testing, we minimized the temperature at full load by operating the engine with a rich air-fuel mixture. The temperatures seen were well within the operating range of new Pd-only catalysts which are capable of withstanding prolonged exposure to temperatures approaching 1100°C.[17]

In on-highway applications, catalysts are designed to operate in gasoline vehicles for more than 100,000 miles. This translates to about 4,000-5,000 hours of use on the engine/catalyst. We estimate that, due to low annual hours of operation, the average useful life of Small SI and Marine SI engines is only a fraction percent of this value. This suggests that catalysts designed for automotive use should be durable over the useful life of a Small SI and Marine SI engines. Use of catalysts in automotive, motorcycle, and hand-held equipment applications suggests that catalysts can be packaged to withstand the vibration in the exhaust manifold. As discussed later in this chapter, catalysts have recently been demonstrated, through in-use testing, to be durable over the useful lives of SD/I marine vessels.

4.2.6.4 Water Reversion

Another aspect of marine applications that could affect catalyst durability is the effect of water contact with the catalyst. There is concern that, in some designs, water could creep back up the exhaust passages, due to pressure pulses in the exhaust, and damage the catalyst and oxygen sensor. This damage could be due to thermal shock from cold water coming into contact with a hot catalyst or due to salt deposition on the catalyst. One study was performed, using a two-stroke outboard equipped with a catalyst, to investigate the effect of water exposure on a catalyst.[18] The results of this study are summarized in Table 4.2-1.

Table 4.2-1: Summary of Marine Catalyst Durability Study

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

The above study on catalysts in marine applications was performed supplemental to an earlier study.[19] The earlier study also showed that immersing the catalysts in saltwater would hurt the conversion efficiency of the catalyst, but that operating in a marine environment would not. In addition, this earlier study showed that much of the efficiency loss due to salt on the catalyst could be reversed by flushing the catalyst with water. This paper also showed that with the catalyst activated, temperatures at full power were less than at mid power because the space velocity of the exhaust gases at rated speed was high enough to reduce the conversion efficiency of the catalyst.

A study of water reversion was performed on a vessel powered by a sterndrive engine.[20] However, it was found that the water found in the exhaust system upstream of where the exhaust and water mix was due to condensation. This condensation was a result of cool surfaces in the exhaust pipe due to the water-jacketing of the exhaust. This study found that the condensation could be largely resolved by controlling the exhaust cooling water temperature with a thermostat.

Since that time, data has been collected on a number of catalyst-equipped SD/I vessels operated either in salt or fresh-water. This data, which showed no significant catalyst deterioration, is discussed later in this chapter. These engines were designed to prevent water reversion by placing the catalyst near the engine and away from the water/exhaust mixing point. In addition, some of the prototype designs used either a water dam or mist barrier to help limit any potential water reversion.

4.2.7 Advanced Emission Controls

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

To reduce emissions, gasoline-fueled vehicle manufacturers have designed their engines to achieve virtually complete combustion and have installed catalytic converters in the exhaust system. In order for these controls to work well for gasoline-fueled vehicles, it is necessary to maintain the mixture of air and fuel at a nearly stoichiometric ratio (that is, just enough air to completely burn the fuel). Poor air-fuel mixture can result in significantly higher emissions of incompletely combusted fuel. Current generation highway vehicles are able to maintain stoichiometry by using closed-loop electronic feedback control of the fuel systems. As part of these systems, technologies have been developed to closely meter the amount of fuel entering the combustion chamber to promote complete combustion. Sequential multi-point fuel injection delivers a more precise amount of fuel to each cylinder independently and at the appropriate time increasing engine efficiency and fuel economy. Electronic throttle control offers a faster response to engine operational changes than mechanical throttle control can achieve, but it is currently considered expensive and only used on some higher-price vehicles. The greatest gains in fuel control can be made through engine calibrations -- the algorithms contained in the powertrain control module (PCM) software that control the operation of various engine and emission control components/systems. As microprocessor speed becomes faster, it is possible to perform quicker calculations and to increase response times for controlling engine parameters such as fuel rate and spark timing. Other advances in engine design have also been used to reduce engine-out emissions, including: the reduction of crevice volumes in the combustion chamber to prevent trapping of unburned fuel; "fast burn" combustion chamber designs that promote swirl and flame propagation; and multiple valves with variable-valve timing to reduce pumping losses and improve efficiency. These technologies are discussed in more detail in the RIA for the Tier 2 FRM.[21]

As noted above, manufacturers are also using aftertreatment control devices to control emissions. New three-way catalysts for highway vehicles are so effective that once a TWC reaches its operating temperature, emissions are virtually undetectable.[22] Manufacturers are now working to improve the durability of the TWC and to reduce light-off time (that is, the amount of time necessary after starting the engine before the catalyst reaches its operating temperature and is effectively controlling VOCs and other pollutants). EPA expects that manufacturers will be able to design their catalyst systems so that they light off within less than thirty seconds of engine starting. Other potential exhaust aftertreatment systems that could further reduce cold-start emissions are thermally insulated catalysts, electrically heated catalysts, and HC adsorbers (or traps). Each of these technologies, which are discussed below, offer the potential for VOC reductions in the future. There are technological, implementation, and cost issues that still need to be addressed, and at this time, it appears that these technologies would not be a cost-effective means of reducing nonroad emissions on a nationwide basis.

Thermally insulated catalysts maintain sufficiently high catalyst temperatures by surrounding the catalyst with an insulating vacuum. Prototypes of this technology have demonstrated the ability to store heat for more than 12 hours.[23] Since ordinary catalysts typically cool down below their light-off temperature in less than one hour, this technology could reduce in-use emissions for vehicles that have multiple cold-starts in a single day. However, this technology would have less impact on emissions from vehicles that have only one or two cold-starts per day.

Electrically-heated catalysts reduce cold-start emissions by applying an electric current to the catalyst before the engine is started to get the catalyst up to its operating temperature more quickly.[24] These systems require a modified catalyst, as well as an upgraded battery and charging system. These can greatly reduce cold-start emissions, but could require the driver to wait until the catalyst is heated before the engine would start to achieve optimum performance.

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

4.3 Feasibility of Small SI Engine Standards

We are proposing new, more stringent HC+NOx standards for Small SI engines (<19kW) used in nonhandheld, terrestrial applications (we are also proposing a CO std for Small SI engines used in marine applications that is discussed in Section 4.4). The standards differ by engine size. Class I engines have a total cylinder displacement of < 225cc. Class II engines have a total displacement of ≥225cc. We are also proposing changes to the emission certification protocols for durability testing and test fuel specifications for both classes. The new certification requirements will improve emissions performance of these engines over their regulatory lifetime and better align the test fuel with in-use fuel characteristics.

Table 4.3-1 shows the present Phase 2 exhaust emission standards for Class I and II small spark ignition engines as well as the proposed Phase 3 standards. The proposed standards represent a nominal 35-40 percent reduction from current standards.

Table 4.3-1: Comparison of Phase 2 and Proposed Phase 3 Standards for Small Spark-Ignition Engines

Engine Class	Current Phase 2 Standards (HC+NOx g/kW-hr)	Proposed Phase Standards (HC+NOx g/kW-hr)	Percent Reduction (%)
Class I (<225 cc)	16.1	10.0	38
Class II (≥225cc)	12.1	8.0	34

The following sections present the technical analyses and information that support our view that the proposed Phase 3 exhaust emission requirements are technically feasible. We begin with a review of the current state of compliance with the Phase 2 standards relative to the proposed standards and conclude with a more in depth assessment of the technical feasibility of the proposed requirements for Class I gasoline-fueled engines, Class II single-cylinder gasoline-fueled engines, Class II multi-cylinder gasoline-fueled engines, and both classes of gaseous-fueled (e.g., liquid propane gas) engines.

4.3.1 Current Technology and 2005 Certification Test Data

In the 2005 model year manufacturers certified engines to the Phase 2 standards using a variety of engine designs and emission control technology. Table 4.3-2 shows manufacturers' projected engine sales by technology type. For Class I engines, side-valve designs represent the majority of sales, although there are also a significant number of overhead-valve sales. An extremely small number of engines used catalyst-based emission control technology. Class II is dominated by overhead-valve engine designs. A limited number of these engines used catalyst technology, electronic fuel injection, or were water cooled.

Table 4.3-2: 2005 Engine Sales by Technology Market Mix

Engine Technology	Class I	Class II
Side Valve	60%	2%
Overhead Valve	40%	98%
With Catalyst	0.04%	0.2%
With Other (Electronic Fuel Injection and/or water cooled)	0	2%

Looking at the industry from an engine family rather than a sales perspective, shows that 75 and 136 engine families were emission certified in Class I and II, respectively for 2005. The range of technology types is shown in Table 4.3-3. The most of engine families in Class I are overhead-valve, carbureted engines, with only six families using side-valve, carbureted designs (the side-valve engines still account for the bulk of Class I sales). Four families utilized catalytic exhaust aftertreatment.

Table 4.3-2: 2005 Small Spark-Ignition Engine Technology Types and Number of Engine Families

Engine Class	Side-Valve		Overhead Valve				
	Single-Cylinder Carburetor	Single-Cylinder Carburetor w. Catalyst	Single-Cylinder Carburetor	Single-Cylinder Carburetor w. Catalyst	Multi-Cylinder Carburetor	Multi-Cylinder Fuel Injection	Multi-Cylinder Fuel Injection w. Catalyst
Class I	yes (5)	yes (1)	yes (66)	yes (3)	no	no	no
Class II	yes (4)	yes (1)	yes (67)	no	yes (58)	yes (2)	yes (4)

In Class II, about half of the engine families are overhead-valve, carbureted, single-cylinder designs. Based on Table 4.3-2, these families dominate the sales in this class. None of these carbureted families used a catalyst. There are several single-cylinder engine families using the older, less sophisticated side-valve technology. One of these uses a catalyst. Also, about half of this class is comprised of engine families that use multi-cylinder (predominately v-twins) designs incorporating overhead-valve technology. Most of these multi-cylinder families utilized carburetors, with a few using fuel injection and electronic engine controls. Several of these engine families use catalytic aftertreatment.

Figures 4.3-1 and 4.3-2 present the 2005 certification results at full life for Class I and 2 engine families, respectively, by technology type. In both cases, several engine families were certified at levels necessary to comply with the proposed Phase 3 standards. A number of families are very close to the requisite emission levels. This suggests that, even accounting for the relative increase in stringency associated with our proposed certification protocols, a number of families will either not need to do anything or require only modest reductions in their emission performance to meet the proposed standards.

Figure 4.3-1: Class I HC+NOx Full Life Certification Results

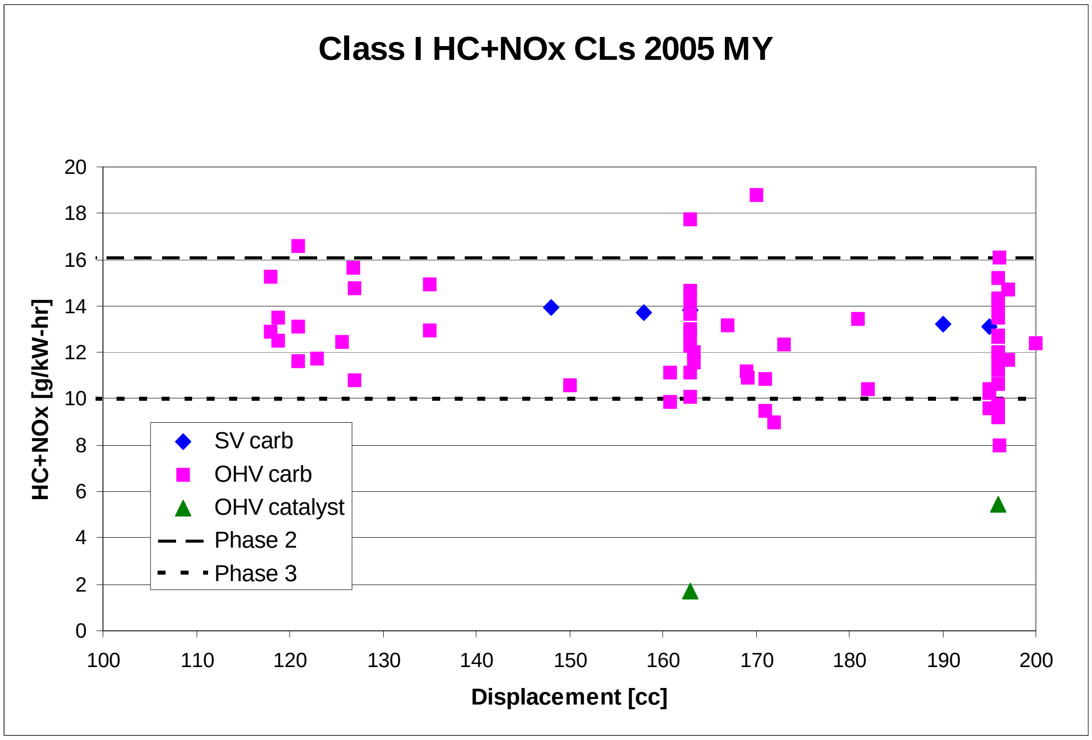
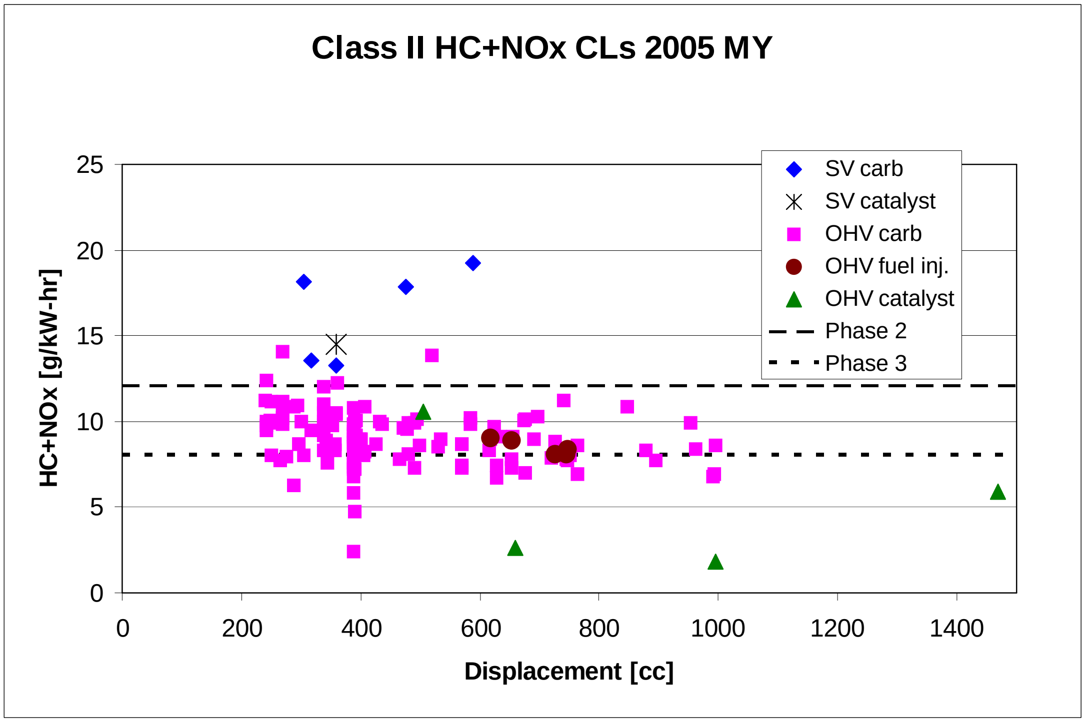


Figure 4.3-2: Class II HC+NOx Full Life Certification Results



4.3.2 Technology Assessment and Demonstration

As described above, a number of engine families already are certified to emission levels that likely would comply with the proposed Phase 3 standards. However, many engine families clearly will have to do more to improve emission performance. Generally, we believe the proposed requirements will require many engine manufacturers to adopt exhaust aftertreatment technology using catalyst-based systems. Other likely changes include improved engine designs and fuel delivery systems. Finally, adding electronic controls or fuel injection systems may obviate the need for catalytic aftertreatment for some engine families, with the most likely candidates being multi-cylinder engine designs.

Many of the technical design considerations for adapting advanced emission controls to Small SI engines were presented in Section 4.2. These included redirected air from the cooling fan, redirected exhaust flow through multiple chamber and baffles within the catalyst muffler, or other design considerations. (These are also the kinds of design elements that engine manufacturers will need to consider for safe and durable emission control systems.) In the remainder of this section we describe the specific results of our emission control assessment based on engine testing of exhaust catalyst systems, as well as a more specific discussion of other potential emission reduction technology for certain engine types such as electronic engine controls and fuel injection. The results of our safety assessment are described later in section 4.8 of this chapter.

4.3.2.1 Overview of Technology Assessment

Our feasibility assessment began by evaluating the emissions performance of current technology for Small SI engines and equipment. These initial efforts focused on developing a baseline for emissions and general engine performance so that we could assess the potential for new emission standards for engines and equipment in this category. This process involved laboratory and field evaluations of the current engines and equipment. We reviewed engineering information and data on existing engine designs and their emissions performance. We also reviewed patents of existing catalyst/muffler designs for Class I engines. We engaged engine manufacturers and suppliers of emission control-related engine components in discussions regarding recent and expected advances in emissions performance beyond that required to comply with the current Phase 2 standards. Finally, we purchased catalyst/muffler units that were already in mass production by an original equipment manufacturer for use on European walk-behind lawn mowers and conducted engineering and chemical analysis on the design and materials of those units.

We used the information and experience gathered in the above effort along with the previous catalyst design experience of our engineering staff to design and build prototype catalyst-based emission control systems that were capable of effectively and safely achieving the proposed Phase 3 requirement based on dynamometer and field testing. We also used the information and the results of our engine testing to assess the potential need for improvements to engine and fuel system designs, and the selective use of electronic engine controls and fuel injection on some engine types. A great deal of this effort was conducted in association with our more exhaustive study regarding the efficacy and safety of implementing advanced exhaust emission controls on Small SI engines, as well as new evaporative requirements for these engines.[25] In other testing, we evaluated advanced emission controls on a multi-cylinder Class II engine with electronic fuel injection.[26]

In designing our engine testing program, we selected engines certified to the Phase 2 emission standards that were expected to remain compliant with those standards for the duration of their useful life based on our low-hour emission testing and the manufacturer's declared deterioration factor from the certification records for that engine family. We also selected engine families that represented: 1) a cross section of Class I and Class II side-valve and overhead-valve technologies; and 2) higher sales volume families. Each engine was maintained based on the manufacturer's specifications.[1] The results of our specific technical feasibility assessment are presented below.

4.3.2.2 Class I Gasoline-Fueled Engines

We tested six side-valve and six overhead-valve Class I engines that used gasoline fuel with prototype catalyst/muffler control systems. The primary design target for selecting the catalyst configuration, e.g., volume, substrate, platinum group metal (PGM), was to achieve emission levels below the proposed limit of 10 g/kW-hr HC+NOx for this class at 125 hours of engine operation. That time period represents the useful life requirement for the most common application in this category, i.e., residential walk-behind lawn mowers. A maximum of about 7 g/kW-hr HC+NOx was set as the low-hour performance target with a catalyst system to allow for engine and emission control degradation over the engine's useful life. This level assumes a certification cushion at low hours of 1 g/kW-hr HC+NOx and a multiplicative deterioration factor of 1.3. Secondary design targets were primarily safety related and included minimizing CO oxidation at moderate to high load conditions to maintain exhaust system surface temperatures comparable to those of the original Phase 2 compliant systems. The test engine, size, and salient catalyst features are shown in Table 4.3-4.

Table 4.3-5 presents the results of our catalyst testing on Class I engines.[27,28] Three of the engines were tested at high hours. The high-hour results for the remaining engines were projected from their low-hour emission performance. We projected high-time emission results for these engines by applying the multiplicative deterioration factor from the manufacturer's Phase 2 certification application to the low-hour emission test results. The certification deterioration factors ranged from 1.097 to 1.302 g/kW-hr HC+NOx. As shown, each of the engines achieved the requisite emission limit of 10 g/kW-hr HC+NOx at the end of their useful lives.

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[1] The specific test engines were generally used in residential lawn mower and lawn tractor applications. These applications were chosen for field testing as part of our safety study because they represented certain potentially unique and challenging safety concerns connected with operation and storage in environments with combustible debris.

Table 4.3-4: Class I Test Engine and Control Technology Description

Engine ID	Displacement (L)	Valve Train	Fuel Metering	Passive (Venturi) Secondary Air?	Catalyst Type	Catalyst Volume	Catalyst Cell Density	PGM Loading (mass/catalyst volume, Pt:Pd:Rh ratio)
236	0.20	Side	Carburetor	Yes	Metal monolith	44 cc	200 cpsi	30 g/ft^3, 4:0:1
246	0.20	Side	Carburetor	Yes	Metal monolith	44 cc	200 cpsi	30 g/ft^3, 4:0:1
248	0.20	Side	Carburetor	Yes	Metal monolith	44 cc	200 cpsi	30 g/ft^3, 0.33:3.66:1
249	0.20	Side	Carburetor		Wire-mesh	60 cc	N/A	proprietary, 0:0:1
6820	0.19	Side	Carburetor	Yes	Cordierite Ceramic Monolith	40 cc	400 cpsi	30 g/ft^3, 5:0:1
258	0.19	Side	Carburetor	Yes	Cordierite Ceramic Monolith	40 cc	400 cpsi	30 g/ft^3, 5:0:1
241	0.19	Overhead	Carburetor	Yes	Cordierite Ceramic Monolith	40 cc	400 cpsi	30 g/ft^3, 5:0:1
255	0.19	Overhead	Carburetor	Yes	Coated tube pre-catalyst, Metal monolith main-body catalyst	20 mm dia. X 73 mm long exhaust tubing, 22 cc metal monolith	Tube: 2 channels (annular shape), Main body: 200 cpsi	Tube: Proprietary Main body: 30 g/ft^3, 3:1:1
2982	0.19	Overhead	Carburetor	Yes	Metal monolith	34 cc	100 cpsi	50 g/ft^3, 5:0:1
243	0.16	Overhead	Carburetor	Yes	Cordierite Ceramic Monolith	30 cc	400 cpsi	30 g/ft^3, 5:0:1
244	0.16	Overhead	Carburetor	Yes	Metal monolith	44 cc	200 cpsi	30 g/ft^3, 1:3:1
245	0.16	Overhead	Carburetor	Yes	Metal monolith	44 cc	200 cpsi	30 g/ft^3, 3:1:1

Table 4.3-5: Class I Emission Results with Advanced Catalytic Control Technology

Engine	Age (hours)[1]	HC+NOx (g/kW-hr)
236	10-20	4.9 ± 0.6[2]
	Projected High	**6.1**
246	10-20	5.6
	Projected High	**7.0**
248	10-20	4.6
	Projected High	**5.7**
249	10-20	6.3
	Projected High	**7.8**
6820	Not Tested	na
	>110	**9.4**
258	10-20	6.7
	>110	**8.2**
241	10-20	3.9 ± 0.2
	>110	**6.6 ± 0.2**
255	10-20	5.0
	Projected High	**6.5**
2982	10-20	4.9 ± 0.3
	>110	**7.0 ± 0.4**
243	10-20	7 ± 1
	Projected High	**7.7**
244	10-20	7.2
	Projected High	**7.9**
245	10-20	5.6
	Projected High	**6.1**

[1] Projected high hour results estimated by multiplying the low hour test results by the manufacturer's certification deterioration rate.

[2] "±" values represent the 95% confidence intervals of 3 tests using a 2-sided t-test.

The above method for projecting high-hour emission results using a certification deterioration factor assumes that the catalyst system will control engine-out emissions to the same extent, i.e., proportional reduction, over the useful life of the engine. For some engines this may not always be the case depending on oil consumption, air-to-fuel ratio and other factors that may change the effectiveness of the catalyst over time.[2] Our approach also did not explicitly account for the fact that manufacturer's will generally design the engine and catalyst to provide some certification cushion. It appears that most of the engines in Tables 4.3-5 would accommodate the above design considerations. However, the projected high-time results are uncomfortably close to the 10 g/kW-hr HC+NOx standard for engine number 6820. In these cases, such factors can be accounted for by the engine manufacturer in the engine family's research and design phase by either improving the durability of the engine (see the discussion below) or designing the catalyst to account for necessary improvement in catalyst effectiveness over time, e.g, more precious metal loading, larger catalyst volume, dividing the catalyst into two separate pieces within the exhaust stream, etc.

The technical feasibility of the Phase 3 standard for Class I engines is supported by a number of Small SI engine manufacturers.[29,30,31,32] Also, a manufacturer of emission controls specifically indicated the types of hardware that may be needed to comply with new standards.[33] That manufacturer concluded that, depending on the application and engine family, either catalyst or electronic engine controls should be able to achieve emission standards as low as 9 g/kW-hr HC+NOx. As demonstrated above, we believe the proposed standard of 10 g/kW-hr HC+NOx can be achieved using catalysts only. However, based on our engineering judgment, we agree that it may be possible to achieve the standard with the sole use of electronic engine controls because of the more precise management of air-fuel mixtures and ignition spark timing offered by that technology.

We conducted a design and process Failure Mode and Effects Analysis study to assess the safety of implementing advanced exhaust emission controls on Small SI engines.[34] That work, which was based in part on our engine test program, suggests that manufacturers of Class I may need to improve the durability of basic engine designs, ignition systems, or fuel metering systems for some engines in order to comply with the emission regulations at full useful life. Some of these emission-related improvements may include:

1. Adding a fuel filter or improving the needle and seat design in the carburetor to minimize fuel metering problems caused by debris from the fuel tank;
2. Improving intake manifold design or materials to reduce air leaks;
3. Upgrading the ignition system design for better ignition spark reliability and durability;

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[2] Catalyst performance degradation can occur from thermal sintering and catalyst poisoning due to oil consumption. Catalyst performance can also improve as engine air-to-fuel ratio slowly drifts towards stoichiometry over the useful life of the engine. Air-cooled engines are typically designed with air-to-fuel ratio calibrations that take into account lean-drift with extended operation, and are designed with a sufficiently rich air-to-fuel ratio to prevent net-lean operation at high hours that could result in engine damage or deteriorating engine performance.

4. Improving design and manufacturing processes for carburetors to reduce the production variability in air-fuel mixtures; and
5. Enhancing exhaust manifold design for better reliability and durability.

4.3.2.3 Class II Single-Cylinder Gasoline-Fueled Engines

Class II single-cylinder engines that use gasoline fuel are currently certified and sold under the Phase 2 standard in both side-valve and overhead-valve configurations. In 2005, only 5 out of 78 Class II single-cylinder engine families used side-value designs. Manufacturers certified these families under the averaging provisions of the applicable regulations with emission credits that were generated by (low emitting) overhead-valve engines. We believe that the proposed Phase 3 standard will reduce the number of emission credits available for the certification of side-valve technology. As a result, we assume that a number of the remaining Class II side-valve engines may be phased out of applicable manufacturer's product line in the future.

Based on the above, we did not directly assess the technical feasibility of the proposed standard for side-valve Class II engines in our test program. Instead we assessed only single-cylinder, overhead-valve Class II engines with prototype catalyst/muffler control systems. The primary design target for selecting the catalyst configuration for these engines, e.g., volume, substrate, design and PGM loading, was to achieve emission levels well below the proposed limit of 8 g/kW-hr HC+NOx for this class to accommodate the longer useful life of many of these engines. (The emission regulations allow useful lives ranging from 250 to1000 hours.) For two of the engines families, we selected emission control technology with a target of meeting a 3.5 g/kW-hr HC+NOx. This included the use of electronic engine and fuel controls to improve the management of air-fuel mixtures and ignition spark timing that allow, among other advantages, the use of larger catalyst volumes and higher precious metal loading. Secondary design targets were primarily safety related and included minimizing CO oxidation at moderate to high load conditions to maintain exhaust system surface temperatures comparable to those of the original Phase 2 compliant systems. The test engines, size, salient catalyst parameters, and use of electronic engine controls are shown in Table 4.3-6.

Table 4.3-6: Class II Single-Cylinder Test Engine and Control Technology Description

Engine	Displacement (L)	Valve Train	Fuel Metering	Catalyst Type	Catalyst Volume	Catalyst Cell Density	Catalyst Loading
142	0.40	Overhead	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1[1]
231	0.50	Overhead	Electronic Fuel Injection	Metal monolith	280 cc	200 cpsi	70 g/ft^3, 0:5:1
251	0.50	Overhead	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1
253	0.50	Overhead	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1
232	0.49	Overhead	Electronic Fuel Injection	Metal monolith	250 cc	200 cpsi	40 g/ft^3, 5:0:1

[1] Metal loading expressed as a ratio of platinum:paladium:rodium.

Table 4.3-7 shows the results of our catalyst testing on single cylinder Class II engines. Only one of the engines was tested at high hours. As explained above for the Class I engines, the high-hour results for the remaining engines were projected from their low-hour emission performance. We projected high-time emission results for these engines by applying the multiplicative deterioration factor from the manufacturer's Phase 2 certification application to the low-hour emission test results. The certification deterioration factors ranged from 1.033 to 1.240 g/kW-hr HC+NOx. As shown, each of the engines achieved the requisite emission limit of 8 g/kW-hr HC+NOx.

Table 4.3-7: Class II Single-Cylinder Emission Results with Advanced Catalytic Control Technology

Engine	Age (hours)[1]	HC+NOx (g/kW-hr)
231	10-40	1.8 ± 0.4[2]
	Projected High	**2.2**
232	10-40	2.2 ± 0.1
	Projected High	**2.3**
251	10-40	3.1 ± .3
	Projected High	**3.8**
253	10-40	4.5 ± 0.1
	Projected High	**5.6**
142	50	2.5 ± 0.6
	500	**2.8**

[1] Projected high-hour results estimated by multiplying the low-hour test results by the manufacturer's 2004 certification deterioration rate.

[2] "±" values represent the 95% confidence intervals of 3 tests using a 2-sided t-test.

Again, as with Class I engines, the technical feasibility of the Class II standard was supported by a number of Small SI engine manufacturers.[35][36][37][38] Also, a manufacturer of emission controls specifically indicated the types of hardware that may be needed to comply with new standards.[39] That manufacturer concluded that, depending on application and engine family, a catalyst and electronic engine controls should be capable of achieving emission standards as low as 7 g/kW-hr HC+NOx. Also, as described above, that same manufacturer concluded that, again depending on the application and engine family, either catalyst or electronic engine controls should be able to achieve emission standards as low as 9 g/kW-hr HC+NOx. Our proposed standard of 8 g/kW-hr HC+NOx is in between these two regions. Therefore, based solely on that manufacturer's conclusions, complying with the proposed standard may require control technology ranging from either a catalyst or electronic engine controls, or a combination of both.

Based on the above information, especially our testing as discussed previously, we conclude that catalysts do not necessarily need to be used in conjunction with electronic engine controls to achieve our proposed standard of 8 g/kW-hr HC+NOx. Either one of those technologies appear sufficient. In fact, market forces may cause some manufacturers to shift to electronic controls in the absence of more stringent emission standards. Nonetheless, we can not discount the possibility that both technologies may be used by some manufacturers to meet the proposed standard on single-cylinder Class II engines. (See section 4.2.3.4 for more on electronic engine control and fuel injection.)

The design and process Failure Mode and Effects Analysis study mentioned previously suggests that manufacturers of Class II may need to improve the durability of basic engine designs, ignition systems, or fuel metering systems for some engines in order to comply with the emission regulations at full useful life.[40] Some of these emission-related improvements may include:

1. Reducing the variability in air-fuel mixtures with tighter manufacturing tolerances for fuel metering components; and

2. Improving the ignition system design for better ignition spark reliability and durability.

4.3.2.4 Class II Multi-Cylinder Gasoline-Fueled Engines

Gasoline-fueled Class II multi-cylinder engines are very similar to their single-cylinder counterparts. Beyond the difference in the number of cylinders, several more Class II multi-cylinder engine families are currently certified with catalysts and electronic engine control technology (either with or without a catalyst). Because of the direct similarities and the use of more sophisticated emission control-related technology on some engine families, we find that our conclusions regarding the technical feasibility of the proposed 8 g/kW-hr HC+NOx standard for single-cylinder Class II engines is directly transferable to multi-cylinder Class II engines.

Nonetheless, we also tested two twin-cylinder gasoline-fueled Class II engines from different engine families by the same manufacturer.[41] The engines were basically identical except for their fuel metering systems, i.e., carbureted or electronic fuel injection. We tested both without modification and tested the electronic fuel injected engine with a catalyst system that we developed. All the tests were conducted when the engines had accumulated 10-15 total hours of operating time.

The results of this testing are shown in Table 4.3-8. As was done for the Class I and II single-cylinder engines discussed earlier, we projected emission levels at the end of each engine's useful life using the multiplicative deterioration factors for each engine family as reported in the manufacturer's 2005 Phase 2 certification application. As shown, the carbureted engine is projected to have end of life emissions of approximately 9.1 g/kW-hr. Based on our experience with single-cylinder engines, compliance with the proposed standard may require the use of a catalyst for this engine family. The unmodified engine with electronic fuel injection is projected to achieve about 7.3 g/kW-hr. This engine is very close to complying with the proposed standard and will most likely require only additional fuel-air mixture and injection timing calibration changes for compliance.

Table 4.3-8: Class II Multi-Cylinder Emission Results with Advanced Catalytic Control Technology (V-Twin, Approximately 0.7 Liter Displacement, 3-Way Catalyst)

Engine Configur-ation	Fuel Metering	Age (hours)[1]	HC+NOx (g/kW-hr)	Catalyst Type	Catalyst Volume	Catalyst Cell Density	Catalyst Loading
OEM	Carburet	10-40	7.2	--	--	--	--
		Projected	**9.1**	--	--	--	--
OEM	EFI	10-40	5.9	--	--	--	--
		Projected	**7.3**	--	--	--	--
OEM w.	EFI	10-40	1.8	Cordierite	700cc	400	60
		Projected	2.2	same	same	same	same

[1] Projected high-hour results estimated by multiplying the low-hour test results by the manufacturer's 2004 certification deterioration rate.

[2] Metal loading expressed as a ratio of platinum:paladium:rodium.

Finally, the combination of electronic fuel injection and catalytic exhaust aftertreatment clearly has the potential to reduce emission well below the proposed standard as shown in the table.

We also evaluated emission control technology for twin-cylinder Class II engines, and by analogy all multi-cylinder engines, as part of our safety study.[42] Here again we did not find any unique challenges in designing catalyst-based control systems for these multi-cylinder engines relative to the feasibility of complying with the proposed exhaust standards under normal engine operation. However, we did conclude that these engines may present unique concern with the application of catalytic control technology under atypical operation conditions. More specifically, the concern relates to the potential consequences of combustion misfire or a complete lack of combustion in one of the two or more cylinders when a single catalyst/muffler design is used. (A single muffler is typically used in Class II applications.) In a single-catalyst system, the unburned fuel and air mixture from the malfunctioning cylinder would combine with hot exhaust gases from the other, properly operating cylinder. This condition would create high temperatures within the muffler system as the unburned fuel and air charge from the misfiring cylinder combusts within the exhaust system. This could potentially destroy the catalyst.

One solution is simply to have a separate catalyst/muffler for each cylinder. Another solution is to employ electronic engine controls to monitor ignition and either put the engine into "limp-mode" or shut the engine down until the condition clears on re-start or until necessary repairs are made, if appropriate. For engines using carburetors, this would effectively require the addition of electronic controls. For engines employing electronic fuel injection that may need to also employ a small catalyst, it would require that the electronic controls incorporate ignition misfire detection if they do not already utilize the inherent capabilities within the engine management system.

We expect some engine families will use electronic fuel injection to meet the proposed Phase 3 standard without employing catalytic aftertreatment. As described earlier, engine families that already use these fuel metering systems and are reasonably close to complying with the proposed requirement are likely to need only additional calibration changes to the engine management system for compliance. In addition, we expect that some engine families which currently use carbureted fuel systems will convert directly to electronic fuel injection. Manufacturers may adopt this strategy to couple achieving the standard without a catalyst and realizing other advantages of using fuel injection such as easier starting, more stable and reliable engine operation, and reduced fuel consumption. A few engine manufacturers have confidentially confirmed their plans to use electronic fuel injection on some engine families in the future as part of an engine management strategy in lieu of using catalysts.

Our evaluation of electronic fuel injection systems that could be used to attain the proposed standard found that a rather simple, low cost system should be sufficient. We demonstrated this proof of concept as part of the engine test program we conducted for our safety study. In that program, we fitted two single-cylinder Class II engines with an electronic control unit and fuel system components developed for Asian motor-scooters and small-displacement motorcycles. The sensors for the system were minimized to included a throttle position sensor, air charge temperature sensor, oil temperature sensor, manifold absolute pressure sensor, and a crankshaft position sensor. This is in contrast to the original equipment manufacturer (OEM) fuel injection systems currently used in some with two-cylinder Class II engine applications that employ more sophisticated and expensive automotive-based components.

Regarding the electronic control unit and fuel system components referenced above and in previous sections, at least two small engine manufacturers have developed simplified, compact, low-cost electronically controlled fuel injection systems for small motorcycles and scooters.[43][44] One manufacturer has also developed a general purpose small engine with electronic engine speed control technology that eliminates the need for a battery.[45][46] These manufacturers have generally reported a number of benefits for these advanced systems, including lower emissions and better fuel economy.

4.3.2.5 Class II Gaseous-Fueled Engines

Engine manufacturers and equipment manufacturers certify engines to run on liquid propane gas (LPG) or compressed natural gas (CNG) in a number of applications including indoor floor buffers which require low CO emissions. The technology to reduce emissions to the Phase 3 levels is catalyst due the fact that most engines run closer to stoichiometry than gasoline engines and further enleanment to reduce emissions may not be feasible. Due to the high amount of NOx compared with HC, as seen from engine data in the certification database, the catalysts may need to be designed to reduce NOx and oxidize a limited amount of CO. The EPA 2005 Certification Database lists 8 multi-cylinder engine families in the Class II 500 useful life category as having catalysts. Due to this fact, it is assumed that gaseous engines do not have the same concerns with multi-cylinder engines and catalysts as gasoline engines.

4.4 Feasibility of Outboard/Personal Watercraft Marine Engine Standards

Outboard and personal watercraft (OB/PWC) engines are subject to exhaust emission standards which require approximately a 75 percent reduction in hydrocarbon emissions compared to conventional carbureted, crankcase-scavenged two-stroke engines. Because of the emission credit program included in these requirements, manufacturers are able to sell a mix of old and new technology engines to meet the standards on average.

We are proposing new exhaust emission standards for OB/PWC engines based on the emissions results achievable from the newer technology engines. These technologies have primarily been two-stroke direct injection and four-stroke engine designs. For a few model years, one manufacturer certified PWC engines with catalytic aftertreatment. This section presents emission data for 2004 model year outboard and personal watercraft engines and includes a description of the various emission control technologies used. In addition, the possibility of using catalytic aftertreatment on OB/PWC engines is discussed.

4.4.1 2004 OB/PWC Certification Test Data

When engine manufacturers apply for certification to exhaust emission standards, they submit exhaust emission test data. In the case of the OB/PWC engines, the emission standards are based on the sum of hydrocarbons and oxides of nitrogen (HC+NOx). Manufacturers submit emission test data on HC and NOx to demonstrate their emission levels. Although carbon monoxide (CO) emissions are not currently regulated, manufacturers submit data on CO emissions as well.

Three primary technologies are used on Marine SI engines: conventional two-stroke engines, direct injection two-stroke engines, and four-stroke engines. Conventional two-stroke engines are primarily carbureted, but larger engines may have indirect fuel injection systems as well (IDI). Four stroke engines come in carbureted, throttle-body fuel injected (TBI), and multi-port fuel injection (MPI) versions. These technologies are discussed in more detail in Section 4.4.2.

4.4.1.1 HC+NOx Certification Data

Figure 4.4-1 presents HC+NOx certification levels for 2006 model year outboard engines and compares this data to the existing and proposed exhaust emission standards. These certification levels are based on test data over the ISO E4 duty cycle with an adjustment for emissions deterioration over the regulatory useful life. The certification data set includes engines well above and below the emission standard. Manufacturers are able to certify to the standard by meeting it on average. In other words, clean engines generate emission credits which offset the debits incurred by the engines emitting above the standard. Figure 4.4-2 presents only the data from engines that meet the 2006 standard. As shown in these figures, two-stroke direct injection engines and four-stroke engines easily meet the 2006 standard.

Figure 4.4-1: 2006 MY Outboard HC+NOx Certification Levels

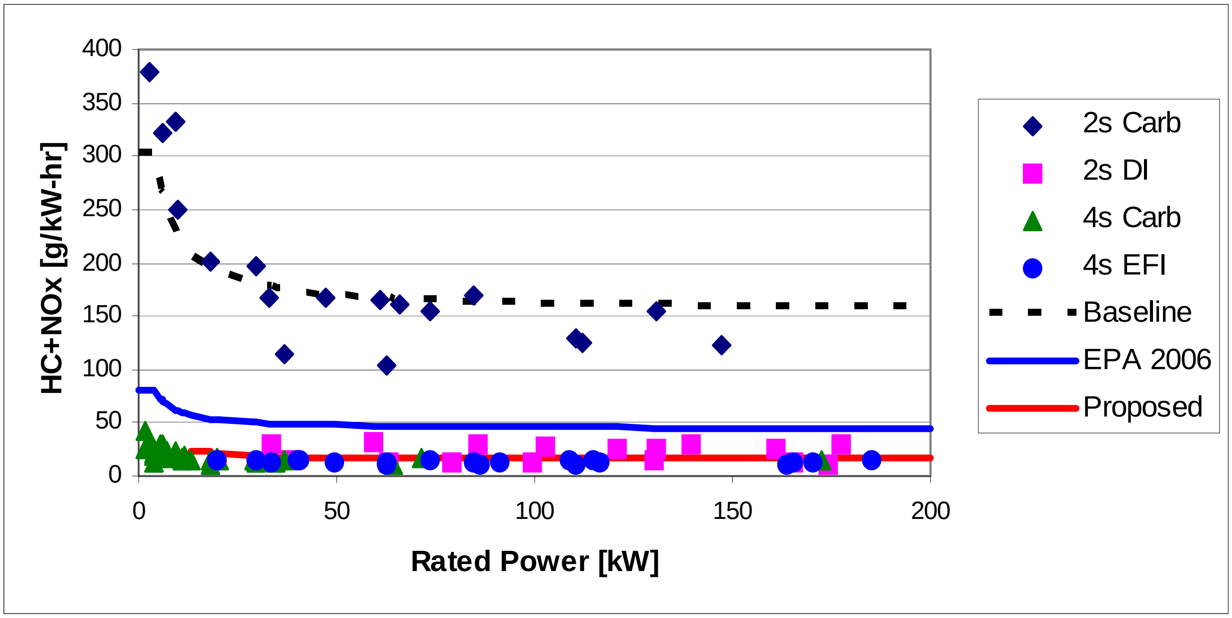
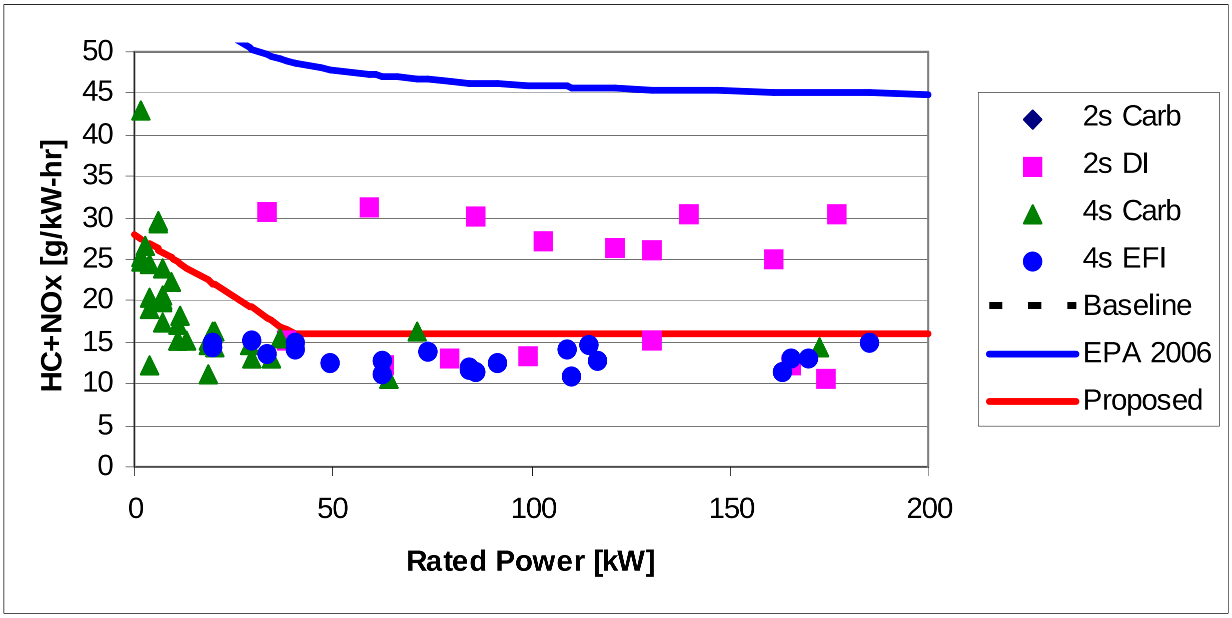


Figure 4.4-2: 2006 MY New Technology Outboard HC+NOx Certification Levels



Figures 4.4-3 and 4.4-4 present similar data for personal watercraft engines. These engines use similar technology, but the HC+NOx emissions are a little higher on average, presumably due to higher average power densities for PWC engines. This difference in emissions is reflected in the proposed HC+NOx standards.

Figure 4.4-3: 2006 MY Personal Watercraft HC+NOx Certification Levels

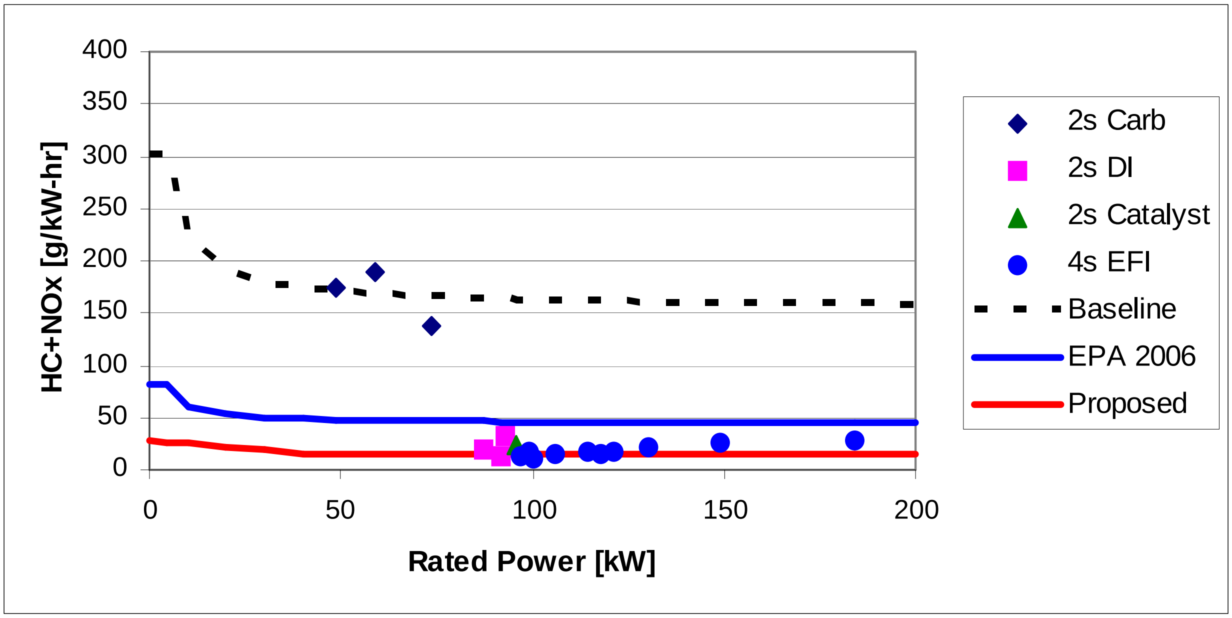
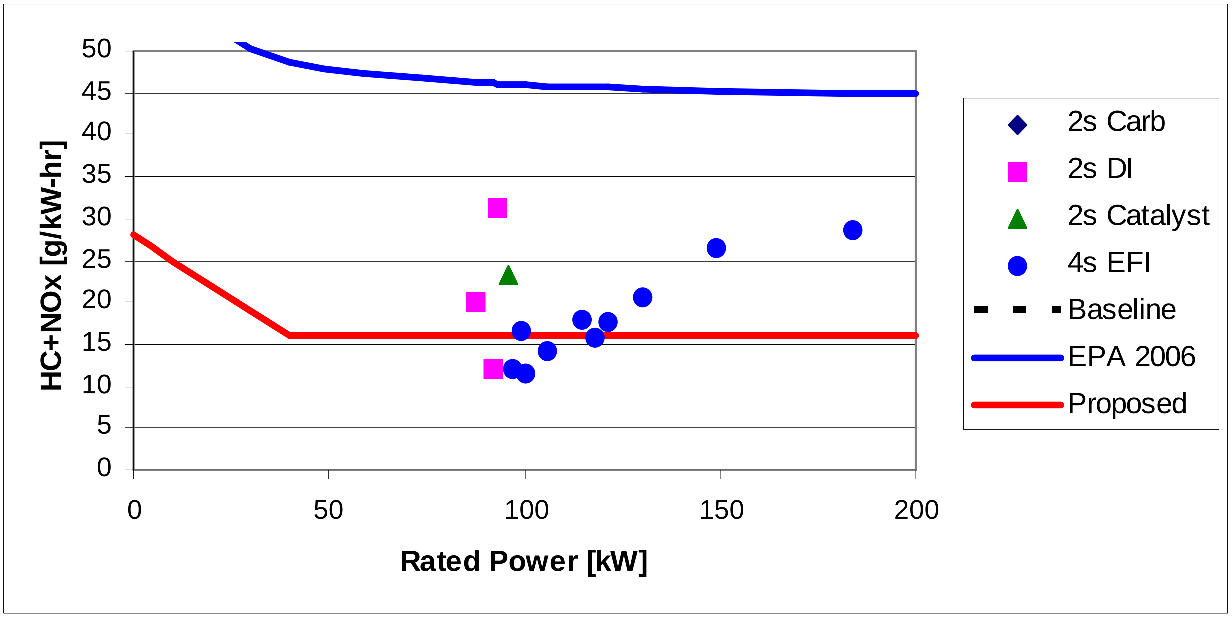


Figure 4.4-4: 2006 MY New Technology PWC HC+NOx Certification Levels



4.4.1.2 CO Certification Data

Although no exhaust emission standards for CO are currently in place for Marine SI engines, the technological advances associated with the HC+NOx standards have resulted in lower CO emissions for many engines. Figures 4.4-5 and 4.4-6 present reported CO exhaust emission levels for certified outboard and personal watercraft engines. These engines use similar technology as outboard engines and show similar emission results.

Figure 4.4-5: Reported CO Emission Levels for 2006 MY Outboard Engines

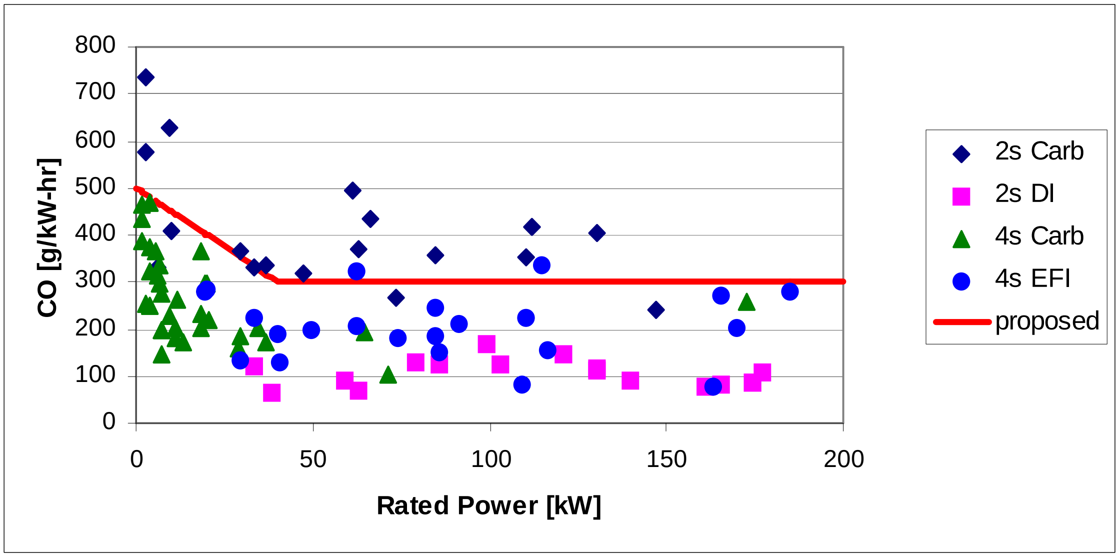
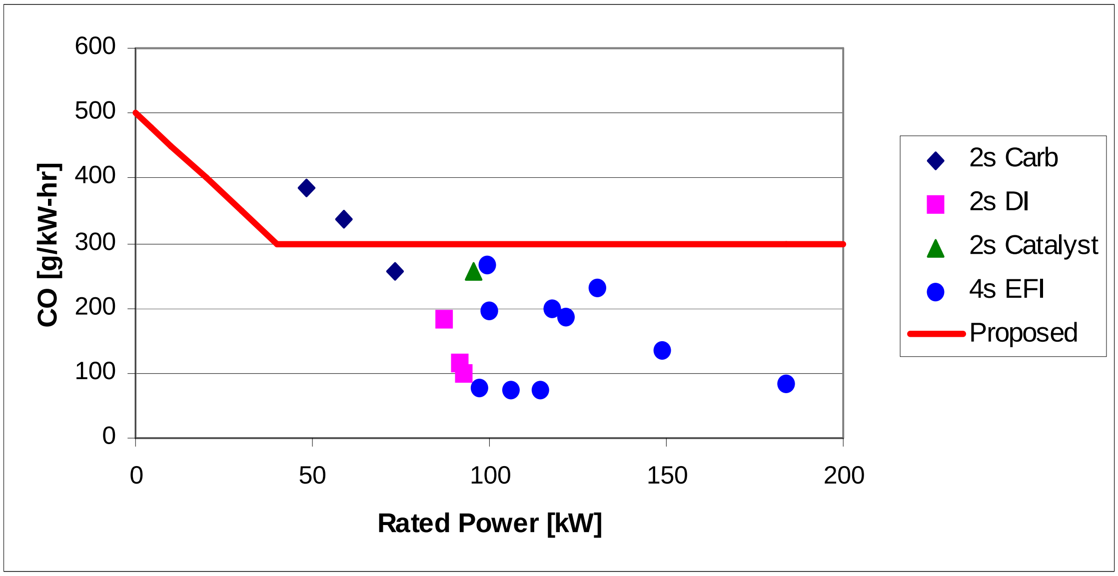


Figure 4.4-6: Reported CO Emission Levels for 2006 MY PWC Engines



4.4.2 OB/PWC Emission Control Technologies

This section discusses the how general technologies discussed above apply to outboard and PWC applications and discusses specific OB/PWC technology.

4.4.2.1 Conventional Two-Stroke Engines

As discussed earlier in this chapter, hydrocarbon emissions from two-stroke engines are primarily the result of short-circuiting losses where unburned fuel passes through the engine and out the exhaust during cylinder charging. Even with an indirect injection system, the air and fuel are mixed prior to entering the cylinder. Therefore, even though there is better metering of fuel and air than with a carbureted engine, short-circuiting losses still occur. Because of the very rich and cool conditions, little NOx is formed. As shown in Figures 4.4-1 and 4.4-2, HC emissions can range from 100 to 400 g/kW-hr. CO is formed as a product of incomplete combustion. As a result, CO emissions range from 200 to 500 g/kW-hr from these engines.

4.4.2.2 Direct Injection Two-Stroke Engines

The primary advantage of direct-injection (DI) for a two-stroke is that the exhaust gases can be scavenged with fresh air and fuel can be injected into the combustion chamber after the exhaust port closes. As a result, hydrocarbon emissions, fuel economy, and oil consumption are greatly improved. Some users prefer direct-injection two-stroke engines over four-stroke engines due to the higher power to weight ratio. Today, this technology is used on engines with power ratings ranging from 35 to 220 kW. One manufacturer has recently stated its plans to manufacture DI two-stroke engines as low as 7.4 kW.

Most of the DI two-stroke engines currently certified to the current OB/PWC emissions standards have HC+NOx emissions levels somewhat higher than certified four-stroke engines. These engines also typically have lower CO emissions due to the nature of a heterogeneous charge. By injecting the fuel directly into a charge of air in the combustion chamber, localized areas of lean air/fuel mixtures are created where CO is efficiently oxidized. PM emissions may be higher for DI two-stroke engines than for four-stroke engines because oil is burned in the combustion chamber and because of localized rich areas in the fuel injection stream.

Recently, one manufacturer has introduced a newer technology DI two-stroke engine that has comparable HC+NOx emission results as many of the certified four-stroke engines.[47] This engine makes use of a low-pressure fuel injection nozzle that relies on high swirl to produce uniform fuel flow rates and droplet sizes. Also, significant improvements have been made in oil consumption. As with the older DI two-stroke designs, CO emissions are much lower than comparable four-stroke engines. What is unique about this design is that the manufacturer has reported lower PM emissions than for a comparable four-stroke engine.

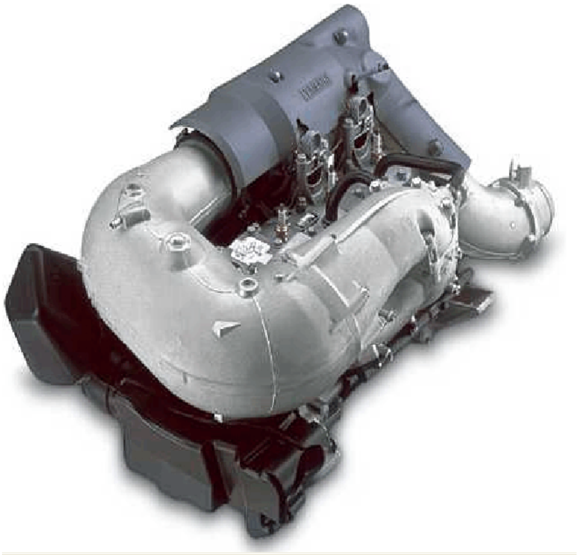
4.4.2.3 Four Stroke Engines

Manufacturers currently offer four-stroke Marine SI engines with power ratings ranging from 1.5 to 224 kW. These engines are available with carburetion, throttle-body fuel injection, or multi-point fuel injection. Carbureted engines are offered from 1.5 to 60 kW while fuel injected engines are offered from 22 to 224 kW. One manufacturer has stated that the fuel injection systems are too expensive to use on the smaller engine sizes. Most of the four-stroke outboard engines above 19 kW have HC+NOx emissions below 16 g/kW-hr and many have emissions below 13 g/kW-hr. CO emissions for these engines range from 150 to 250 g/kW-hr. Based on the certification data, whether the engine is carbureted or fuel injected does not have a significant effect on combined HC+NOx emissions. For PWC engines, the HC+NOx levels are somewhat higher. However, many of the four-stroke PWC engines are below 16 g/kW-hr. CO emissions for these engines are similar as those for four-stroke outboards.

4.4.2.4 Catalysts

One manufacturer has certified two PWC engine models with oxidation catalysts. One engine model uses the oxidation catalyst in conjunction with a carburetor while the other uses throttle-body fuel injection. The engine with throttle-body fuel injection has an HC+NOx emission rate of 25 g/kW-hr which is significantly below the EPA 2006 standard. In this application, the exhaust system is shaped in such a way to protect the catalyst from water and is nearly as large as the engine (see Figure 4.4-7). We are not aware of any efforts to develop a three-way catalyst system for PWC engines.

Figure 4.4-7: PWC Engine with Catalyst



We are also not aware of any development efforts to package a catalyst into the exhaust system of an outboard marine engine. In current designs, water and exhaust are mixed in the exhaust system to help cool the exhaust and tune the engine. Water often works its way up through the exhaust system because the lower end in under water and due to pressure pulses. As discussed above, salt-water can be detrimental to catalyst performance and durability. In addition, the lower unit of outboards are designed to be as thin as possible to improve the ability to turn the engine on the back of the boat and to reduce drag on the lowest part of the unit. Certainly, the success of packaging catalysts in sterndrive and inboard boats in recent development efforts (see below) suggests that catalysts may be feasible for outboards. However, this has not yet been demonstrated and significant development efforts would be necessary.

4.5 Feasibility of Sterndrive/Inboard Marine Engine Standards

We are proposing exhaust emission standards for spark-ignition sterndrive and inboard (SD/I) engines. These proposed emission standards are supported by data collected on SD/I engines equipped with catalysts. This section presents exhaust emission data from baseline SD/I engines as well as data from SD/I engines equipped with lean calibrations, exhaust gas recirculation, and catalytic control.

4.5.1 Baseline SD/I Emissions Data

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

Table 4.5-1 presents baseline emissions for four-stroke SD/I engines built up from automotive engine blocks.[48,49,50,51,52,53,54] All these data were collected during laboratory tests over the ISO E4 duty cycle. Five of these engines are carbureted, one uses throttle-body fuel injection, and four use multi-port fuel injection. One of the multi-port fuel injected engines was tested with three calibrations. Note that without emissions calibrations performed specifically for low emissions, the HC+NOx emissions are roughly equal for the carbureted and fuel injected engines. Using the straight average, HC+NOx from the carbureted engines is 15.6 g/kW-hr while it is 16.0 g/kW-hr from the fuel injected engines (15.1 g/kW-hr if the low HC calibration outlier is excluded).

Table 4.5-1: Baseline SD/I Exhaust Emission Data

Engine #	Power [kW]	Fuel Delivery System	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]
1	79	carburetor	11.2	8.0	281
2	91	carburetor	4.4	13.9	98
3	121	carburetor	8.5	6.0	247
4	153	multi-port electronic fuel injection	4.9	11.7	111
5	158	carburetor	7.3	6.0	229
6	167	carburetor	8.0	5.7	174
7	196	carburetor	4.4	10.3	101
8	159	throttle-body fuel injection	2.9	8.7	42
9	185	multi-port electronic fuel injection	5.2	9.7	149
9	181	#9, low CO calibration	5.8	11.7	48
9	191	#9, low HC calibration	3.3	18.2	72
10	219	multi-port electronic fuel injection	4.7	9.4	160
11	229	multi-port electronic fuel injection	2.7	13.1	44

A distinct class of SD/I engines are the high-performance engines. These engines are similar to SD/I engines except that they are designed for high power output at the expense of engine durability. This high power output is typically achieved through higher fuel and air rates, larger combustion chambers, and through higher peak engine speeds. In most cases, custom engine blocks are used. Even in the engines that use an automotive block, few stock automotive engine components are used. Table 4.5-2 presents emission data collected on five high-performance engines.[55,56,57]

Table 4.5-2: Baseline High Performance SD/I Exhaust Emission Data [g/kW-hr]

Engine #	Power [kW]	Fuel Delivery System	HC	NOx	CO	BSFC
1	391	multi-port electronic fuel injection	14.7	3.8	243	354
2	550	carburetor	13.2*	8.4	253	376
3	634	multi-port electronic fuel injection, supercharger	16.9	9.1	135	348
4	778	throttle-body fuel-injection, supercharger, intercooler	7.6	4.9	349	448
5	802	multi-port electronic fuel injection, supercharger	16.1	9.4	102	299

* may be higher, HC concentration at idle was out of measurement range

4.5.2 Exhaust Gas Recirculation Emission Data

We collected data on three engines over the ISO E4 marine test cycle with and without the use of exhaust gas recirculation (EGR).[58,59,60] The first engine was a 6.8 L Ford heavy-duty highway engine. Although this was not a marine engine, it uses the same basic technology as SD/I engines. The second and third engines were the 7.4 L and 4.3 L SD/I engines used in the catalyst development described below. These engines are marinized versions of GM heavy-duty highway engines. The baseline emissions from the 7.4 L engine are a little different than presented below in the catalyst discussion because engine head was rebuilt prior to the catalyst development work.

This test data suggests that, through the use of EGR on a SD/I marine engine, a 40-50 percent reduction in NOx (30-40 percent reduction in HC+NOx) can be achieved. EGR was not applied at peak power in this testing because the throttle is wide open at this point and displacing fresh air with exhaust gas at this mode of operation would reduce power. We also did not apply EGR at idle because the idle mode does not contribute significantly to the cycle weighted NOx.

Table 4.5-3: Exhaust Emission Data Using EGR on the E4 Marine Duty Cycle

EGR Scenario	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	Power [kW]	BSFC [g/kW-hr]
6.8 L Engine: baseline	2.7	13.4	26.5	145	326
with EGR	2.7	7.1	24.3	145	360
7.4 L Engine: baseline	4.5	8.4	171	209	349
with EGR	4.5	4.8	184	209	356
4.3 L Engine: baseline	4.9	11.7	111	153	329
with EGR	4.2	5.3	92	148	350

4.5.3 Catalytic Control Emission Data

4.5.3.1 Engine Testing

In a joint effort with the California Air Resources Board (ARB), we contracted with Southwest Research Institute to perform catalyst development and emission testing on a SD/I marine engine.[61] This test program was performed on a 7.4 L electronically controlled Mercruiser engine with multi-port fuel injection. Figure 4.5-1 illustrates the three primary catalyst packaging configurations used in this test program. The upper right-hand picture shows a catalyst packaged in a riser extension which would be placed between the lower exhaust manifold and the exhaust elbow. This riser had the same outer dimensions as the stock riser extension produced by Mercury Marine. The upper left-hand picture shows a catalyst packaged in the elbow. The lower picture shows a larger catalyst that was packaged downstream of the exhaust elbow. All of these catalyst configurations were water jacketed to prevent high surface temperatures.

Figure 4.5-1: Three Catalyst Configurations Used in SD/I Test Program

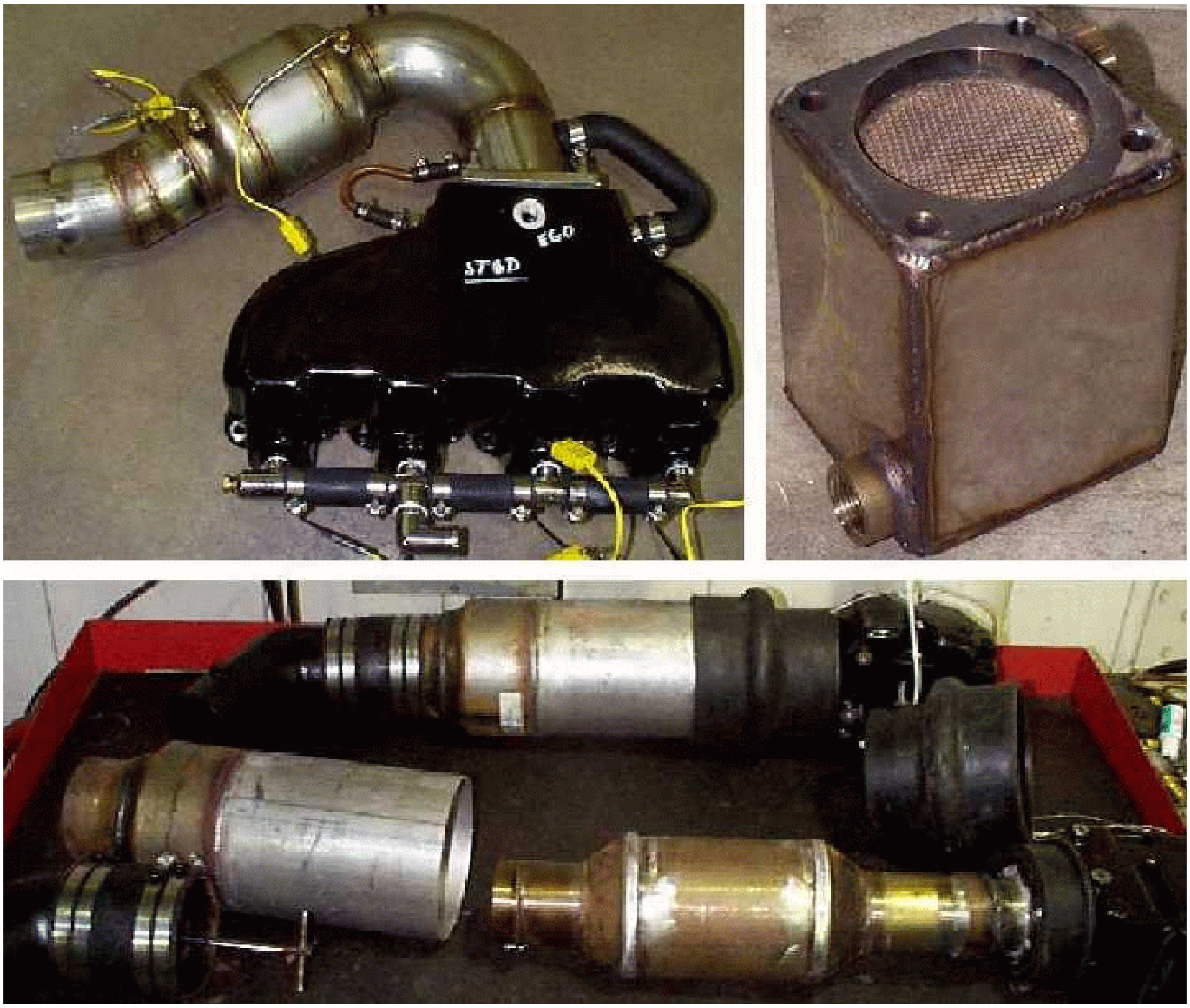


Table 4.5-4 presents the exhaust emission results for the baseline test and three catalyst packaging configurations. In each case a pair of catalysts were used, one for each exhaust manifold. For the riser catalyst configuration, we tested the engine with two cell densities, 60 and 300 cells per square inch (cpsi), to investigate the effects of back-pressure on power. The catalysts reduced in HC+NOx in the range of 42 to 77 percent and reduced CO in the range of 46 to 54 percent. There were no significant impacts on power, and fuel consumption actually improved due to the closed-loop engine calibrations necessary to optimize the catalyst effectiveness. At the full power mode, we left the engine controls in open-loop and allowed it to operate rich to protect the catalysts from over-heating.

Table 4.5-4: Exhaust Emission Data on a 7.4 L SD/I Engine with Various Catalysts

Catalyst Scenario* (cell density, volume, location)	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	Power [kW]	BSFC [g/kW-hr]
baseline (no catalyst)	4.7	9.4	160	219	357
60 cpsi, 0.7 L, riser	2.5	5.7	81	214	345
300 cpsi, 0.7 L, riser	1.7	1.9	87	213	349
400 cpsi, 1.3 L, elbow	2.8	1.1	81	217	337
200 cpsi, 1.7 L, downstream	2.1	1.2	83	221	341

*Multiply volume by two for total catalyst volume per engine.

Additional reductions in HC+NOx and CO can be achieved by using EGR in addition to a catalyst. However, the added benefit of EGR is small combined to the emission reductions achieved by the catalysts. Regardless, the use of EGR could give manufacturers some flexibility in the design of their catalyst. In the catalyst testing work described above on the 7.4 L SD/I marine engine, each of the catalyst configurations were tested with and without EGR. Table 4.5-5 presents these test results.

Table 4.5-5: Exhaust Emission Data on a 7.4 L SD/I Engine with Catalysts and EGR

Catalyst Scenario* (cell density, volume, location)	HC+NOx [g/kW-hr]		CO [g/kW-hr]	
	catalyst	catalyst + EGR	catalyst	catalyst + EGR
60 cpsi, 0.7 L, riser	8.2	6.8	81	74
300 cpsi, 0.7 L, riser	3.6	2.8	87	77
400 cpsi, 1.3 L, elbow	3.9	3.3	81	76
200 cpsi, 1.7 L, downstream	3.3	2.5	83	73

*Multiply volume by two for total catalyst volume per engine.

4.5.3.2 Freshwater Boat Testing

The catalyst testing described above was a first step in developing and demonstrating catalysts that can reduce emissions from Marine SI engines. However, this program only looked at catalysts operating in a laboratory. Additional efforts have been made to address issues with using catalyst in marine applications by operating an engines in boats with catalysts. When the California Air Resources Board finalized their catalyst-based emission standards for SD/I engines, they agreed to further assessment of the durability of catalyst used in boats through technology review.

To that end, ARB, industry and the U.S. Coast Guard recently performed a cooperative in-boat demonstration program designed to demonstrate the feasibility of using catalysts in SD/I applications.[62,63] This testing included four boats, two engine types, and four catalysts. The catalysts were packaged in the exhaust emission manifold in such a way that they were water-jacketed and capable of fitting within the existing boat design. Each of the boats were operated by the U.S. Coast Guard for 480 hours on a fresh water lake. This service accumulation period, which was intended to represent the useful life of typical SD/I engines, began in December of 2003 and was completed in September of 2004. Table 4.5-6 presents a description of the boats that were used in the test program.

Table 4.5-6: Vessel Configurations for Full Useful Life Catalyst Testing

Boat	Engine	Catalyst Type	Catalyst Volume*	Catalyst Cell Density
Inboard Straight-Drive Ski Boat	5.7 L, V-8	metallic	1.4 L	300 cpsi
Inboard V-Drive Runabout	5.7 L, V-8	ceramic	1.7 L	400 cpsi
22 ft, Sterndrive Bowrider	5.7 L, V-8	metallic	1.4 L	200 cpsi
19 ft. Sterndrive Runabout	4.3 L, V-6	ceramic	0.7 L	400 cpsi

*Multiply volume by two for total catalyst volume per engine.

Exhaust emissions were measured for each catalyst before and after the durability testing.[64] No significant deterioration was observed on any of the catalysts. In fact, all of the 5.7 L engines were below the proposed standard of 5 g/kW-hr HC+NOx even after the durability testing. Although the zero hour emissions for the 4.3 L engine were less than half of the proposed HC+NOx standard, the final emissions for the 4.3 L engine were 15 percent above the proposed HC+NOx standard. However, it should be noted that the 4.3L engine was determined to have excessive fuel delivered to one cylinder bank and low compression in one of the cylinders. These problems did not appear to be related to the catalyst installations and would account for the increase in emissions even without catalyst deterioration. Once the calibration on this engine was corrected, a level of 5 g/kW-hr HC+NOx was achieved. In addition, no deterioration was observed in the oxygen sensors which were installed upstream of the catalysts.

Significant carbon monoxide emission reductions were achieved, especially at lower power modes. At wide-open-throttle, the engines operated in open-loop to prevent the exhaust valves from overheating. Additional reductions in CO could be achieved through better fuel air ratio control. For instance, although the engines in this test program were fuel injected, batch injections were used. In other words, all of the fuel injectors for each bank were firing at the same time rather than timing the fuel injection with the valve timing for each individual cylinder. Because of this strategy, the engine would need to be calibrated somewhat rich. The next generation of electronics for these engines are expected to have more sophisticated control which would allow for optimized timing for each fuel injector.

Table 4.5-7: Vessel Configurations for Full Useful Life Catalyst Testing

Boat	Catalyst Aging	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]
5.7 L engine	baseline (no catalyst)	5.4	6.7	193
4.3 L engine	baseline (no catalyst)	4.9	11.7	111
Inboard Straight-Drive Ski Boat	0 hours	1.7	1.0	100
	480 hours	2.1	1.7	117
Inboard V-Drive Runabout	0 hours	1.8	0.5	87
	480 hours	1.7	1.0	102
22 ft, Sterndrive Bowrider	0 hours	1.8	0.5	74
	480 hours	1.5	0.9	93
19 ft. Sterndrive Runabout	0 hours	1.9	0.5	106
	480 hours*	2.9	2.1	116

* after calibration corrected

4.5.3.3 Saltwater Boat Testing

Two test programs were initiated to investigate the feasibility of using catalysts on boats used in saltwater. In the first program, a small boat with a catalyst was operated over a set of operation conditions, developed by industry, to represent the worst case conditions for water reversion. In the second test program, three boats were equipped with catalysts and operated for an extended period similar to the fresh water testing.

4.5.3.3.1 Safety, Durability, and Performance Testing

We contracted with SwRI to test catalysts on a sterndrive engine before and after operation on a boat in saltwater.[65] The purpose of the testing was to determine if the catalyst would be damaged by water reversion in the exhaust manifold. This testing was performed on a 19 foot runabout with a 4.3 L sterndrive engine. On previous testing on this boat without a catalyst, SwRI found that the only water collected in the exhaust manifold was due to condensation. They were able to prevent this condensation by fitting the water jacket around the exhaust system with a thermostat to keep the manifold walls from becoming too cool.

The 4.3 L engine was fitted with a pair of riser catalysts similar to the one illustrated in Figure 4.5-1. These catalysts had a cell density of 300 cpsi and a combined volume of 1.4 L. The catalysts were water-jacketed to maintain low surface temperatures and, to prevent any possible water reversion, cones were inserted in the exhaust elbows. These cones were intended to increase the difficulty for water to creep up the inner walls of the exhaust manifold. The water jacketing system was fitted with a 82°C thermostat to keep the manifold wall temperatures above the dew point of the exhaust gas (~50°C) thereby preventing water condensation in the exhaust manifold.

Prior to testing, the catalysts were aged using a rapid aging cycle designed to represent 50,000 miles of vehicle operation. SwRI estimated that this would likely be more severe than would be seen over the useful life of an SD/I engine. The engine was then tested for emissions, in a test cell, with and without the aged catalysts installed in the exhaust manifold risers. In addition to adding the catalysts, the engine fueling was optimized using closed-loop electronic emission control.

After the baseline emission tests, the catalysts were installed on a 19 foot runabout equipped with a similar 4.3 L engine used in the emissions test cell. The boat was operated on saltwater over a number of safety, durability, and performance tests that were developed by industry for heat soak, water ingestion, and engine exhaust back-pressure. In addition, SwRI operated the boat over tests that they designed to represent operation and use that would most likely induce water reversion. After this boat testing, the catalyst was returned to the laboratory for a repetition of the baseline emission tests.

Table 4.5-8 presents the baseline, aged catalyst, and post boat operation catalyst emission test results. No significant deterioration of the catalysts were observed. Prior to boat testing, the aged catalysts achieved a 75 percent reduction in HC+NOx and a 36 percent reduction in CO. After the boat operation in saltwater, the catalysts achieved a 73 percent reduction in HC+NOx and a 34 percent reduction in CO. As described in Chapter 3, if saltwater had reached the catalyst, there would have been a large reduction in catalyst efficiency. No salt deposits were observed on the catalysts when they were removed from the boat.

Table 4.5-8: Exhaust Emission Data on a 4.3 L SD/I Engine with Catalysts

Catalyst Scenario	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	Power [kW]	BSFC [g/kW-hr]
open-loop, no catalyst	4.9	11.7	111	153	329
closed-loop, no catalyst	4.5	10.4	101	153	327
aged catalyst pre boat	2.1	2.0	70	154	321
aged catalyst post boat	2.2	2.3	73	150	327

4.5.3.3.2 Extended Period In-Use Testing

We engaged in a test program with the California Resources Board, United States Coast Guard, National Marine Manufacturers Association, the Texas Department of Parks and Wildlife, and Southwest Research Institute to evaluate three additional engines with catalysts in vessels operating on salt-water. Early in the program, two of the three manifolds experienced corrosion in the salt-water environment resulting in water leaks and damage to the catalyst.

These manifolds were rebuilt with guidance from experts in the marine industry and additional hours were accumulated on the boats. Although the accumulated hours are well below the 480 hours performed on fresh water, the completed operation showed no visible evidence of water reversion or damage to the catalysts. Table 4.5-9 presents initial exhaust emission results for the three engines, equipped with catalysts, included in this test program.

Table 4.5-9: Baseline Emission Data for Engines/Catalysts in Saltwater Test Program

Catalyst Scenario	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	Power [kW]	BSFC [g/kW-hr]
Maxum, 4.3L V6, ceramic catalysts	2.1	0.7	136	150	345
Sea Ray, 5.7L V8, metal catalysts	1.3	0.3	114	191	351
Malibu, 5.7L V8, ceramic catalysts	0.5	0.4	107	194	348

4.5.3.4 Production Engines

To date, one manufacturer is selling inboard Marine SI engines equipped with catalysts. These engines are certified in California and are being sold nationwide. The engines are based on 5.7L automotive blocks and use electronically controlled fuel injection, twin catalysts, and onboard diagnostics. The manufacturer, Indmar, has also performed extended durability testing in a saltwater environment. Test data from this engine is presented in Table 4.5-10, with and without an applied deterioration factor.[66] One advantage that Indmar has promoted with this engine is very low CO at part throttle. Part throttle operation is associated with lower boat speeds where the risk of CO poisoning is highest. The measured CO over the marine duty cycle is primarily due to emissions at wide open throttle, where the engine goes to open loop rich operation to protect the exhaust valves from overheating.

Table 4.5-10: Exhaust Emission Data on a 5.7L Production SD/I Engine with Catalysts

	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]
measured test results	1.8	2.0	46.6
with deterioration factor applied	2.0	2.3	51.8

Other marine engine manufacturers have indicated that they will produce catalyst-equipped SD/I engines, certified to the California emission standards, by the end of this year.

4.5.3.5 CO Emissions Reductions at Low versus High Power

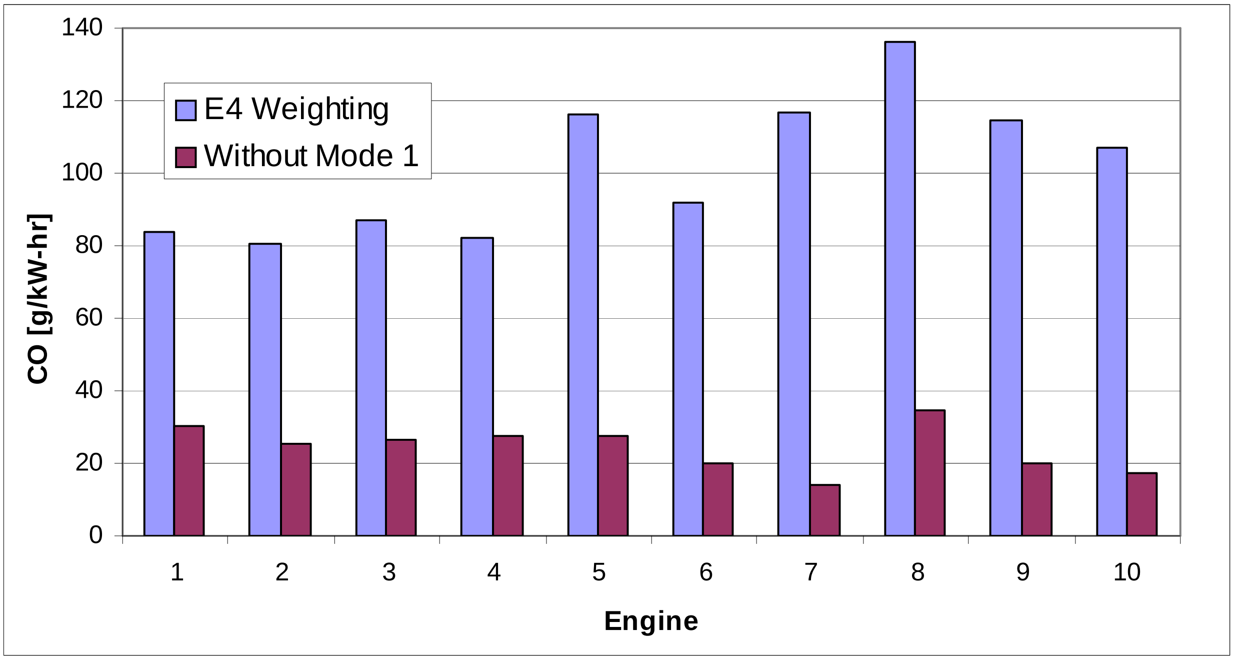
Under stoichiometric or lean conditions, catalysts are effective at oxidizing CO in the exhaust. However, under very rich conditions, catalysts are not effective for reducing CO emissions. SD/I engines often run at high power modes for extended periods of time. At these temperatures, engine marinizers must calibrate the engine to run rich as an engine protection strategy. If the engine were calibrated for a stoichometric air-fuel ratio at high power, high temperatures could lead to failures in exhaust valves and engine heads.

All of the data presented above on SD/I engines equipped with catalysts were based on engines that used open-loop engine control at high power. As a result, the catalysts achieved little reduction in HC and CO at full power (test mode 1). However, NOx reductions were achieved at mode 1 because NOx is effectively reduced under rich conditions.

The catalysts were effective in reducing CO in modes 2 through 5 of the proposed test procedure. In these lower power modes, the engines described above saw CO reductions on the order of 80 percent. However, the weighted values over the proposed test cycle only show about a 50 percent reduction in CO because of the high contribution of mode 1 to the total weighted CO value. Studies have shown that there is a higher risk of operator exposure to CO at lower boat speeds[67] which would correspond to lower engine power modes. This suggests that CO reductions at lower power modes may be more beneficial than CO reductions at full power.

To look at the effect of mode 1 on the cycle weighted CO levels, we performed an analysis in which we recalculated the CO level for ten catalyst-equipped SD/I engines without mode 1. To determine the weighted value without mode 1, the weighting factor for mode 1 was set to zero percent and the weighting factors for modes 2 and 3 were each increased so that weighting factors would sum to 100 percent. Figure 4.5-2 compares the CO emissions with and without including mode 1 for these engines. Although mode 1 is only weighted as 6 percent of the proposed test cycle, but makes up the majority of the cycle weighted CO value. Based on this analysis, the weighed CO level would be 70-90 percent lower if mode 1 were not included in the test procedure.

Figure 4.5-2: CO Emissions for SD/I Engines Equipped with Catalysts with and without Including Mode 1 in the Weighted Results



4.6 Feasibility of Standard for Marine Generator Sets

Currently, SI marine generator sets are regulated as Small SI or Large SI engines, depending on their size. Most SI marine generators are less than 25 hp and are therefore classified as Small SI engines. Generator sets in marine applications are unique in that they use liquid-cooled engines. Liquid cooling allows manufacturers to minimize the temperature of hot surfaces on marine generators, thereby reducing the risk of fires on a boat. For marine applications, liquid cooling is practical because of the nearly unlimited source of cooling water around the boat.

Another safety issue that has become apparent in recent years is carbon monoxide poisoning on boats. Studies have shown that exhaust emissions from engines on boats can lead to user exposure of high levels of carbon monoxide.[68] The marine industry, Coast Guard, American Boat and Yacht Council, and other stakeholders have been meeting regularly over the past several years in an attempt to mitigate the risk of CO poisoning in boating.[69,70] Mitigation strategies that have been discussed at these meetings include labeling, education, diverting the exhaust flow with smoke stacks, CO detectors, low CO emission technologies, and emission standards.

The vast majority of gasoline marine generators are produced by two engine manufacturers. Recently, these two manufacturers have announced that they are converting their marine generator product lines over to low CO engines.[71,72] They have stated that this is to reduce the risk of CO poisoning and that this action is a result of boat builder demand. Both manufacturers are using a combination of closed-loop electronic fuel injection and catalytic control. To date, both of these manufacturers have certified some low CO engines and have stated their intent to convert their full product lines in the near future. These manufacturers also make use of the electronic controls to monitor catalyst function. Table 4.6-1 presents the 2005 model year certification levels for these engines.

Table 4.6-1: 2005 MY Certification Levels for Low CO Marine Generator Engines

Engine Manufacturer	Power [kW]	Emission Control System	HC+NOx [g/kW-hr]	CO [g/kW-hr]
Kohler Power Systems	10.2	throttle-body injection, O_2 sensor, catalyst	7.2	5.2
Westerbeke	7.5 17.9	throttle-body injection, O_2 sensor, catalyst throttle-body injection, O_2 sensor, catalyst	2.0 4.4	0.01 0.0

In use testing has been performed on two marine generator engine equipped with catalysts. These engines were installed on rental houseboats and operated for a boating season. Testing was first performed with low hours of operation; 108 hours for the 14 kW engine and 159 hours for the 20 kW.[73] The CO performance was reported to be "impressive with exhaust stack CO emissions of approximately 200 ppm for a fully warmed generator." The emissions measured around the boat were much lower due to dilution. According to the manufacturer, no significant deterioration has been found in the emission performance of the catalysts. Note that the manufacturer recommends changing the catalysts at 2000 hours and inspecting for CO at 1000 hours.

4.7 Test Procedures

We are proposing several technical amendments to the existing exhaust emission test procedures for Small SI and OB/PWC engines. These amendments are part of a larger effort to develop uniform test procedures across all of our programs. We are proposing to include SD/I engines in these test procedures. In addition we are proposing not-to-exceed requirements for Marine SI engines. These new procedures are discussed in this section.

4.7.1 SD/I Certification Test Procedure

We are proposing to use the same certification duty cycle and test procedures for all Marine SI engines, including sterndrives and inboards. Table 4.5-6 presents the proposed certification test duty cycle. This duty cycle is commonly referred to as the E4 duty cycle and was developed using operational data on outboard and sterndrive marine gasoline engines.[74] In addition, the E4 duty cycle is recommended by the International Standards Organization for use with all spark-ignition pleasurecraft less than 24 meters in length.[75] Although some Marine SI engines may be used for commercial activities, these engines would not likely be made or used differently than those used for pleasure.

Table 4.7-1: SI Marine Certification Steady-State Test Duty Cycle

Mode	% of Maximum Test Speed (MES)	% of Maximum Torque at MES	% of Maximum Power* at MES	Weighting Factor
1	100	100	100	0.06
2	80	71.6	57.2	0.14
3	60	46.5	27.9	0.15
4	40	25.0	10.1	0.25
5	idle	0	0	0.40

*% power = (% speed) × (% torque).

4.7.2 SI Marine Not-To-Exceed Requirements

EPA is concerned that if a marine engine is designed for low emissions on average over a low number of discrete test points, it may not necessarily operate with low emissions in-use. This is due to a range of speed and load combinations that can occur on a vessel which do not necessarily lie on the test duty cycle. For instance, the test modes on the E4 duty cycle lie on an average propeller curve. However, a propulsion engine may never be fitted with an “average propellor.” In addition, a light planing hull boat may operate at much lower torques than a heavily loaded boat.

It is our intent that an engine operate with low emissions under all in-use speed and load combinations that can occur on a boat, rather than just the discrete test modes in the five-mode duty cycle. To ensure this, we are proposing requirements that extend to typical in-use operation. We are proposing not-to-exceed (NTE) requirements similar to those established for marine diesel engines. Under this approach, manufacturers would design their engines to comply with a not-to-exceed limit, tied to the standard, for HC+NOx and CO, within the NTE zone. In the cases where the engine is included in averaging, banking, and trading of credits, the NTE limits would be tied to the family emission limits. We would reserve the right to test an engine in a lab or installed in a boat to confirm compliance to this requirement.

We believe there are significant advantages to taking this approach. The test procedure is very flexible so it can represent the majority of in-use engine operation and ambient conditions. Therefore, the NTE approach takes all of the benefits of a numerical standard and test procedure and expands it to cover a broad range of conditions. Also, laboratory testing makes it harder to perform in-use testing because either the engines would have to be removed from the vessel or care would have to be taken that laboratory-type conditions can be achieved on the vessel. With the NTE approach, in-use testing and compliance become much easier because emissions may be sampled during normal vessel use. Because this approach is objective, it makes enforcement easier and provides more certainty to the industry of what is expected in use versus over a fixed laboratory test procedure.

Even with the NTE requirements, we believe it is still important to retain standards based on the steady-state duty cycle. This is the standard that we expect the certified marine engines to meet on average in use. The NTE testing is more focused on maximum emissions for segments of operation and should not require additional technology beyond what is used to meet the proposed standards. We believe basing the emission standards on a distinct cycle and using the NTE zone to ensure in-use control creates a comprehensive program. In addition, the steady-state duty cycles give a basis for calculating credits for averaging, banking, and trading.

We believe that the same technology that can be used to meet the standards over the five-mode certification duty cycle can be used to meet the NTE caps in the NTE zone. We therefore do not expect the proposed NTE standards to cause marinizers to need additional technology. We do not believe the NTE concept results in a large amount of additional testing, because these engines should be designed to perform as well in use as they do over the steady-state five-mode certification test.

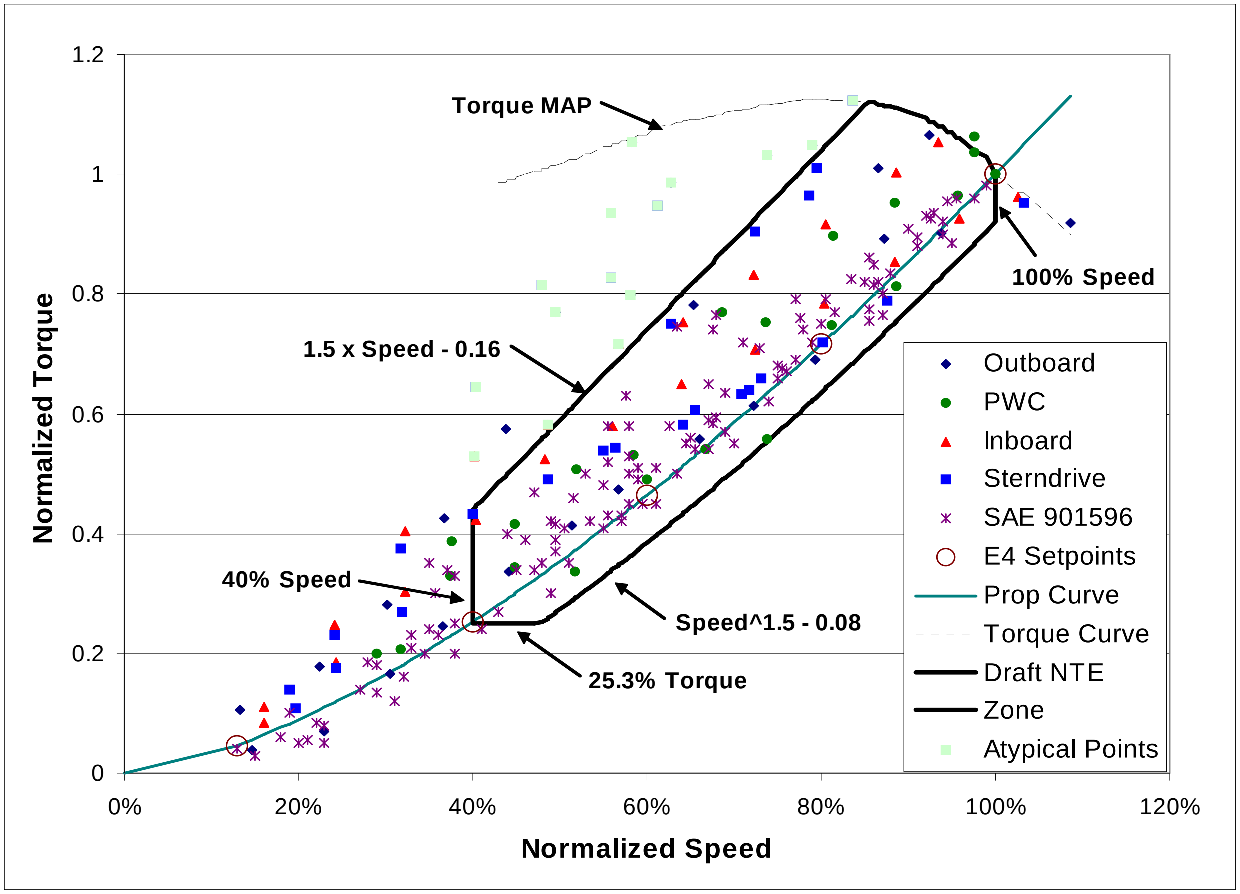
4.7.2.1 Shape of the NTE Zone

The proposed NTE zone is intended to capture typical in-use operation for marine vessels. We used two data sources to define this operation. The first data source was the collection of data on marine engine operation that was used to develop the ISO E4 steady-state duty cycle.[76] Speed and torque data were collected on 33 outboards and three sterndrives. This data showed that the marine engines generally operated along a propeller curve with some variation due to differences in boat design and operation. A propeller curve defines the relationship between engine speed and torque for a marine engine and is generally presented in terms of torque as a function of engine speed in RPM raised to an exponent. The paper uses an exponent of 1.5 as a general fit, but states that the propeller curves for Marine SI applications range from exponents of 1.15 to 2.0.

The second source of data was a study of marine engine operation recently initiated by the marine industry.[77] In this study, sixteen boats were tested in the water at various engine speeds. These boats included seven sterndrives, three inboards, four outboards, and two personal watercraft. To identify the full range of loads at each engine speed, boats were operated both fully loaded and lightly loaded. Boats were operated at steady speeds to identify torque at each speed. In some cases, the operation was clearly unsafe or atypical. We did not include these operating points in our analysis. An example of atypical operation would be with a boat so highly loaded that it was operating in an unstable displacement mode with its bow sticking up into the air.

Figure 4.7-1 presents test data from the two studies as well as the proposed NTE zone for Marine SI engines. This zone includes operation above and below the theoretical propeller curve used in the E4 duty cycle. Operation below 25 percent of rated speed is excluded because brake-specific emissions at low loads becomes very high due to low power in the denominator. This approach is consistent with the marine diesel NTE zone. The upper and lower borders of the NTE zone are designed to capture all of the typical operation that was observed in the two studies. The curve functions for these boarders are presented in Figure 4.7-1.

Figure 4.7-1: Proposed NTE Zone and Marine Engine Operation Data



When testing the engine within the NTE zone, only steady-state operation would be considered. It is unlikely that transient operation is necessary under the NTE concept to ensure that emissions reductions are achieved. We designed the proposed NTE zone to contain the operation near an assumed propeller curve that the steady-state duty cycle represents. We believe that the vast majority of the operation in the proposed NTE zone would be steady-state. When bringing a boat to plane, marine engine operation would be transient and would likely be above the proposed NTE zone. However we do not have enough information to quantify this. Also we do not believe that the NTE zone should be extended to include areas an engine may see under transient operation, but not under steady-state operation. For this reason, we do not believe that adding transient operation to the NTE requirements is necessary at this time. We would revise this opinion in the future if there were evidence that in-use emissions were increased due to insufficient emission control under transient operation

4.7.2.2 Emissions Limits for the NTE Zone

We are proposing emission caps for the NTE zone which represent a multiplier times the weighted test result used for certification. Although ideally the engine should meet the certification level throughout the NTE zone, we understand that a cap of 1.0 times the standard is not reasonable because there is inevitably some variation in emissions over the range of engine operation. This is consistent with the concept of a weighted modal emission test such as the E4 duty cycle.

In developing proposed emission caps in the NTE zone, we collected modal HC+NOx and CO emission data on a large number of OB, PWC, and SD/I engines. Because limited modal data is available in published literature,[78,79,80] most of the modal data on outboards and personal watercraft was provided confidentially by individual manufacturers. Data on SD/I engines with catalysts was collected as part of the catalyst development efforts discussed earlier in this chapter.[81,82,83,84] Our analysis focuses only on engines using technology that could be used to meet the proposed standards. The modal data is presented in Figures 4.7-2 through 4.7-9 in terms of the modal emission rate divided by the weighted E4 average for that engine. Each color bar represents a different engine. Because of the large volume of data and differences in engine operation an emissions performance, data is presented separately for carbureted 4-stroke, fuel-injected 4-stroke, and direct-injected 2-stroke OB/PWC, and for catalyst-equipped SD/I engines.

Figures 4.7-2 and 4.7-4 present normalized HC+NOx modal data for carbureted and EFI 4-stroke OB/PWC engines. Note that most of the data points are near or below the E4 weighted average (represented by bars near or below 1.0). This is largely due to the exclusion of idle operation from the NTE zone compared to the E4 duty cycle that is 40 percent weighted at idle. As mentioned above, idle is excluded because brake-specific emissions become very large at low power due to a low power figure in the denominator (g/kW-hr). Especially for the carbureted engines, higher normalized HC+NOx emissions are observed at the low power end of the NTE zone (40 percent speed, 25 percent torque). As shown in Figures 4.7-3 and 4.7-5, a similar trend is observed with normalized CO emissions from these engines.

Figure 4.7-2: Normalized Modal HC+NOx for Carbureted 4-Stroke OB/PWC

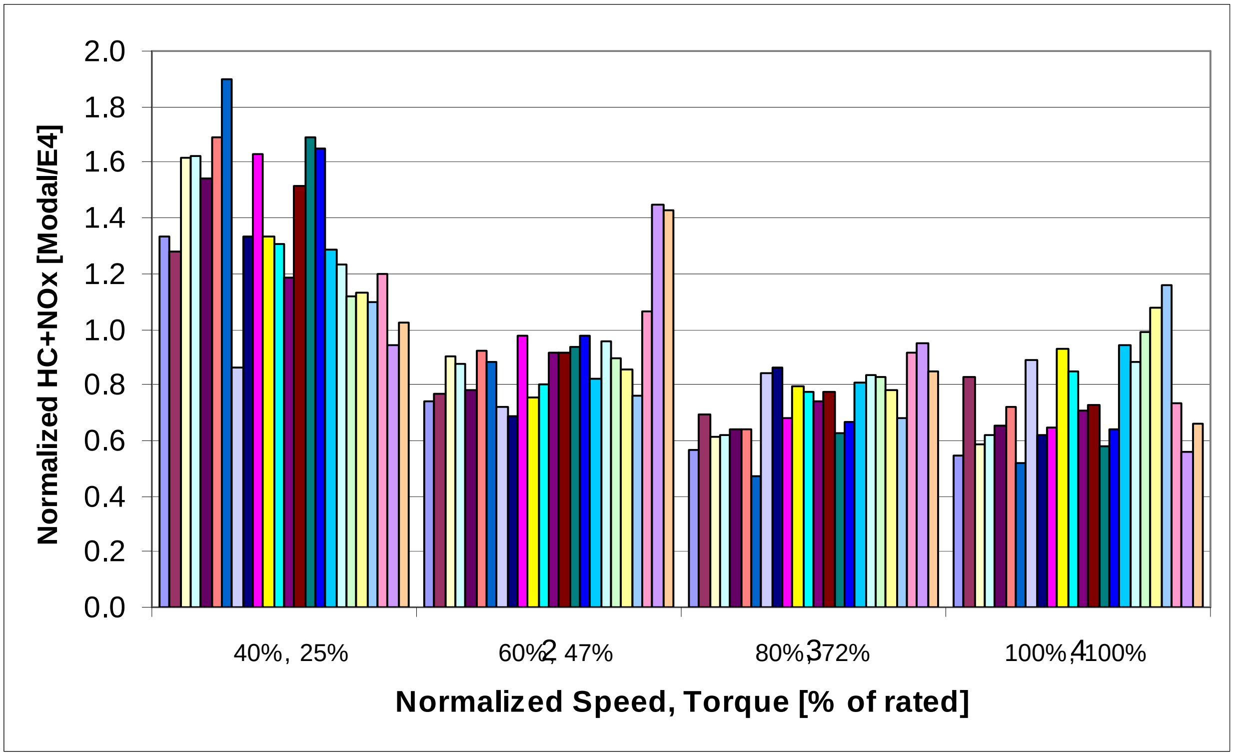


Figure 4.7-3: Normalized Modal CO for Carbureted 4-Stroke OB/PWC

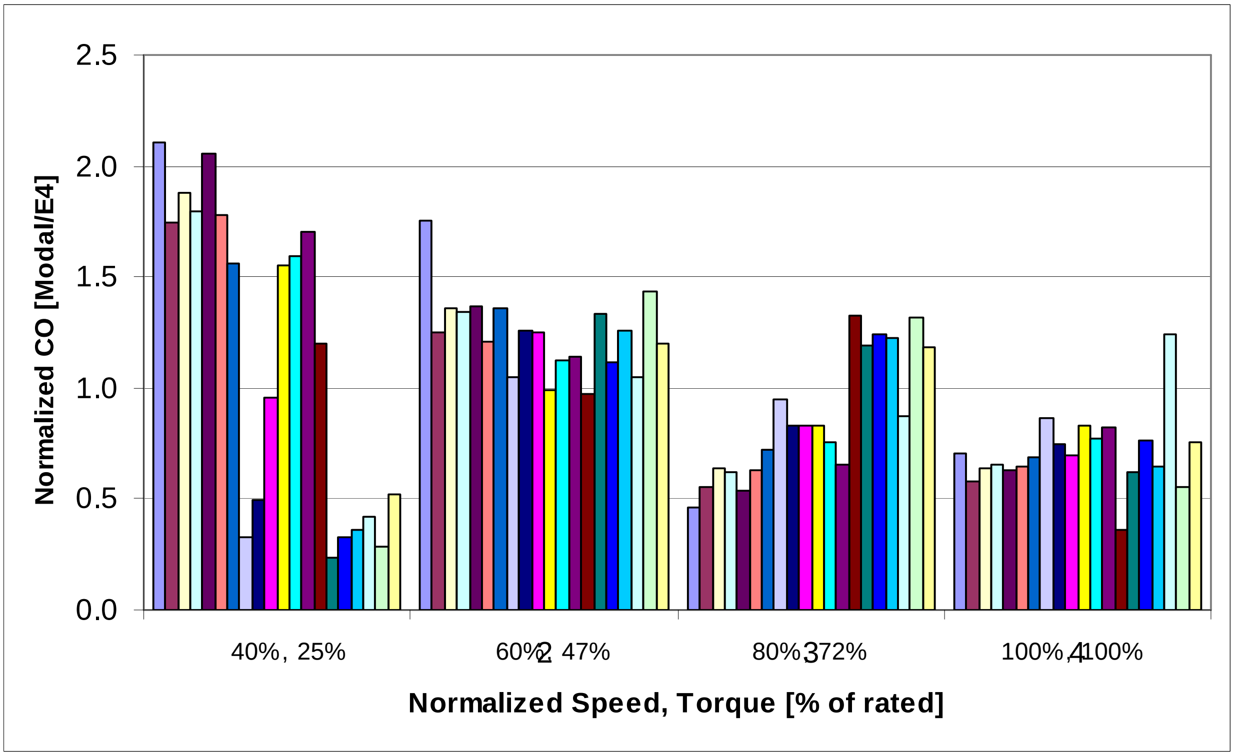


Figure 4.7-4: Normalized Modal HC+NOx for EFI 4-Stroke OB/PWC

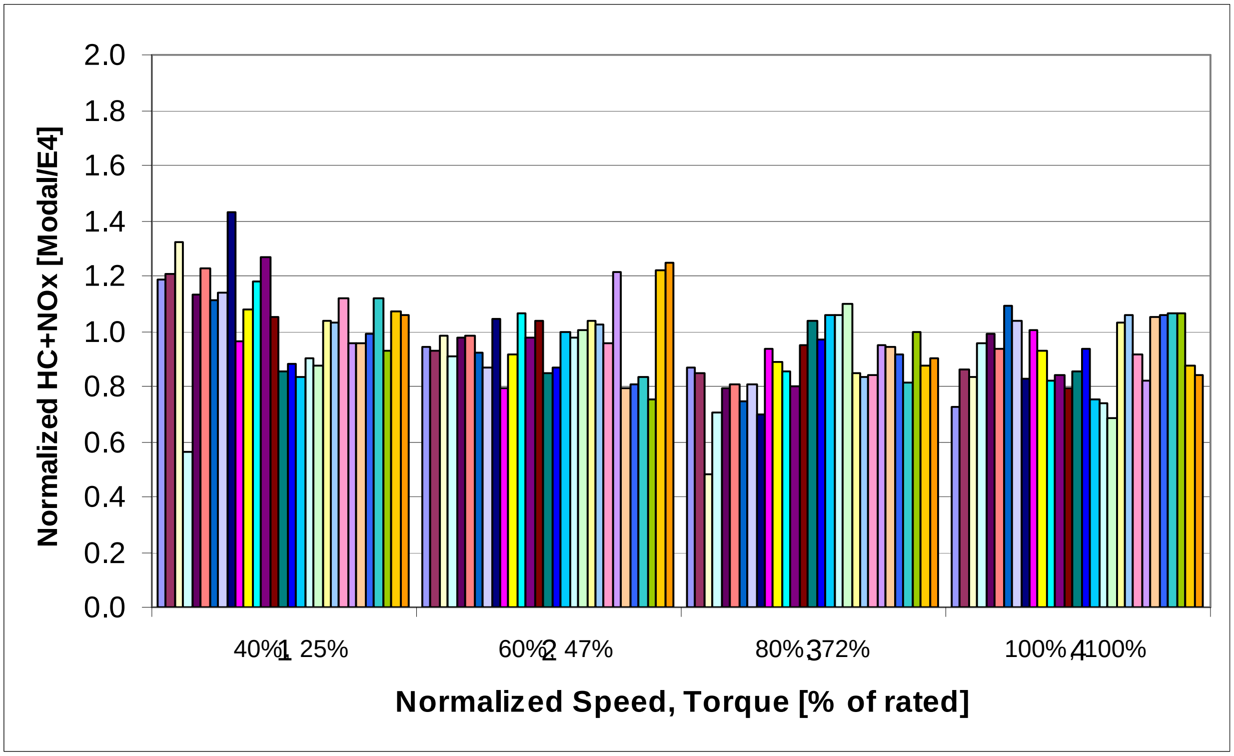
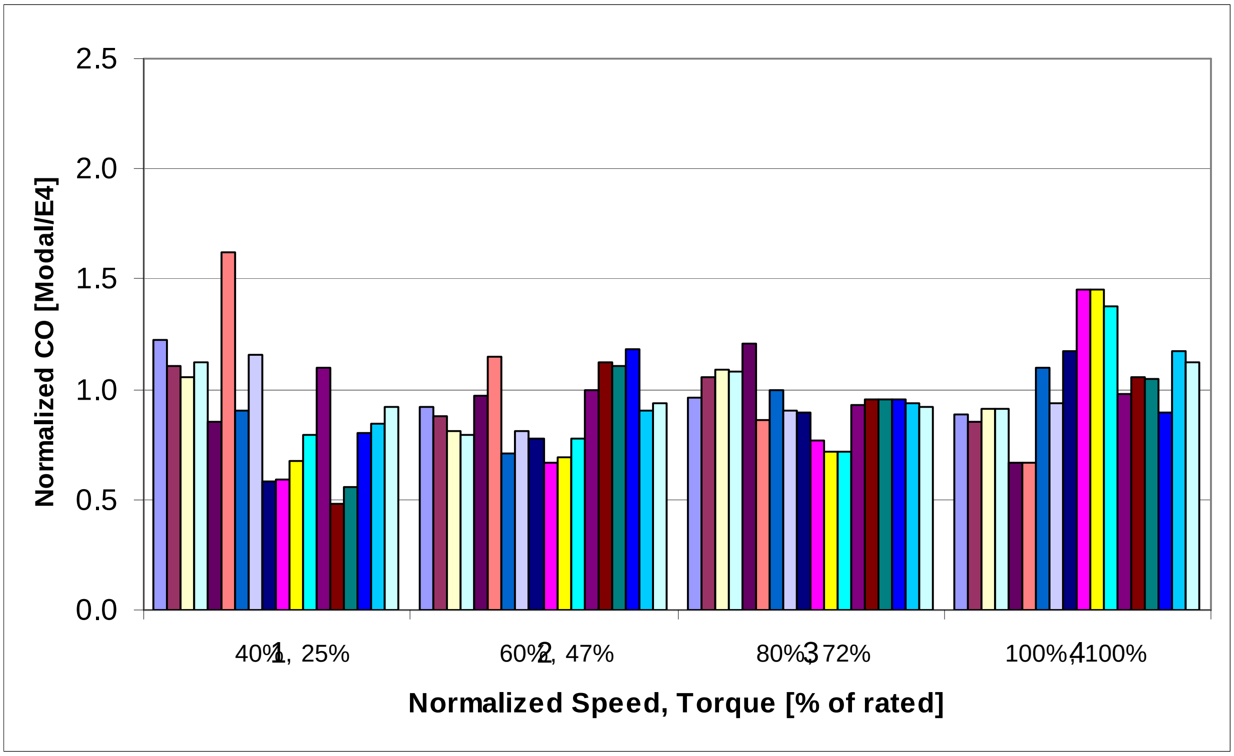


Figure 4.7-5: Normalized Modal CO for EFI 4-Stroke OB/PWC



Figures 4.7-6 through 4.7-9 present normalized HC+NOx and CO modal data for direct-injected 2-stroke OB/PWC engines. Based on the data collected, there appear to be two distinct types of direct-injection 2-stroke engines. One manufacturer uses a higher pressure fuel system with a unique combustion chamber design for low emissions. Because the modal variation in emission results are significantly different for the two engine designs, we designate them headings of Type 1 and Type 2 engines and look at them separately for the purposes of this analysis. As shown in Figure 4.7-6 and 4.7-7, Type 1 engines tend to have relatively high HC+NOx at low power, then fairly low emissions over the rest of the modes. For CO, these engines show much less variability between modes. For Type 2 engines, HC+NOx is below the E4 average in the mid-speed range as shown in Figure 4.7-8. However, there is a wide degree of variation in how these engines behave at low and high speed. Most of these engines seem to have high normalized HC+NOx emissions either at low or at high speed. Figure 4.7-9 presents CO values for Type 1 engines. These engines tend to have high CO at full power with decreasing CO at lower power modes.

Figure 4.7-6: Normalized Modal HC+NOx for Type 1 DI 2-Stroke OB/PWC

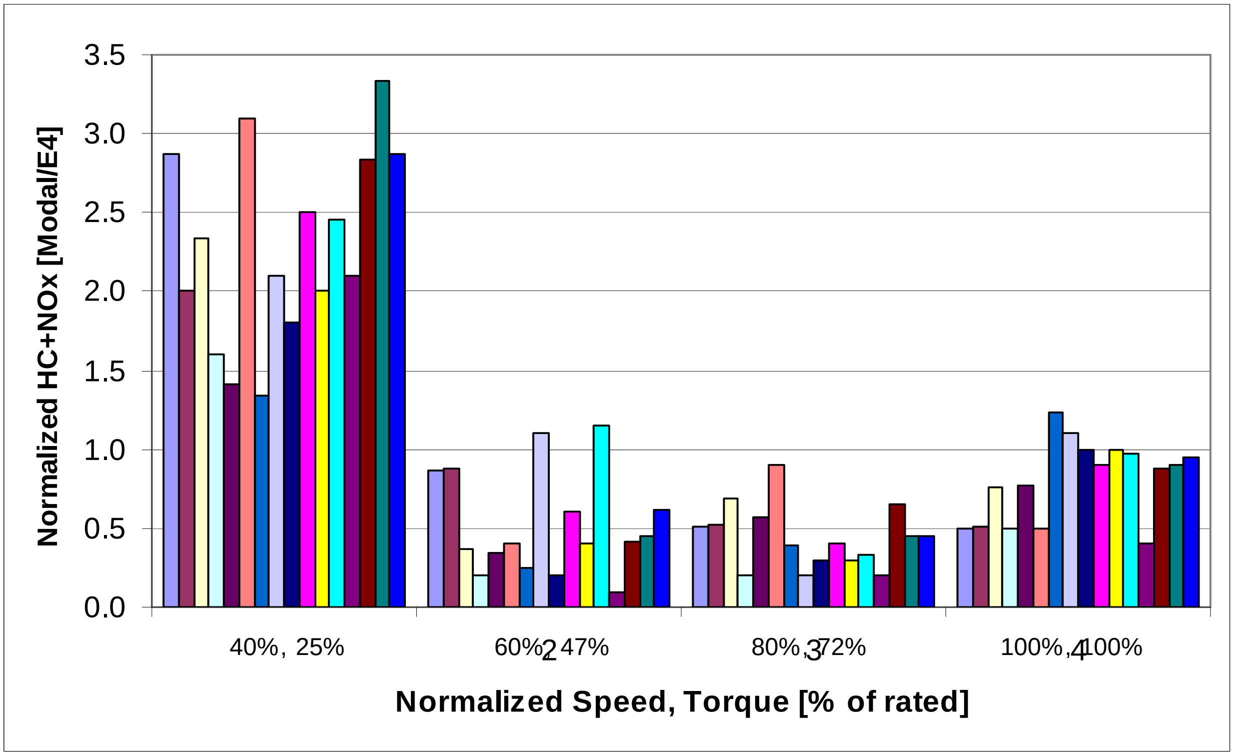


Figure 4.7-7: Normalized Modal CO for Type 1 DI 2-Stroke OB/PWC

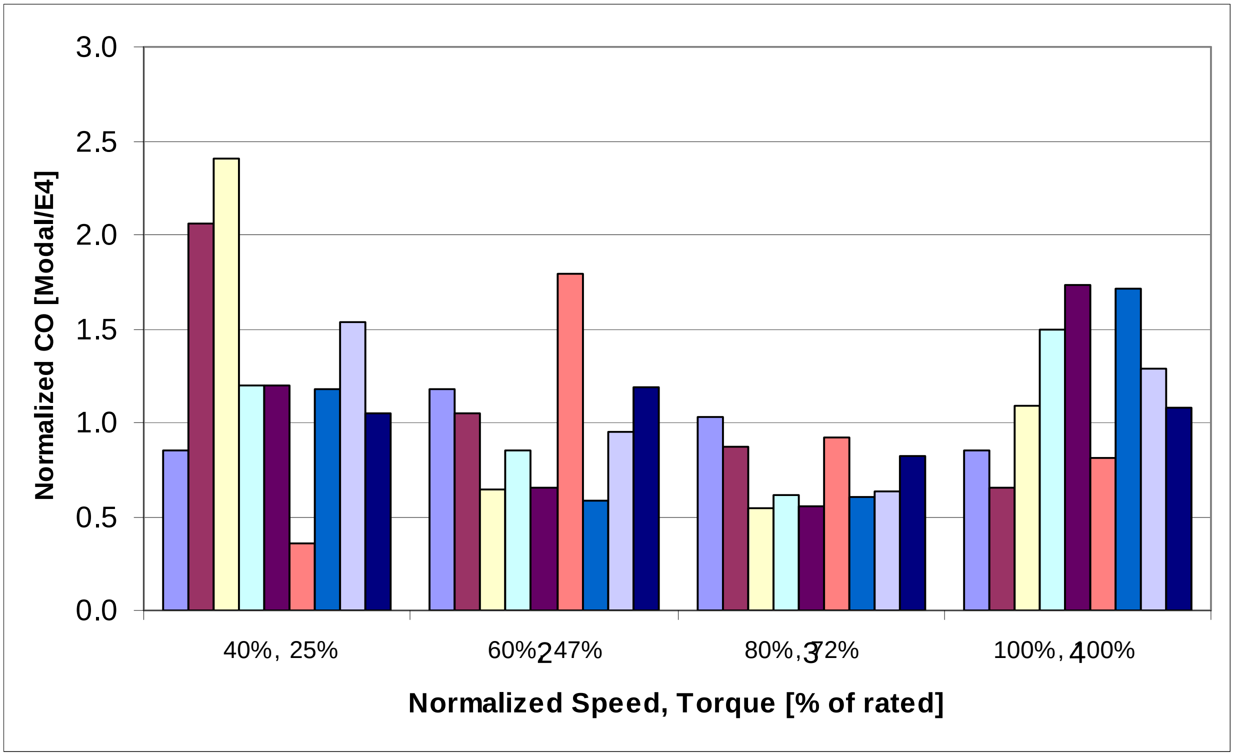


Figure 4.7-8: Normalized Modal HC+NOx for Type 2 DI 2-Stroke OB/PWC

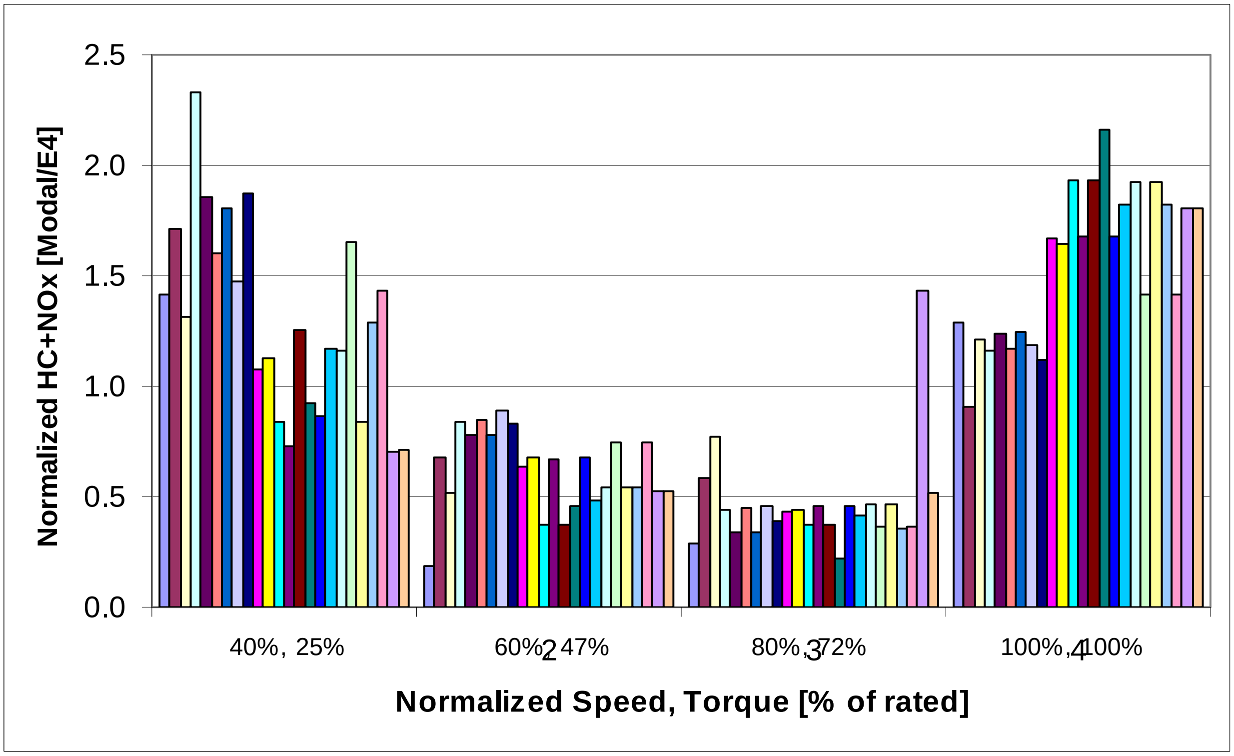
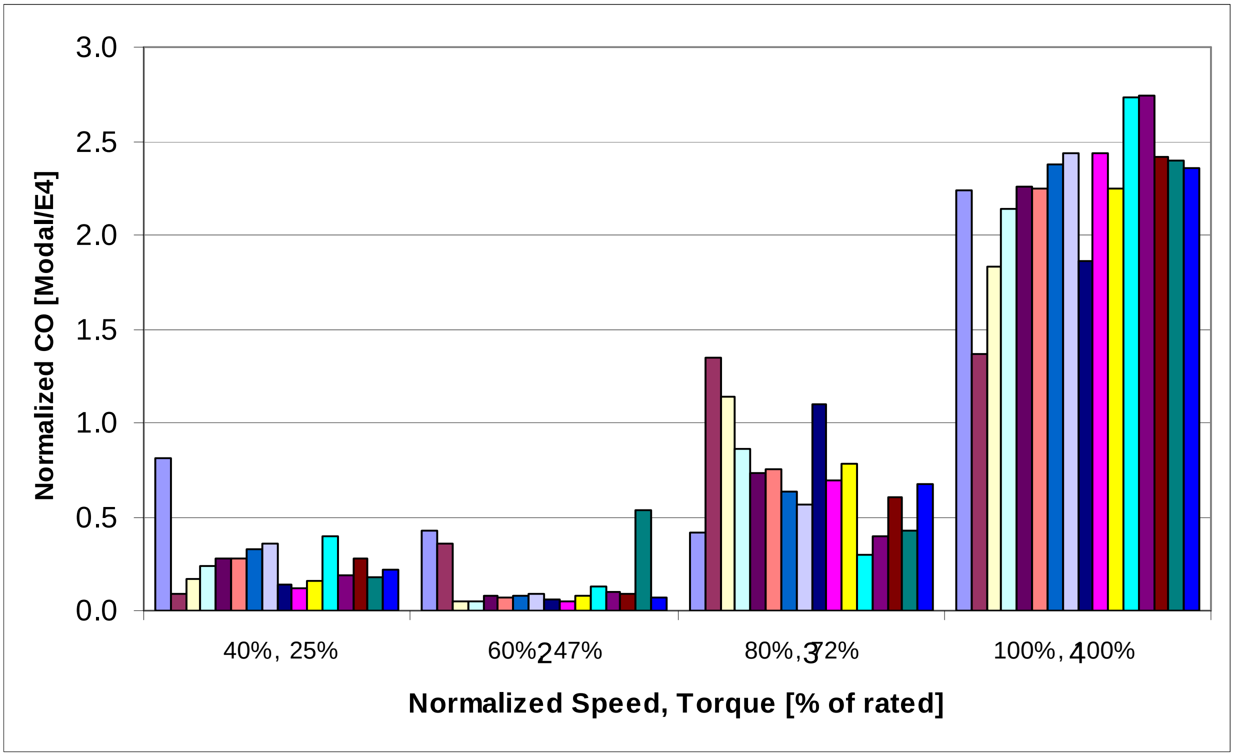


Figure 4.7-9: Normalized Modal CO for Type 2 DI 2-Stroke OB/PWC



Figures 4.7-10 and 4.7-11 present normalized HC+NOx and CO modal data for SD/I engines equipped with catalysts. All of these engines demonstrated HC+NOx emissions below the E4 average in the mid-speed range. However, some of these engines show somewhat higher normalized HC+NOx emissions at either the low-power or full power mode. These differences are likely a function of catalyst design and location as well as air/fuel calibration. At wide open throttle, all of these engines were calibrated to run rich as an engine protection strategy, so emission reductions at this mode are due to NOx reductions in the catalyst. Because these engines are designed to run rich at full power, high CO emissions were observed at this mode. For the rest of the power range, CO emissions were generally below the E4 average for these engines. As part of the catalyst development work for SD/I engines, one engine was tested over 26 modes, most of which are contained in the proposed NTE zone.[85] This engine was tested in its baseline configuration (open-loop fuel injection) as well as with three catalyst configurations. The three catalyst configurations included one close-coupled to the engine (in the riser), one a little farther downstream (in the exhaust elbow), and a larger catalyst external to the existing exhaust manifold. This data provided insight into how exhaust emissions throughout the proposed NTE zone for Marine SI engines compare to the modal test data on the theoretical propeller curve. This data is presented in Appendix 4A.

Figure 4.7-10: Normalized Modal HC+NOx for SD/I with Catalysts

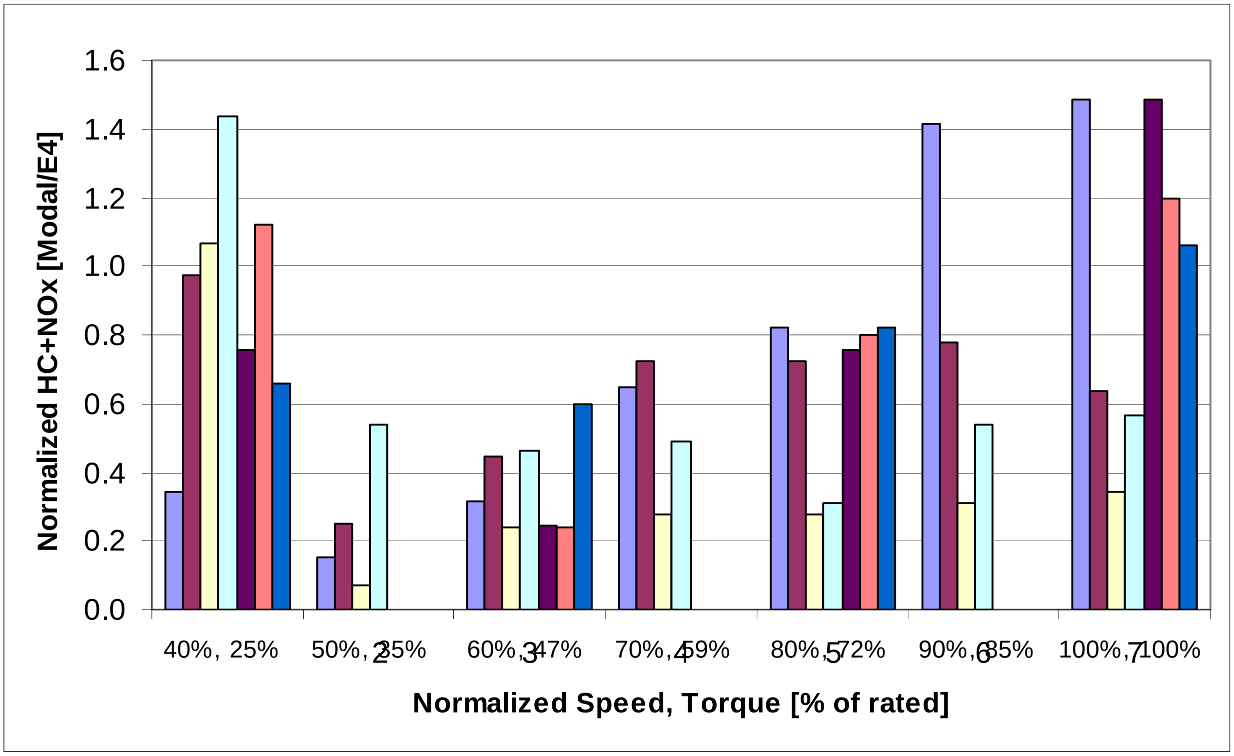
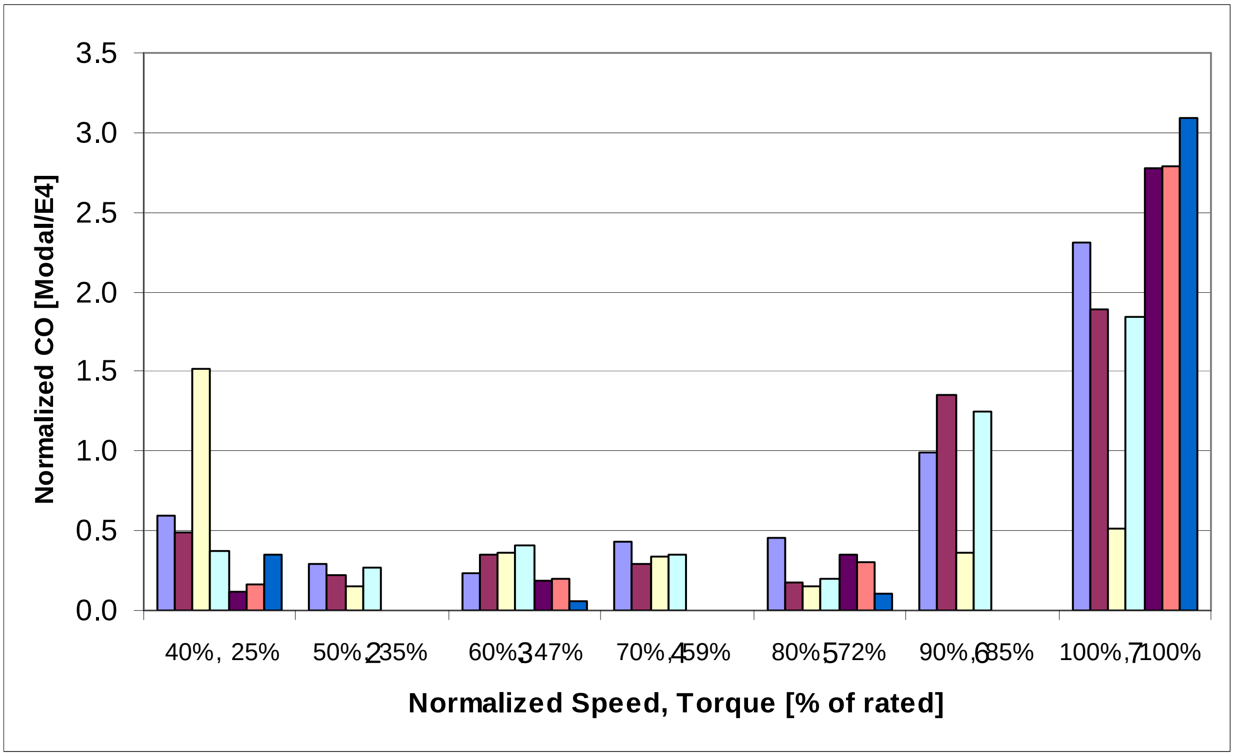
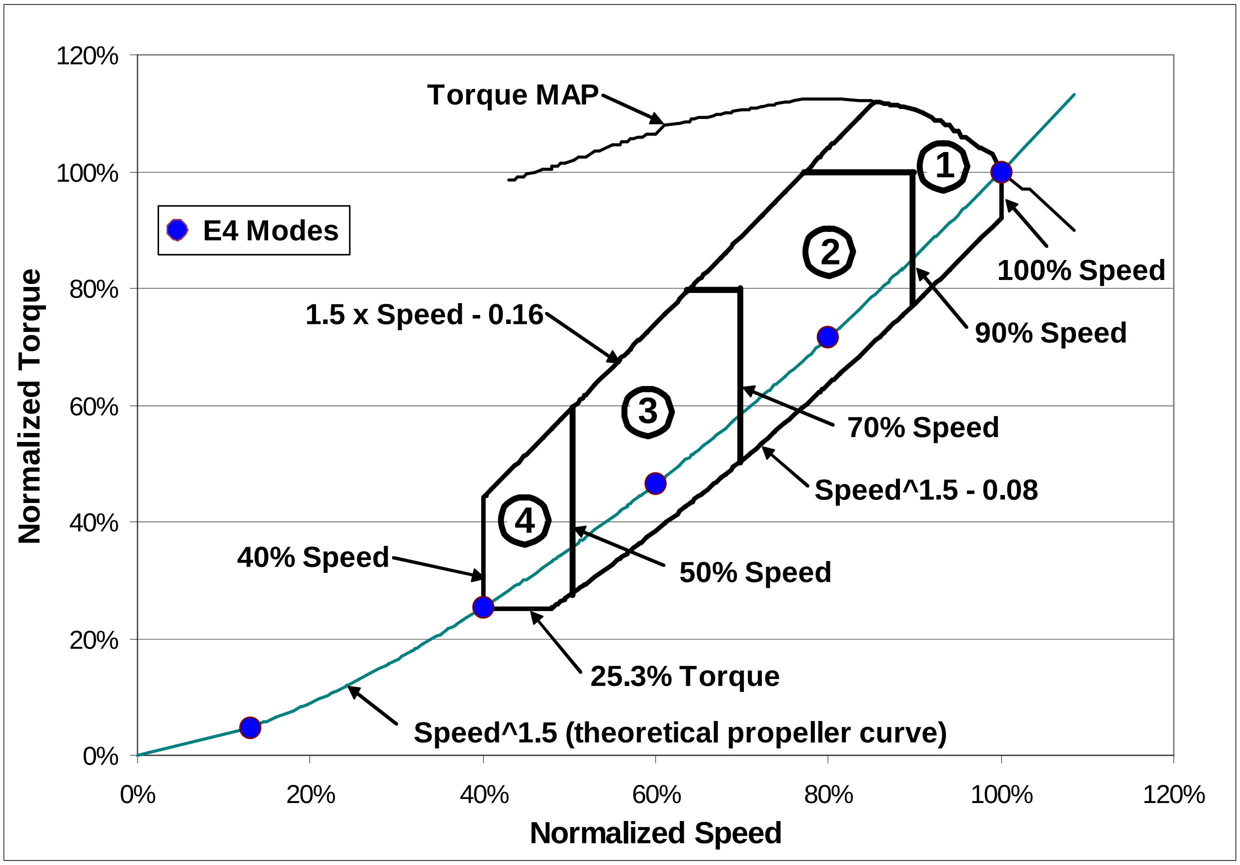


Figure 4.7-11: Normalized Modal CO for SD/I with Catalysts



Based on the above data, we believe that a single NTE limit is not appropriate for the entire NTE zone. For this reason, we are proposing to divide the NTE zone into four subzones. These subzones are numbered to correspond with the E4 mode that they contain. For instance, subzone 1 includes full-power operation which is mode 1 in the E4 duty cycle. Subzone one is all operation at or above 90 percent maximum test speed and/or 100 percent torque at maximum test speed. Mode 2 is (operation below subzone 1) at or above 70 percent maximum test speed and/or 80 percent torque at maximum test speed. Subzone 4 includes operation in the proposed NTE zone at or below 50 percent speed. Subzone 3 includes the remaining section of the proposed NTE zone. Figure 4.7-12 presents the proposed NTE zone and subzones.

Figure 4.7-12: Proposed NTE Zone and Subzones



The data presented above suggests that separate NTE limits may be necessary for HC+NOx and for CO. Also this data suggests that different NTE limits by be appropriate for different engine types (especially catalyzed SD/I versus OB/PWC). We are proposing separate NTE limits for SD/I and OB/PWC. These limits are presented in Table 4.7-2. In addition, due to the wide variability of modal emission rates for the two types of direct-injected two-stroke engines, we are proposing two alternative sets of NTE limits than manufacturers would have the option of choosing for their OB/PWC engines. These alternative limits are based on the data presented above and give more room in some subzones while imposing tighter caps in other subzones to give a net stringency roughly equivalent to the primary option. To offset these relaxed standards in subzones 1 and 4, we are proposing more stringent limits in subzones 2 and 3 for this alternative approach.

Table 4.7-2: Proposed NTE Limits by Subzone

Application	Pollutant	Subzone 4	Subzone 3	Subzone 2	Subzone 1
SD/I	HC+NOx CO	1.5 1.0	1.0 1.0	1.0 1.0	1.5 3.5
OB/PWC (primary)	HC+NOx CO	1.6 1.5	1.2 1.5	1.2 1.5	1.2 1.5
OB/PWC (alternative 1)	HC+NOx CO	2.0 1.0	0.8 1.0	0.8 1.5	2.0 3.0
OB/PWC (alternative 2)	HC+NOx CO	3.0 2.0	1.0 1.0	1.0 1.0	1.0 1.5

We used the modal data presented above and the data on additional operation points presented in Appendix 4A to develop these NTE limits. The proposed limits represent the levels that can be met by the majority of the marine engines tested. In the case of engines that have modal emissions that are somewhat higher than the proposed NTE limits, we believe that these engines can be calibrated to meet these proposed limits. In addition, the limits are based on the Family Emission Limits chosen by manufacturers at certification. Therefore, manufacturers would have the option of increasing their FELs, in some cases, to bring otherwise problem engines into compliance with the proposed NTE limits.

4.7.2.3 Ambient Conditions

Ambient air conditions, including temperature and humidity, may have a significant effect on emissions from marine engines in-use. To ensure real world emissions control, the NTE zone testing should include a wide range of ambient air conditions representative of real world conditions. Because these engines are used in similar environments as marine diesel engines, we are proposing to apply the same ambient ranges to the Marine SI NTE requirements as already exist for marine diesel engine NTE requirements.

We believe that the appropriate ranges should be 13-30°C (55-86°F) for air temperature and 7.1-10.7 grams water per kilogram dry air (50-75 grains/pound of dry air) for air humidity. The air temperature ranges are based on temperatures seen during ozone exceedences, except that the upper end of the temperature range has been adjusted to account for the cooling effect of a body of water on the air above it.[86] We are also aware, however, that marine engines sometimes draw their intake air from an engine compartment or engine room such that intake air temperatures are substantially higher than ambient air temperatures. In this case, we would retain 35°C as the end of the NTE temperature range for engines that do not draw their intake air directly from the outdoor ambient.

For NTE testing in which the air temperature or humidity is outside the proposed range, we propose that the emissions must be corrected back to the specified air temperature or humidity range. These corrections would be consistent with the equations in 40 CFR Part 91, Subpart E except that these equations correct to 25°C and 10.7 grams per kilogram of dry air while the NTE corrections would be to the nearest outside edge of the specified ranges. For instance, if the outdoor air temperature were higher than 30°C for an engine that drew fresh outdoor air into the intake, a temperature correction factor could be applied to the emissions results to determine what emissions would be at 30°C.

Ambient water temperature also may affect emissions due to it's impact on engine cooling. For this reason, we are proposing that the NTE testing include a range of ambient water temperatures from 5 to 27°C (41 to 80°F). The proposed water temperature range is based on temperatures that marine engines experience in the U.S. in-use. At this time, we are not aware of an established correction for ambient water temperature, therefore the NTE zone testing would have to be withing the specified ambient water temperature range.

4.8 Impacts on Safety, Noise, and Energy

Section 213 of the Clean Air Act directs us to consider the potential impacts on safety, noise, and energy when establishing the feasibility of emission standards for nonroad engines. Furthermore, section 205 of Public Law 109-54 requires us to assess potential safety issues, including the risk of fire and burn to consumers in use, associated with the proposed emission standards for nonroad spark-ignition engines under 50 horsepower. As further detailed in the following sections, we expect that the proposed exhaust emission standards will either have no adverse affect on safety, noise, and energy or will improve certain aspects of these important characteristics.

4.8.1 Safety

We conducted a comprehensive, multi-year safety study of nonroad SI engines that focused on the following areas where we are proposing new exhaust standards.[87] These areas are:

- New catalyst-based HC+NOx exhaust emission standards for Class I and II nonhandheld (NHH) engines; and

- New HC+NOx exhaust emission standards for outboard and personal watercraft (OB/PWC) engines and vessels, and a new CO exhaust emission standard for NHH engines used in marine auxiliary applications.

Each of these four areas is discussed in greater detail in the next sections.

4.8.1.1 Exhaust Emission Standards for Small Spark-Ignition Engines

The technology approaches that we assessed for achieving the proposed Small SI engine standards included exhaust catalyst aftertreatment and improvements to engine and fuel system designs. In addition to our own testing and development effort, we also met with engine and equipment manufacturers to better understand their designs and technology and to determine the state of technological progress beyond EPA's Phase 2 standards.

The scope of our safety study included Class I and Class II engine systems that are used in residential walk-behind and ride-on lawn mower applications, respectively. Residential lawn mower equipment was chosen for the following reasons.

- Lawn mowers and the closely-related category of lawn tractors overwhelmingly represent the largest categories of equipment using Class I and Class II engines. We estimate that over 47 million walk-behind mowers and ride-on lawn and turf equipment are in-use in the US today.
- These equipment types represent the majority of sales for Small SI engines.
- Consumer Product Safety Commission (CPSC) data indicates that more thermal burn injuries associated with lawn mowers occur than with other NHH equipment; lawn mowers therefore represent the largest thermal burn risk for these classes of engines.
- General findings regarding advanced emission control technologies for residential lawn and garden equipment carry over to commercial lawn and turf care equipment as well as to other NHH equipment using Class I and Class II engines. Lawn mower design and use characteristics pose unique safety implications not encountered by other NHH equipment using these engines (i.e. a mower deck collects debris during operation whereas a pressure washer collects no debris). Thus, other NHH equipment may employ similar advanced emission control technologies for meeting the proposed standards without a corresponding concern regarding the safety issues analyzed in this study.

We conducted the technical study of the incremental risk on several fronts. First, working with the CPSC, we evaluated their reports and databases and other outside sources to identify those in-use situations which create fire and burn risk for consumers. The outside sources included meetings, workshops, and discussions with engine and equipment manufacturers. The following scenarios were identified for evaluation:

- Thermal burns due to inadvertent contact with hot surface on engine or equipment;
- Fires from grass and leaf debris on the engine or equipment;
- Fires due to fuel leaks on hot surfaces;
- Fires related to spilled fuel or refueling vapor;
- Equipment or structure fire when equipment is left unattended after being used;
- Engine malfunction resulting in an ignitable mixture of unburned fuel and air in the muffler (engine misfire); and
- Fire due to operation with richer than designed air-fuel ratio in the engine or catalyst.

These scenarios cover a comprehensive variety of in-use conditions or circumstances which potentially could lead to an increase in burns or fires. They may occur presently or not at all, but were included in our study because of the potential impact on safety if they were to occur. The focus of the analysis was, therefore, on the incremental impact on the likelihood and severity of the adverse condition in addition to the potential causes as it related to the use of more advanced emissions control technology.

Second, we conducted extensive laboratory and field testing of both current technology (Phase 2) and prototype catalyst-equipped advanced-technology engines and equipment (Phase 3) to assess the emission control performance and thermal characteristics of the engines and equipment. This testing included a comparison of exhaust system, engine, and equipment surface temperatures using thermal imaging equipment.

Third, we contracted with Southwest Research Institute (SwRI) to conduct design and process Failure Mode and Effects Analyses (FMEA).[88] The SwRI FMEA focused on comparing current Phase 2 and Phase 3 compliant engines and equipment to evaluate incremental changes in risk probability as a way of evaluating the incremental risk of upgrading Phase 2 engines to meet Phase 3 emission standards. This is an engineering analysis tool to help engineers and other professional staff on the FMEA team to identify and manage risk. In a FMEA, potential failure modes, causes of failure, and failure effects are identified and a resulting risk probability is calculated from these results. This risk probability is used by the FMEA team to rank problems for potential action to reduce or eliminate the causal factors. Identifying these causal factors is important because they are the elements that a manufacturer can consider reducing the adverse effects that might result from a particular failure mode.

Our technical work and subsequent analysis of all of the data and information strongly indicate that effective catalyst-based standards can be implemented without an incremental increase in the risk of fire or burn to the consumer either during or after using the equipment. Similarly, we did not find any increase in the risk of fire during storage near typical combustible materials. In many cases, the designs used for catalyst-based technology can lead to an incremental decrease in such risk.

More specifically, our work included taking temperature measurements and infrared thermal images of both OEM mufflers and prototype catalyst/mufflers on six Class 1 engines and three Class 2 engines as part of the safety study. We integrated the emission reduction catalyst into the muffler. In doing so, we generally designed heat management features into the catalyst/muffler and cooling system. These heat management design elements, all of which were not used on every prototype, included: 1) positioning the catalyst within the cooling air flow of the engine fan or redirecting some cooling air over the catalyst area with a steel shroud; 2) redirecting exhaust flow through multiple chambers or baffles within the catalyst/muffler; 3) larger catalyst/muffler volumes than the original equipment muffler; and 4) minimizing CO oxidation at moderate to high load conditions to maintain exhaust system surface temperatures comparable to those of the OEM systems. The measurements and images were taken during various engine operating conditions and as the engines cooled down after being shut off.. This latter event, termed “hot soak,” is an important consideration since it is often when the operator is in close proximity to the engine either performing maintenance or refueling the equipment.

Figures 4.8-1 and 4.8-2 are an example of the measurements and images taken to compare Class 1 engine original equipment (OEM) mufflers to the same engines equipped with prototype catalyst/mufflers. The first figure depicts surface temperatures from engine number 244 while operated on a laboratory dynamometer over three modes of EPA's A-cycle steady-state test cycle. The second figure shows surface temperatures for the same engine at different times during hot soak. The prototype catalyst/muffler system shown in these figures uses one of the most effective heat management designs in the safety study. As shown, the catalyst system in this example has much lower surface temperatures during both engine operation and hot soak.

Similar information was collected in the laboratory for Class 2 engines used in lawn tractors. However, those tests were conducted on the "raw" engines without the chassis, which is an integral part of the overall engine cooling system for most residential Class 2 applications. Because of this, we believe it is more appropriate to compare the thermal measurements from field testing of the integrated unit.

The test results for engine 251 are fairly typical of the Class 2 lawn tractor test results. During engine operation, the OEM muffler configuration had exposed surface temperatures of approximately 200 ˚C as viewed from both sides of the tractor when cutting moderate to heavy grass and peak temperatures as high as 300 to 365 ˚C. The lawn tractor equipped with engine 253, which is from the same engine family as number 251, was fitted with a prototype catalyst/muffler exhibited exposed surface temperatures of approximately 115 to 130 ˚C and peaks of 160 to 190 ˚C. The lower temperatures for the prototype catalyst system is in part due to the more effective cooling of the catalyst/mufflers due to the re-routing of cooling air through the chassis and other heat management design elements.

The hot soak results for the above engines and two other related Class 2 lawn mowers are shown in Figure 4.8-3. The two-minute nominal refueling point after engine shut-down following 30 minutes of grass-cutting operation is shown for reference. In these tests, both of the engines with prototype catalyst/mufflers had lower peak surface temperatures than the OEM muffler configurations.

Figure 4.8-1: Surface Temperature Infrared Thermal Images of Exhaust System Components for Class 1 Engine 244 with a Catalyst/Muffler (left) and an OEM Muffler (right) at Various Operating Modes.

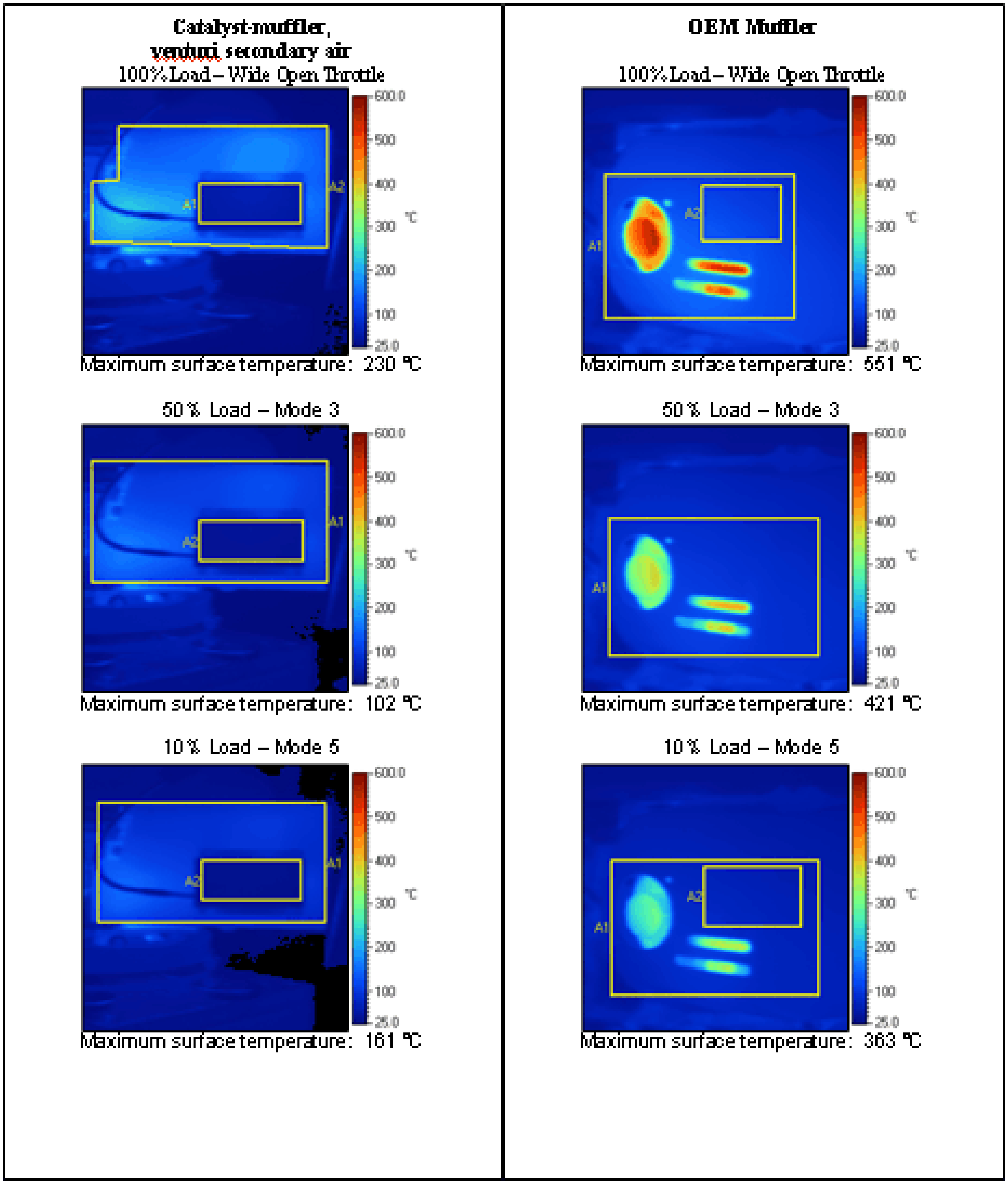


Figure 4.8-2: Hot Soak Surface Temperature Infrared Thermal Images of Exhaust System Components for Class 1 Engine 244 After Sustained Wide Open Throttle and 100 Percent Load.

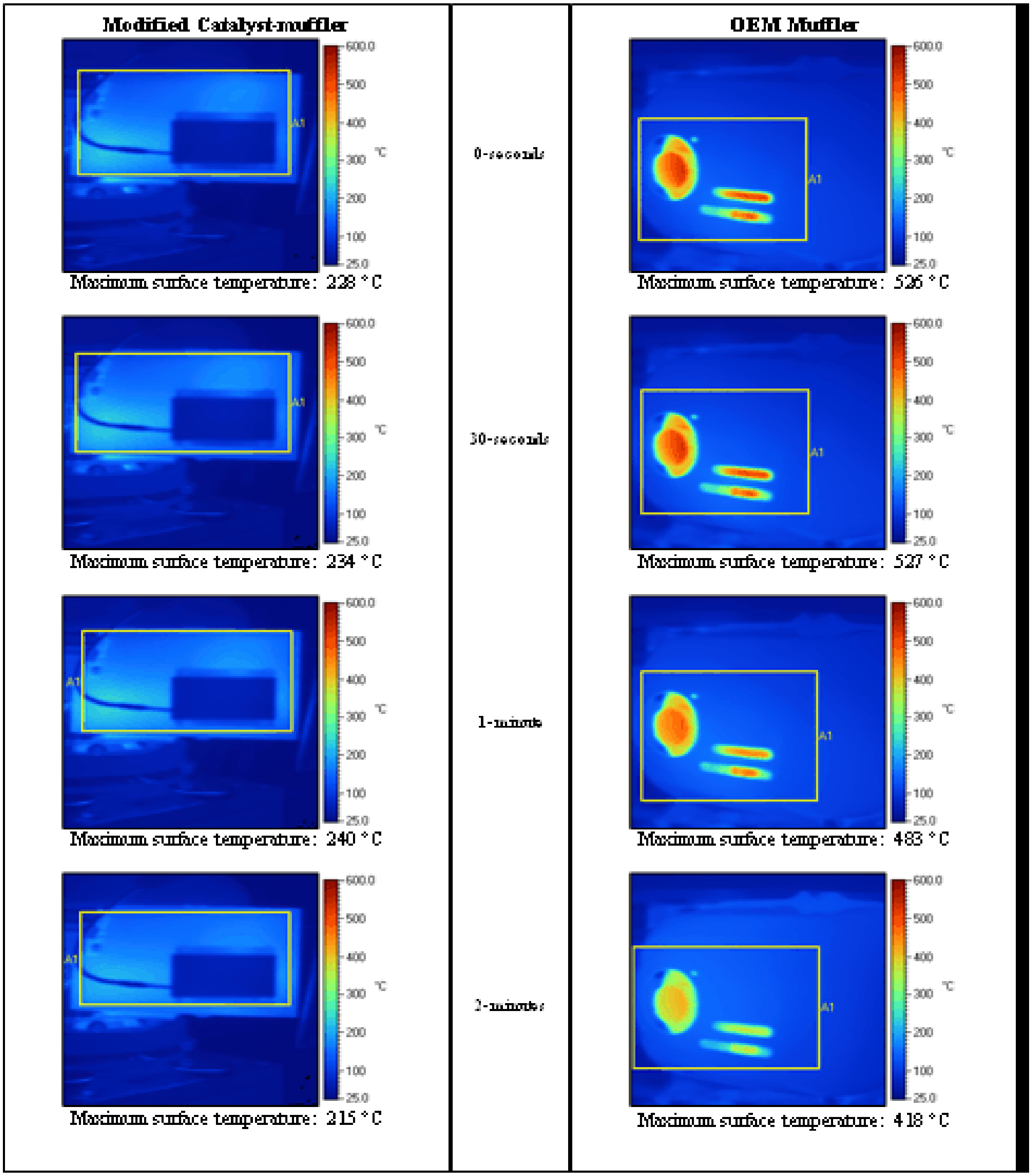
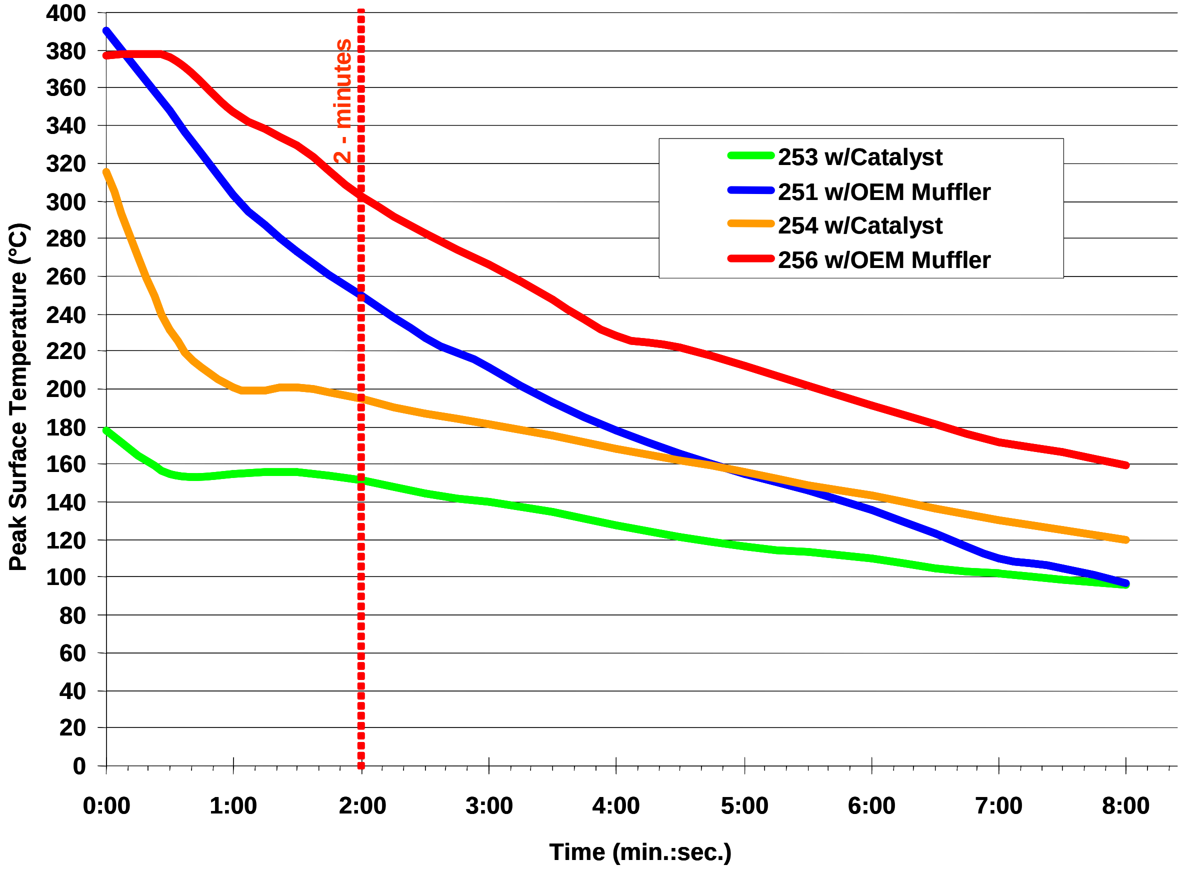


Figure 4.8-3: Hot Soak Peak Surface Temperatures Infrared Thermal Images for Class 2 Lawn Tractors Following After Approximately 30-Minutes of Grass Cutting.



4.8.1.2 Exhaust Emission Standards for Marine SI Engines

Our analysis of exhaust emission standards for Marine SI engines found that the U.S. Coast Guard has comprehensive safety standards that apply to engines and fuel systems used in these vessels. Additionally, organizations such as the Society of Automotive Engineers, Underwriters Laboratories, and the American Boat and Yacht Council (ABYC) also have safety standards that apply in this area. We also found that the four-stroke and two-stroke direct injection engine technologies likely to be used to meet the exhaust emission standards contemplated for Marine SI engines are in widespread use in the vessel fleet today. These more sophisticated engine technologies are replacing the traditional two-stroke carbureted engines. The four-stroke and two-stroke direct injection engines meet applicable Coast Guard and ABYC safety standards and future products will do so as well. The proposed emission standards must be complementary to existing safety standards and our analysis indicates that this will be the case. There are no known safety issues with the advanced technologies compared with two-stroke carbureted engines. The newer-technology engines arguably provide safety benefits due to improved engine reliability in-use. Based on the applicability of Coast Guard and ABYC safety standards and the good in-use experience with advanced-technology engines in the current vessel fleet, we believe new emission standards would not create an incremental increase in the risk of fire or burn to the consumer.

4.8.2 Noise

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Direct-injection two-stroke and four-stroke OB/PWC have been reported to be much quieter than traditional carbureted two-stroke engines. Catalysts in the exhaust act as mufflers which can reduce noise. Additionally, adding a properly designed catalyst to the existing muffler found on all Small SI engines can offer the opportunity to incrementally reduce noise.

4.8.3 Energy

Adopting new technologies for controlling fuel metering and air-fuel mixing, particularly the conversion of some carbureted engines to advanced fuel injection technologies, will lead to improvements in fuel consumption. This is especially true for OB/PWC engines where we expect the proposed standards to result in the replacement of old-technology two stroke engines with more fuel efficient technologies such as two-stroke direct injection or four-stroke engines. Carbureted crankcase-scavenged two-stroke engines are inefficient in that 25 percent or more of the fuel entering the engine may leave the engine unburned. We estimate a fuel savings of about 61 million gallons of gasoline from marine engines in 2030, when most boats would be using engines complying with the proposed standard.

The conversion of some carbureted Small SI engines to fuel injection technologies is also expected to improve fuel economy. We estimate approximately 18 percent of the Class II engines will be converted to fuel injection and that this will result in a fuel savings of about 10 percent for each converted engine. This translates to a fuel savings of about 56 million gallons of gasoline in 2030 when all of the Class II engines used in the U.S. will comply with the proposed Phase 3 standards. By contrast, the use of catalyst-based control systems on Small SI engines is not expected to change their fuel consumption characteristics. These estimates are discussed in more detail in Chapter 6.

APPENDIX 4A: Normalized Modal Emissions for a 7.4 L MPI SD/I

Figure 4A-1: HC+NOx Ratios for 7.4L MPI Engine, Baseline

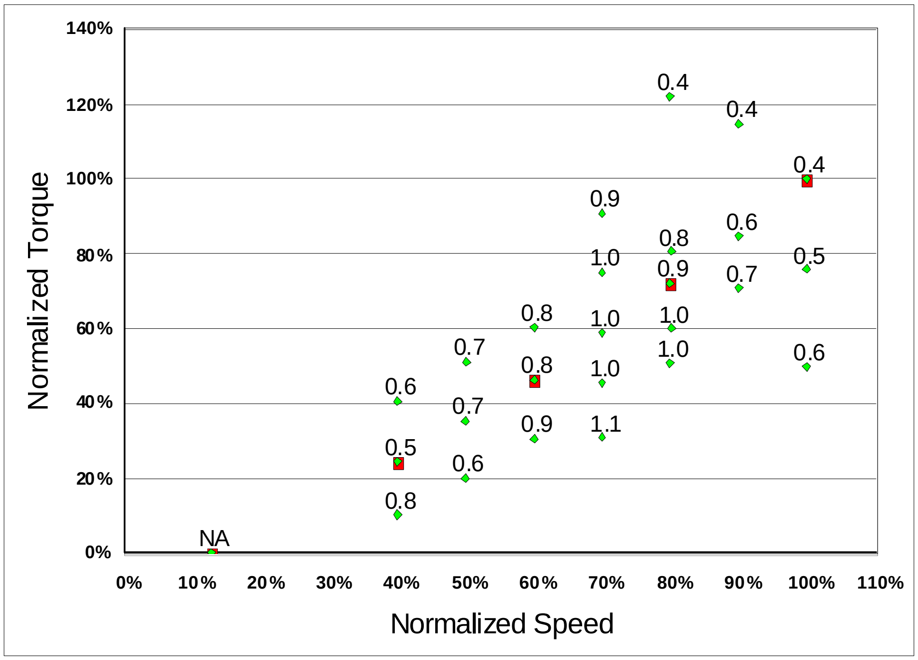


Figure 4A-2: CO Ratios for 7.4L MPI Engine, Baseline

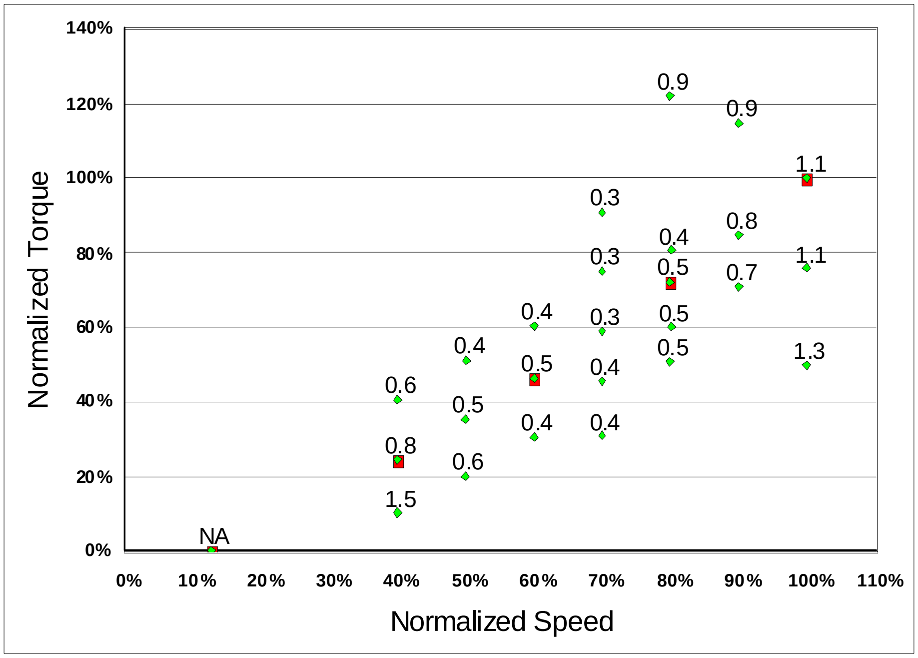


Figure 4A-3: HC+NOx Ratios for 7.4L MPI Engine, Riser Catalysts

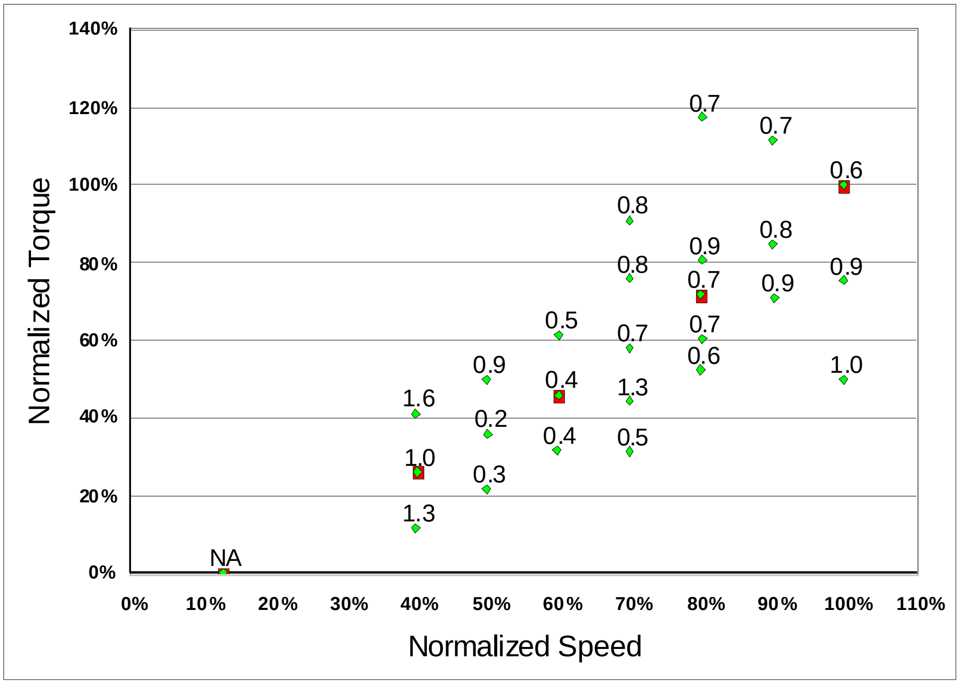


Figure 4A-4: CO Ratios for 7.4L MPI Engine, Riser Catalysts

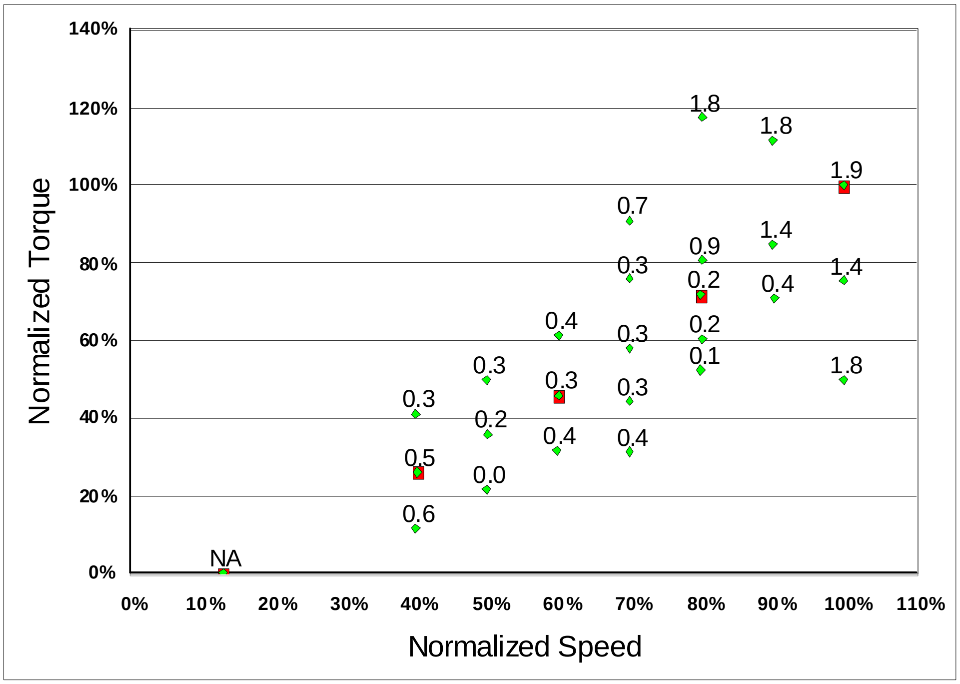


Figure 4A-5: HC+NOx Ratios for 7.4L MPI Engine, Elbow Catalysts

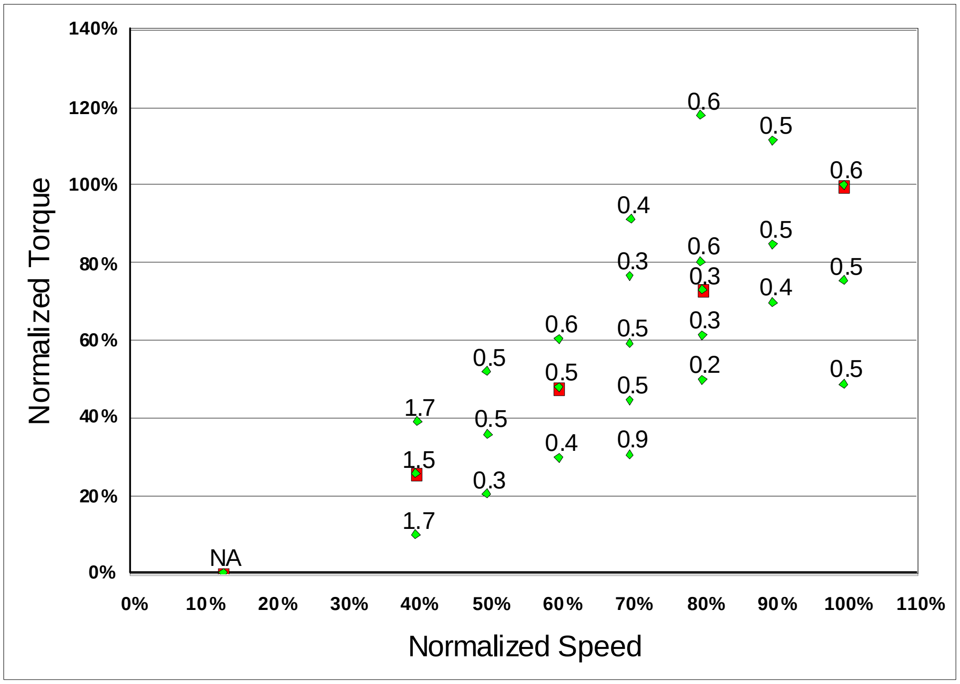


Figure 4A-6: CO Ratios for 7.4L MPI Engine, Elbow Catalysts

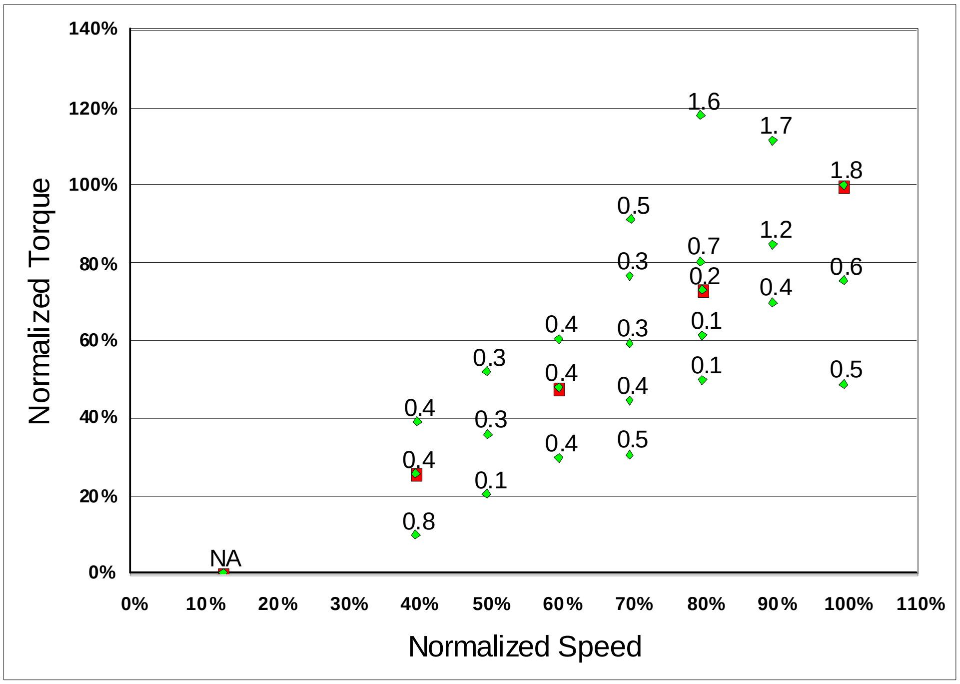


Figure 4A-7: HC+NOx Ratios for 7.4L MPI Engine, External Catalysts

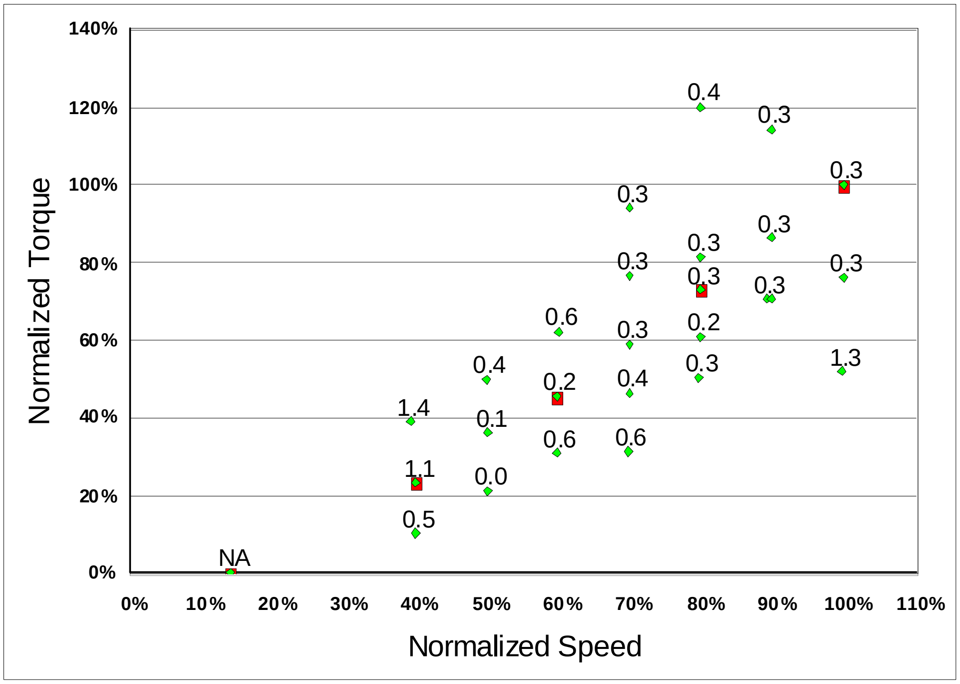
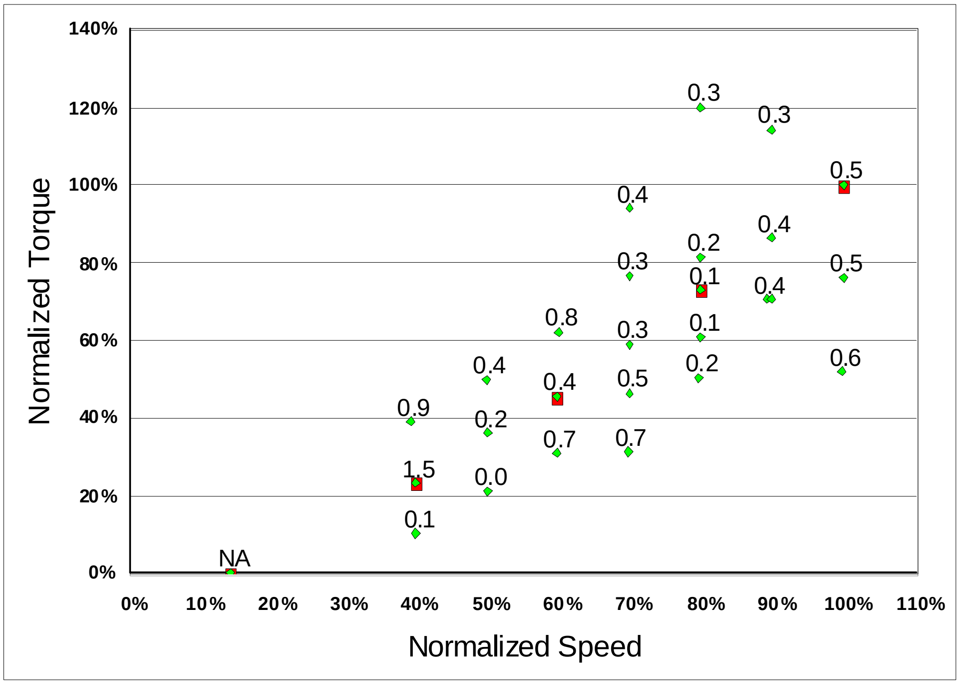


Figure 4A-8: CO Ratios for 7.4L MPI Engine, External Catalysts



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CHAPTER 5: Feasibility of Evaporative Emission Control

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

The proposed evaporative emission standards for Small SI equipment and Marine SI vessels are summarized in the Executive Summary. This chapter presents available emissions data on baseline emissions and on emission reductions achieved through the application of emission control technology. In addition, this chapter provides a description of the proposed test procedures for evaporative emission determination.

Evaporative emissions from equipment and vessels using spark-ignition (SI) engines can be very high. This is largely because Small SI and Marine SI applications generally have fuel tanks that are vented to the atmosphere and because materials used in the construction of the plastic fuel tanks and hoses generally have high permeation rates. Evaporative emissions can be grouped into five categories:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day, heating the fuel tank and venting gasoline vapors. We also include, under this heading, diffusion losses which are vapors that will escape from an open vent even without a change in temperature.

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

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

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

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

5.1 Diurnal Breathing Loss Evaporative Emissions

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

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

As fuel is used by the engine, and the liquid fuel volume decreases, air is drawn into the tank to replace the volume of the fuel. (Note: the decrease in liquid fuel could be offset to some degree by increasing fuel vapor pressure caused by increasing fuel temperature.) This would continue while the engine was running. If the engine was shut off and the tank was left overnight, the vapor pressure of the fuel would drop as the temperature of the fuel dropped. This would cause a small negative pressure within the tank that would cause it to fill with more air until the pressure equilibrated. The next day, the vapor pressure of the fuel would increase as the temperature of the fuel increased. This would cause a small positive pressure within the tank that would force a mixture of fuel vapor and air out. In poorly designed gasoline systems, where the engine or exhaust is very close to the fuel tank the engine/exhaust heating may cause large amounts of gasoline vapor to be vented directly to the atmosphere.

Several emission-control technologies can be used to reduce diurnal evaporative emissions. Many of these technologies would also control running loss and hot soak emissions and some could be used to control refueling emissions. We believe manufacturers will have the opportunity use a wide variety of technology approaches to meet the proposed evaporative emission standards. The advantages and disadvantages of the various possible emission-control strategies are discussed below. This section summarizes the data and rationale supporting the diurnal emission standard for Marine SI vessels and Small SI equipment presented in the Executive Summary.

5.1.1 Baseline Emissions

5.1.1.1 Marine Vessels

We tested two aluminum marine fuel tanks in their baseline configurations for diurnal emissions. Aluminum fuel tanks were used so that permeation emissions would not occur during the testing. The 17 gallon aluminum tank was constructed for this testing, but is representative of a typical marine fuel tank; the 30 gallon aluminum tank was removed from an 18 foot runabout. The fuel tanks were tested with the venting through a length of $^5/_8$ inch hose to ensure that the emissions measured were a direct result of the fuel temperature heating and not diffusion through the vent (see Section 5.1.3). The advantage of using the aluminum fuel tanks for this testing was to exclude permeation emissions from the measured results. All of the testing was performed with fuel tanks filled to 40 percent of capacity with 9RVP[1] test fuel.

The diurnal test results are presented in units of grams per gallon capacity of the fuel tank per day. These units are used because gallons capacity is a defining characteristic of the fuel tank. Diurnal vapor formation itself is actually a function of the vapor space above the fuel in the fuel tank rather than the total capacity.

Table 5.1-1 presents the test results compared to anticipated results. The anticipated results are based on the Wade model which is a set of theoretical calculations for determining diurnal emissions based of fill level, fuel RVP, and temperature profile. These calculations are presented in Chapter 3. Although the Wade model over-predicts the vapor generation, it does show a similar trend with respect to temperature. To account for this over prediction, we use a correction factor of 0.78. This correction factor is based on empirical data[1], has historically been used in our automotive emission models, and appears to be consistent with the data presented below.

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

Table 5.1-1: Baseline Diurnal Evaporative Emission Results (varied temperature)

Temperatures	*Capacity [gallons]*	*Measured [g/gallon/day]*	*Wade Model [g/gallon/day]*	*Corrected Wade [g/gallon/day]*
22 - 36°C (72 - 96°F)	17	1.40	2.30	1.79
22 - 36°C (72 - 96°F)	30	1.50	2.30	1.79
24 - 33°C (74 - 91°F)	30	1.13	1.33	1.04
22 - 30°C (71 - 86°F)	30	0.88	1.02	0.80
25 - 31°C (77 - 88°F)	30	0.66	0.88	0.69
26 - 32°C (78 - 90°F)	30	0.85	1.04	0.81
28 - 31°C (82 - 87°F)	30	0.47	0.43	0.34

5.1.1.2 Small SI Equipment

We contracted with an outside lab for the testing of thirteen Small SI fuel tanks over various test temperature profiles.[2,3] This testing was performed with the tanks filled to 50 percent capacity with certification gasoline and is discussed in more detail below in the Section 5.2.1. This data is presented in Table 5.1-2. In addition, in cases where the fuel temperature profiles were within the input range of the Wade model for diurnal emissions, theoretical emissions were also calculated using the same correction factor discussed above for marine fuel tanks. As shown below, the measured values are fairly consistent with the theoretical values.

Table 5.1-2: Fuel Temperature Measurements During Operation of Small SI Equipment

Equipment Type	Fuel Capacity [gallons]	Temperature Profile °C	Measured HC grams/gallon	Theoretical HC grams/gallon
Riding mower	1.1	15.7 - 28.4	0.92	0.91
	1.4 x 2	21.9 - 29.7	0.88	0.71
	1.7	19.5 - 30.3	0.82	0.94
	2.5	27.0 - 35.0	1.29	1.16
	3.0	26.6 - 28.4	0.25	0.17
	6.5	24.3 - 33.2	1.20	1.08
	6.5 x 2	20.5 - 23.9	0.26	0.23
Walk-behind mower	0.34	23.3 - 33.0	0.76	1.18
	0.25	28.7 - 46.7	4.92	NA*
	0.22	28.7 - 59.7	36.9	NA*
Generator set	8.5	20.6 - 25.8	0.45	0.38
	7.0	25.8 - 50.0	9.90	NA*
Pressure washer	1.8	19.0 - 50.6	11.6	NA*

* outside the temperature range of the model

The California Air Resources Board performed diurnal testing on seven pieces of handheld equipment and 20 pieces of non-handheld equipment by placing the whole equipment in a SHED.[4] They filled the fuel tanks to 50 percent with 7 RVP fuel and tested over their 65-105° F summer day test cycle. Because the entire piece of equipment was included in these tests, not only were diurnal venting emissions measured, but tank and hose permeation as well (plus any potential leaks). Average test results by equipment type are presented in Table 5.1-3.

Table 5.1-3: ARB Measurement of Evaporative Emissions from Small SI Equipment (7 RVP California Certification Fuel, 50% Fill, 65-105°F)

Equipment Type	Number of Data Points	Average Measured HC [grams/day]
Handheld equipment	7	1.04
Walk-behind lawnmowers	12	3.51
Generators	2	11.2
Riding Mowers	3	8.70
Edgers	2	1.53
Tiller	1	4.12

ARB also performed tests on a subset of the equipment using fuel containing MTBE and fuel containing ethanol to investigate fuel effects. They observed nearly a 50 percent increase in emissions when an ethanol blend was used compared to an MTBE blend. The reason for this increase was not discussed, but may have largely been a permeation effect. On five pieces of equipment, a California wintertime cycle (51.6-69.5° F) was used as well. As would be expected, the emissions were reduced significantly. The theoretical models predict about an 85 percent reduction in diurnal venting emissions and about a 60 percent reduction in permeation. The observed results were about a 70 percent reduction which is in this range.

5.1.2 Insulation of the Fuel Tank

The diurnal vapor generated in a fuel tank is directly related to the diurnal temperature trace of the fuel. A reduction in temperature variation causes less vapor to be formed. To investigate this effect we used insulation around the fuel tank to reduce the effect of the ambient air temperature variation on the fuel temperature variation. In our preliminary testing, we insulated a 23 gallon rotationally molded marine fuel tank using 3 inch thick construction foam with an R-value of 15 as defined by 16 CFR 460.5. This testing was performed with the fuel tank vent open to atmosphere. Table 5.1-4 presents the fuel temperatures and evaporative emissions over the three day test.

We tested this fuel tank over a three day diurnal test with an ambient temperature of 72-96°F. This experiment resulted in a 50 percent reduction in emissions from baseline on the highest of these three test days. The baseline emissions were measured to be 2.5 g/gallon/day; however it should be noted that for both the baseline test and the insulated tank tests we did not control for permeation or diffusion. Over this test, the emissions decreased for subsequent days. We believe this was due to the fuel temperature cycle stabilizing. Although we did not control for permeation or diffusion, the results from this preliminary experiment directionally show the effect of insulation on diurnal emissions.

Table 5.1-4: Evaporative Emission Results for Insulated Flat, Plastic Tank

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

In boats with installed fuel tanks, the fuel tank is generally hidden beneath the deck. As a result, there is a certain amount of “inherent” insulation caused by the boat itself. This effect is increased for a boat that is stored in the water. The water acts as a cooling medium for the fuel tank, especially if it is installed in the bottom of the boat. In addition, the thermal inertia of the fuel in the tank can act to dampen temperature variation imposed from the diurnal heating of the ambient air. To investigate this effect, we tested several boats by recording the ambient air temperature and fuel temperatures over a series of days. Two boats were tested on trailers outside in the summer, two boats were tested on trailers in a SHED, and two boats were tested in the water on summer days. Table 5.1-5 presents the average results of this testing. The temperature traces are presented in Appendix 5A.

Table 5.1-5: Ratio of Fuel to Ambient Temperature Swing for Boats

Boat Type	*Test Conditions*	*Capacity [gallons]*	*Fuel Tank Fill Level*	*Temperature Ratio**
9 ft. personal watercraft	outside, on trailer	13	50%	66%
16 ft. jet boat	outside, on trailer	40	50%	52%
18 ft. runabout	in SHED, on trailer	30	40%	68%
16 ft. jet boat	in SHED, on trailer	40	90%	33%
18 ft. runabout	outside, in water	30	100%	19%
21 ft. deck boat	outside, in water	20	90%	27%

* Average ratio of change in fuel temperature to change in ambient air temperature over test days.

In their comments on the proposed rule, the National Marine Manufacturers Association presented temperature data on 18 foot runabout, with a 32 gallon tank, tested in a SHED with an ambient temperature of 72-96°F.[5] The average fuel to ambient temperature ratio was 54 percent for this testing. This ratio is in the range of EPA test results for boats tested on a trailer. Brunswick also included temperature data in their comments.[6] The average days test on a boat on the water was 19 percent, which is consistent with our water tests. Brunswick's average for boats tested while stored out of the water was 27 percent which is considerably lower than the EPA and NMMA testing. Combining all of the EPA and industry data, the average fuel to ambient temperature ratio (based on test days) is about 20 percent for boats in the water and 50 percent for boats stored out of the water.

During diurnal testing of lawnmowers, ARB found that the fuel and tank skin temperature follow the ambient temperature closely.[7] This same phenomenon would be expected for other Small SI equipment as well (and portable fuel tanks) because of the small fuel volumes and because these tanks are generally exposed to ambient air. One issue that we considered was that Small SI equipment is often stored in garages or sheds. In that case, we were interested in if the garage or shed acts to insulate the fuel tanks from ambient temperature swings. ARB collected data on four garages and one shed. This data included summer and winter California temperature measurements. For each test, the inside and outside temperature were measured for five days. This data is presented in Table 5.1-7. For the garages, the inside temperature was generally warmer than outside, but the variable temperature swings were smaller. For the shed, the inside temperature was warmer and showed higher heat builds than the outside temperature. Table 5.1-6 also presents an estimate of the effect on diurnal emissions using the theoretical equations presented in Chapter 3. No conclusive evidence of was observed to suggest that these fuel tanks are generally subject to inherent insulation.

Table 5.1-6: Comparison of Ambient to Inside Diurnal Temperature Swings

Season	*Enclosure*	*Inside Temperature °C*		*Outside Temperature °C*		*Emission Effect*
		Avg T	*Avg Delta T*	*Avg T*	*Avg Delta T*	
Winter	garage D	13.8	6.4	10.1	9.3	-8%
	garage G	12.1	9.2	5.8	14.3	-9%
	garage J	13.5	2.4	8.0	7.3	-55%
Summer	garage A	27.4	3.6	22.4	12.2	-63%
	garage D	35.9	11.7	30.3	15.6	20%
	garage G	27.4	15.7	21.3	19.5	23%
	garage J	27.6	8.9	23.7	20.3	-61%
	shed	27.1	20.1	23.6	14.1	119%

Some of the variance between the fuel temperature and ambient temperature, especially for larger fuel tanks, is likely due to the thermal inertia of the fuel in the tank. The fuel has mass and therefore takes time to heat up. ARB performed a study in which the fuel temperature and ambient temperature were recorded for aboveground storage fuel tanks.[8,9] Three fuel tanks sizes were included in the study: 350, 550, and 1000 gallons. Because of the large size of these tanks, the thermal inertia effects would be expected to be larger than for typical fuel tanks used in Marine SI and Small SI applications. For the 350 gallon fuel tank, ARB also measured the effect of insulating the fuel tank on temperature. Table 5.1-7 presents the results of this testing. Note that the test results are the average of five days. Ambient temperature on these test days typically had a minimum in the 60-70˚F range and a maximum temperature in the 95-105˚F range.

EPA performed testing on 17 gallon marine fuel tank in a SHED over a single 72-96˚F diurnal test and measured both ambient and fuel temperature.[10] This data is also included in Table 5.1-7. Note that for the smaller tank, there is little difference between the ambient and fuel temperature profiles. However, for larger tanks, the fuel temperature has about a 25-30 percent smaller temperature swing than the ambient temperature. Note that the insulated fuel tank had a temperature ratio similar to the fuel tank stored in a boat in the water.

Table 5.1.7: Ratio of Fuel to Ambient Temperature for Uninsulated Fuel Tanks

Fuel Tank Type	*Tank Capacity [gallons]*	*Temperature Ratio**
marine fuel tank	17	95%
aboveground storage tank (with insulation)	350	75% (18%)
aboveground storage tank	550	70%
aboveground storage tank	1000	76%

* Average ratio of change in fuel temperature to change in ambient air temperature over test days.

5.1.3 Diffusion Effect

For the purposes of this discussion, diffusion refers to the process in which gasoline vapor penetrates air in an attempt to equalize the concentration throughout the gas mixture. This transport phenomenon is driven by the concentration gradient and by effective area. In the case of a mobile source fuel system that has a vent to atmosphere, the fuel vapor concentration is near saturation in the fuel tank and near zero outside of the fuel system. Therefore, the diffusion rate is primarily a function of the path between the fuel tank and atmosphere. The following equation describes the relationship between the flux of gasoline vapor out of the tank, the concentration gradient, and the vent path:

$$Flux = \frac{mass}{area \times time} = D \times \frac{\Delta C}{\Delta x}$$

where: D = diffusion coefficient (constant)
ΔC = concentration gradient
Δx = path length
area = cross sectional area of vent

Based on the above equation, diffusion from a tank through a vent hose would be a function of the cross-sectional area divided by the length of the hose. Therefore a longer hose would theoretically limit fuel vapor venting due to diffusion. Whenever a hydrocarbon (HC) molecule escapes from the fuel tank, a new molecule of air enters the fuel tank to replace the escaped HC. This brings the concentration of HC vapor in the fuel tank out of equilibrium. To balance the partial pressures in the fuel tank, more HC must evaporate as HC in the vapor space is depleted. In this way, the vapor concentration in the fuel tank remains saturated.

5.1.3.1 Marine Fuel Tank Data

In testing diurnal emissions from fuel tanks with open vents, the configuration of the vent can have a significant effect on the measured emissions due to the diffusion of vapor out of any opening in the fuel tank. Depending on the size and configuration of the vent, diffusion can actually occur when the fuel temperature is cooling. Most marine vessels with an installed fuel tank vent through a hose. As shown below this configuration can minimize diffusion.

To quantify the diffusion component for a typical fuel tank, we ran four 72-96°F diurnal tests on a 17 gallon aluminum marine fuel tank using various configurations for venting The first configuration was with the fuel cap cracked open and the vent sealed, the second configuration was with a 68 cm length of vent hose, and the third configuration was with a 1000 micron (1 mm) limiting flow orifice in the vent opening. This 1000 micron orifice was large enough to allow venting without any measurable pressure increase in the fuel tank during the diurnal test. The fourth configuration was a combination of the limited flow orifice and the vent hose. Table 5.1-8 presents the results of this testing.

Table 5.1-8: Diurnal Test Results with Varied Venting Configurations

Vent Configuration	*Evaporative HC [g/gallon/day]*
cracked fuel cap	2.05
68 cm of $^5/_8$" fuel hose	1.40
1000 micron orifice	1.47
1000 micron orifice + 68 cm of $^5/_8$" fuel hose	1.34

The above testing showed a 50 percent higher emission rate for the tank vented through a cracked fuel cap compared to one vented through a hose. In the test with the cracked fuel cap, an increase in HC concentration in the SHED was observed throughout the test, even when the fuel temperature was cooling. For the other three tests, the HC concentration leveled off when the temperature began to cool. This suggests that the difference in measured emissions of 0.6 - 0.7 g/gal/day was due to diffusion losses.

To further investigate this diffusion effect, we tested the 17 gallon aluminum tank with several venting configuration, at two constant temperature settings. Under these conditions, all of the measured evaporative emissions would be expected to be due to diffusion. As seen in Table 5.1-9, diffusion can be very high with too large of a vent opening unless a vent hose is used. The two lengths of vent hose tested did not show a significant difference in diffusion emissions. We believe that the vent hose limits diffusion by creating a gradual gradient in fuel vapor concentration.

Table 5.1-9: Constant Temperature Test Results with Varied Venting Configurations

Vent Configuration	*22°C (72°F)* *Evaporative HC [g/gal/day]*	*36°C (96°F)* *Evaporative HC [g/gal/day]*
½" I.D. fitting	5.65	10.0
68 cm of $^5/_8$" fuel hose	0.11	0.18
137 cm of $^5/_8$" fuel hose	0.07	0.24
1000 micron orifice	0.28	0.41

The above data suggest that, at least for open vent fuel systems, the size and configuration of the venting system can have a significant effect on evaporative emissions. In marine applications, there is typically a vent hose attached to the fuel tank. Diffusion emissions appear to be minimal if the fuel tank is vented through a length of hose. This is probably because the long residence times in the hose cause more opportunities for molecular collisions which direct the HC molecules back towards the fuel tank.

One study looked at the evaporation of liquids from a tube filled to various fill heights.[11] As the fill height decreased (effectively increasing the length of the tube above the liquid surface) the evaporation quickly decreased. These results are consistent with the observed effects of venting through a hose in our testing. Installed marine fuel tanks typically vent through a hose to the outside of the boat; therefore, diffusion losses are likely relatively small for these applications. Another study was performed on automotive fuel caps which suggests that a crack in the gasket on the fuel cap of 1 percent of the gasket area can result in more than 2 grams of HC emissions per day.[12]

5.1.3.2 Small SI Fuel Tank Data

For Small SI applications (and portable marine fuel tanks), the tanks are typically vented through an opening in the fuel cap. Therefore, unless the cap is sealed, we would expect diffusion emissions to occur. The above data suggest that diffusion can account for a significant portion of the evaporative HC emissions measured from a metal tank with a small vent in the cap over a 72-96°F diurnal test. Because diffusion would still occur at constant temperature, the contribution of diffusion to measured diurnal emissions would increase, on a percentage basis, as the diurnal temperature swing approached zero.

To investigate the effect of fuel cap design on diffusion for Small SI applications, we implemented a test program which included four fuel tank configurations (one metal and three plastic) and the corresponding fuel caps. These four fuel tanks were taken from lawnmowers using engines from the three lawnmower engine manufacturers with the highest U.S. sales and represent the majority of lawnmower fuel tanks on the market. Table 5.1-10 presents a description of these fuel tanks.

Table 5.1-10: Lawnmower Fuel Tanks Used in Diurnal/Diffusion Testing

Tank	Tank description	Fuel Cap Vent Description
BM	metal, 800 ml	Three 1/16" dia. holes drilled in top of cap. Four similar holes drilled in fibrous gasket
BP	plastic, 1175 ml	Three torturous pathways through plastic gasket, with venting between tank/cap threads. (Also performed test using a modified cap similar to the cap used on the metal tank.)
HP	plastic, 950 ml	Pinhole in gasket center leading to two indentations in rubber gasket at mating surface, with venting between tank/cap threads
TP	plastic, 920 ml	Four indentations in rubber gasket at mating surface, with venting between tank/cap threads

We contracted with two outside laboratories to perform the diurnal/diffusion tests for the Small SI equipment fuel tanks shown above.[13,14,15,16] In this effort, the fuel tanks were sealed, except for the vents in the fuel cap, and filled to 40 percent of capacity with 9 RVP fuel. These tanks were then tested in a mini-SHED over the EPA 72-96°F 24-hour diurnal test procedure. To minimize the effect of permeation on the test results, new fuel caps and plastic fuel tanks were used for each test that had not been exposed to fuel or fuel vapor prior to the test.

Under this testing, emissions continued to climb even when temperature was cooling back from 96˚F to 72˚F. These emissions were clearly not driven by temperature, so they were determined to represent diffusion emissions. Total diffusion for the test was determined by recording the HC emissions that occurred during the last 12 hours of the test (during the cooling event) and then multiplying these emissions by two to represent 24 hours. Although the peak temperature occurs after nine hours, only the last 12 hours were used to ensure that the fuel in the tank was not still heating due to a thermal time lag. Diffusion was then subtracted off the total HC measurement to determine non-diffusion diurnal emissions. For the fuel cap with the three holes drilled straight through it, the emissions were so high that it went out of measurement range near the end of the tests performed by one of the contractors. However, all of the observed diffusion rates were linear, making it simple to extrapolate the data where necessary. Table 5.1-11 presents the diurnal and diffusion data from these tests and compares it to the theoretical diurnal emissions using the Wade equations discussed above. Charts in Appendix 5B present the time series of the measured HC compared to the mini-SHED temperature.

Table 5.1-11: Diurnal and Diffusion Emissions from Lawnmower Fuel Tanks (g/gal/day) over a 72-96-72 °F (22.2-35.6-22.2 °C) Temperature Profile

Tank	Total HC	Diffusion	Diurnal	Wade Diurnal
BM	47.8	43.6	4.2	1.8
BP	2.1	0.1	2.0	1.8
BP cap 2*	24.1	19.3	4.8	1.8
HP	1.6	0.1	1.5	1.8
TP	2.1	0.2	2.0	1.8

* modified to be similar to cap on metal tank (BM)

The fuel caps in the above table for the lawnmower tanks labeled as BM and BP cap 2 resulted in very high diffusion emissions. Although this fuel cap type is a common design used in Small SI applications, it may represent one of the worst case configurations for diffusion. There are three small holes in the cap itself, and four small holes in the fibrous material imbedded in the inside of the cap. Presumably, this design was intended to minimize fuel from splashing out of the tank while still allowing the tank to breathe to prevent pressure or vacuum from occurring in the tank. Because the carburetor on this lawnmower is gravity fed, too much vacuum in the fuel tank could cause the engine to stall from lack of enough fuel. The reason that this may be a worst case configuration is that there is a direct (and relatively large) path for fuel vapor to escape from the fuel tank.

The other three fuel cap designs were also from stock lawnmower fuel systems. In all three of these designs, the venting occurred through small grooves in the gasket that seals the mating between the fuel cap and the fuel tank. The venting then occurs through the thread paths between the cap and tank. As a result, vapor and air must pass through a tortuous pathway to enter or leave the tank. This tortuous pathway appears to limit diffusion in much the same way as venting through a long hose does.

The above emission testing was repeated except that the vents in the fuel cap were sealed and the tank was vented through a 8 inch length of 1/4" I.D. hose. A lawnmower air intake filter was attached to the end of this hose in order to simulate the venting configuration on a lawnmower with running loss control. To minimize the effect of permeation, a low permeation barrier hose was used that had never before been exposed to fuel or fuel vapor. The test results in which the tanks were vented through hoses are presented in Table 5.1-12.

Table 5.1-12: Diurnal and Diffusion Emissions from Lawnmower Fuel Tanks (g/gal/day) with Modified Venting Through Hose/Air Filter to Simulate Running Loss Control over a 72-96-72 °F (22.2-35.6-22.2 °C) Temperature Profile

Tank	Total HC vent through stock cap	Total HC vent through hose/filter	Reduction in Total HC
BM	47.8	12.9	34.8
BP	2.1	1.9	0.2
BP cap 2*	24.1	1.9	22.2
HP	1.6	2.0	(0.4)
TP	2.1	2.9	(0.7)

* modified to be similar to cap on metal tank (BM)

As shown in the table above, venting through the hose greatly reduced the measured emissions compared to the BM cap vent. When vented through the hose configuration, diffusion emissions were on roughly the same order as when the tortuous cap vents were used. This is consistent with the data presented earlier on marine fuel tanks vented through a hose. In an in-use running loss system, a valve or limited flow orifice would likely also be in the vent line. These components would likely further reduce, or even eliminate, diffusion emissions.

There was some concern that diffusion may have been underestimated in the above tests because air flowing back into the fuel tank during the cooling period may have limited diffusion by pulling HC molecules back into the fuel tank. In addition, we believed that testing at constant temperature would allow us to more directly measure diffusion. Therefore, the above testing was repeated at a constant temperature of 29°C.[17,18,19] However, it should be noted that this testing may have overestimated diffusion somewhat because of small temperature fluctuations (less than 0.5 °C) around the average during the test. Therefore, any HC measurements from the "constant" temperature testing may have overstated diffusion due to vapor generated by the repeated mini-diurnal cycles during in the test. These test results are presented in Table 5.1-13.

Table 5.1-13: Isothermal [29 °C] Diurnal and Diffusion Emissions from Lawnmower Fuel Tanks (g/gal/day) with Modified Venting Through Hose/Air Filter to Simulate Running Loss Control

Tank	Total HC vent through stock cap	Total HC vent through hose/filter	Reduction in Total HC
BM	43.2	8.9	34.3
BP	1.3	1.0	0.3
BP cap 2*	29.3	1.0	28.3
HP	1.0	0.8	0.2
TP	0.9	0.9	0.0

* modified to be similar to cap on metal tank (BM)

At constant temperature, the relationship between measured diffusion emissions between the venting configurations was consistent with the variable temperature testing. However, the indicated diffusion results were somewhat higher. These higher results were influenced by two effects. In the variable temperature testing, the diffusion was measured during the cooling period when air was being drawn into the fuel tank. This would reduce diffusion into the SHED because escaping HC molecules would need to overcome the air flow into the tank. At the same time, the constant temperature test may have overstated diffusion due to the measured small fluctuations in temperature that may have caused mini-diurnal cycles. Likely, the actual diffusion rates are somewhere in-between the results presented in Tables 5.1-11 and 5.1-12. Appendix 5B contains data charts that present the results of the Small SI diffusion testing in more detail.

Although the results are presented above on a gram per gallon basis for comparison with diurnal emissions, diffusion appears to be more a function of orifice size that fuel tank size. Presumably, the diffusion rate on a grams per day basis would be the same through a given orifice regardless of size of the vapor space. This is reflected in the data above in that the permeation rates on a gram per gallon basis from the lawnmower fuel tanks with holes in the fuel cap were much larger than for the marine fuel tank in the testing discussed earlier. At the same time, larger fuel tanks may be designed with larger orifice sizes to account for higher amounts of vapor expansion in the tank.

5.1.4 Carbon Canister

The primary diurnal evaporative emission control device used in automotive applications is a carbon canister. With this technology, vapor generated in the tank is vented through a canister containing activated carbon (similar to charcoal). The fuel tank must be otherwise sealed; however, this only results in a minimal amount of pressure in the tank. The activated carbon collects and stores the hydrocarbons. Once the engine is running, purge air is drawn through the canister and the hydrocarbons are burned in the engine. These carbon canisters generally are about a liter in size for an automotive tank and have the capacity to store three days of vapor over the test procedure conditions. For automotive applications, this technology reduces diurnal emissions by more than 95 percent.

In a marine application, the vessel may sit for weeks without an engine purge; therefore, canisters were not originally considered to be a practical technology for controlling diurnal vapor from boats. Since that time, however, we have collected information showing that, during cooling periods, the canister is purged sufficiently enough so that it can be used effectively to reduce diurnal emissions. When the fuel in the tank cools, fresh air is drawn back through the canister into the fuel tank. This fresh air will partially purge the canister and return hydrocarbons back to the fuel tank.[20,21] Therefore, the canister will have some open sites to collect vapor during the next heating event. Test data presented below show that a canister that starts empty is more than 90 percent effective at capturing hydrocarbons until it reaches saturation. Once the canister reaches saturation, it is still capable of achieving more than a 60 percent reduction in diurnal emissions due to passive purging. Passive purging occurs as a result of fresh air that is pulled through the canister during fuel tank cooling periods. With the addition of an engine (active) purge, greater reductions would be expected.

We tested a 30 gallon aluminum fuel tank over three, multiple-day diurnal cycles with and without a charcoal canister. The carbon canister was 2.1 liters in size with a butane working capacity (BWC) of 11 g/dL (based on EPA test) and was aged using multiple 24 hour diurnal cycles prior to testing. In our first test, the fuel temperature was cycled from 72-96°F using a heating blanket in a SHED for at total of 28 days. Because we were not able to test over weekends, we brought the fuel temperature down to 72°F and held it to prevent the generation or purging of vapors. On Mondays, we saw higher vapor rates than the rest of the week which was likely due to the vapor redistributing itself equally through the canister over the weekend when the temperature was held constant. Under normal conditions, the continued diurnal cycles would maintain a gradient through the canister and this effect would not occur. Appendix 5C contains graph showing the results of the 28 day test. This test is interesting because we began with a purged canister and were able to observe the loading of the canister over the first few days. It took about five test days to achieve canister breakthrough and another ten test days before the canister loading/purging cycle stabilized.

Once the canister was saturated, the emissions results stabilized. Therefore, for the subsequent canister tests, we began with a loaded canister and tested for four days. The results were collected beginning after the first night so that the canister would have a cooling cycle for back-purge. Table 5.1-14 presents our test results for the baseline and stabilized with canister diurnal emission rates.

Table 5.1-14: EPA Diurnal Emission Test Results With and Without a Canister on a 30 Gallon Aluminum Marine Fuel Tank [g/gal/day]

Temperature Range	*Baseline*	*With a Canister*	*Reduction*
22.2-35.6°C (72-96°F)	1.50	0.52	65%
25.6-32.2°C (78-90°F)	0.85	0.28	67%
27.8-30.6°C (82-87°F)	0.47	0.14	71%

Marine manufacturers raised the concern that the high humidity in the areas where boats are used would be detrimental to this technology. They stated that the carbon could become saturated with water vapor, thereby reducing the available sites for hydrocarbon capture. These manufacturers also commented that carbon canisters may not be able to survive shocks and vibration that would be seen on a boat. Carbon canisters have been used in automotive applications for decades, which are subject to high humidity (rainy days) and shocks and vibration. In addition, one manufacturer, who is a primary supplier to the automotive industry, has developed a new grade of carbon that has low moisture adsorption characteristics and about 40 percent harder than typical automotive carbon.[22,23] This carbon has been designed specifically for marine applications. Based on this manufacturer's testing, more than a 60 percent reduction in diurnal vapor emissions can be achieved with a passive purge system. This reduction is based on a canister capacity of 0.03 to 0.04 liters of carbon per gallon of fuel tank capacity.

The National Marine Manufacturers Association has initiated a test program has to demonstrate the durability of carbon canisters in marine applications. This test program includes installing carbon canisters on a total of fourteen boats made by four boat builders.[24] These boat types include cruisers, runabouts, pontoon boats, and fishing boats. The carbon canister design used for these boats is a simple cylinder that can be cut to length with end caps and mounting brackets. The canisters were installed in the vent lines and a valve was added to prevent fuel from reaching the canister during refueling. These canisters use marine grade carbon. At the end of this test program, each of the canisters were tested for working capacity and each canister showed good performance.[25] These canisters will be evaluated further, including destructive testing.

Another issue that has been raised has been the ability of carbon canisters to pass the Coast Guard flame test. The carbon canisters could be made out of a variety of materials, including metal. Even a thin-walled nylon fuel tank could be manufactured to pass the flame test if a flame-resistant coating or cover were used. One study attempted to ignite a carbon canister that was loaded with fuel vapor.[26] When an ignition source was applied to the canister vent, the gases exiting the canister were ignited and burned as a small, steady flame until the canister tube opening began to melt. No explosion occurred.

Recently, the California Air Resources Board (ARB) performed similar testing on a commercial mower and a generator with 6 gallon fuel tanks and 0.65 liter canisters.[27] Their testing showed better than 50 percent reductions, on average, in diurnal emissions through the use of canisters without an engine purge. The testing was performed over two diurnal temperature ranges, 53-71°F and 65-105°F which are intended to represent an average day and a high temperature episode.

Over a decade ago, testing performed on a car showed similar results.[28] A 1988 Regency 98 with an 18 gallon fuel tank was subjected to an 8 day diurnal without driving. This diurnal was performed using a 72-96°F temperature profile, a tank filled to 40 percent with 9RVP gasoline, and a purged canister at the beginning of testing. The test results showed, that the canister loading/purging cycle began to stabilize after 6 days. Due to the canister back-purge, the stabilized diurnal emission rate about 11.5 grams per day which was more than a 50 percent reduction compared to baseline.

A manufacturer of activated carbon performed studies of ethanol fuel blend and carbon bed temperature on carbon efficiency.[29] Testing was performed with carbon canisters using gasoline, E10, and E85 fuel for onboard vapor refueling emissions efficiency. The emissions control was similar for each of the test fuels. Testing was also performed to measure gasoline working capacity for carbon soaked at temperatures ranging from 25 to 80˚C. Over this range only a 10 percent decrease in working capacity was observed with increasing temperature. Over the 25-40˚C range, which is more representative of boat or Small SI equipment use, the effect was only 1-2 percent. Based on the results from these studies, carbon canister efficiency would be expected to be effective at reducing diurnal emissions over the range of fuels and temperatures that may be seen in use.

5.1.5 Sealed System with Pressure Relief

Evaporative emissions are formed when the fuel heats up, evaporates, and passes through a vent into the atmosphere. By closing that vent, evaporative emissions are prevented from escaping. However, as vapor is generated, pressure builds up in fuel tank. Once the fuel cools back down, the pressure subsides. One way to control these emissions is to seal the fuel system. However, depending on the fuel tank design, a pressure relief valve may be necessary which would limit the control.

5.1.5.1 Pressure Relief Valve

For most marine applications, U.S. Coast Guard safety regulations require that fuel tanks be able to withstand at least 3 psi and must be able to pass a pressure impulse test which cycles the tank from 0 to 3 psi 25,000 times (33 CFR part 183).[2] The Coast Guard also requires that these fuel tanks must be vented such that the pressure in the tank in-use never exceeds 80 percent of the pressure that the tank is designed to withstand without leaking. The American Boat and

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[2] These regulations only apply to boats with installed fuel tanks and exclude outboard boats. However, ABYC recommended practice effectively extends many of these requirements to outboard boats as well.

Yacht Council makes the additional recommendation that the vent line should have a minimum inner diameter of 7/16 inch.[30] However, these recommended practices also note that "there may be EPA or state regulations that limit the discharge of hydrocarbon emissions into the atmosphere from gasoline fuel systems. The latest version of these regulations should be consulted."

To prevent pressure from building too high in marine tanks, we first considered a 2 psi pressure relief valve. This is a typical automotive rating and is below the Coast Guard requirements. With this valve, vapors would be retained in the tank until 2 psi of pressure is built up in the tank due to heating of the fuel. Once the tank pressure reached 2 psi, just enough of the vapor would be vented to the atmosphere to maintain 2 psi of pressure. As the fuel cooled, the pressure would decrease. In our August 14, 2002 proposal (67 FR 53050) we considered standards based on a 1 psi valve which would only achieve a modest reduction over the proposed test procedure. However this reduction would be significantly greater in use because the test procedure is designed to represent a hotter than average day. On a more mild day, there would be less pressure buildup in the tank and the valve may not even need to open. With the use of a sealed system, a low pressure vacuum relief valve would also be necessary so that air could be drawn into the tank to replace fuel drawn from the tank when the engine is running.

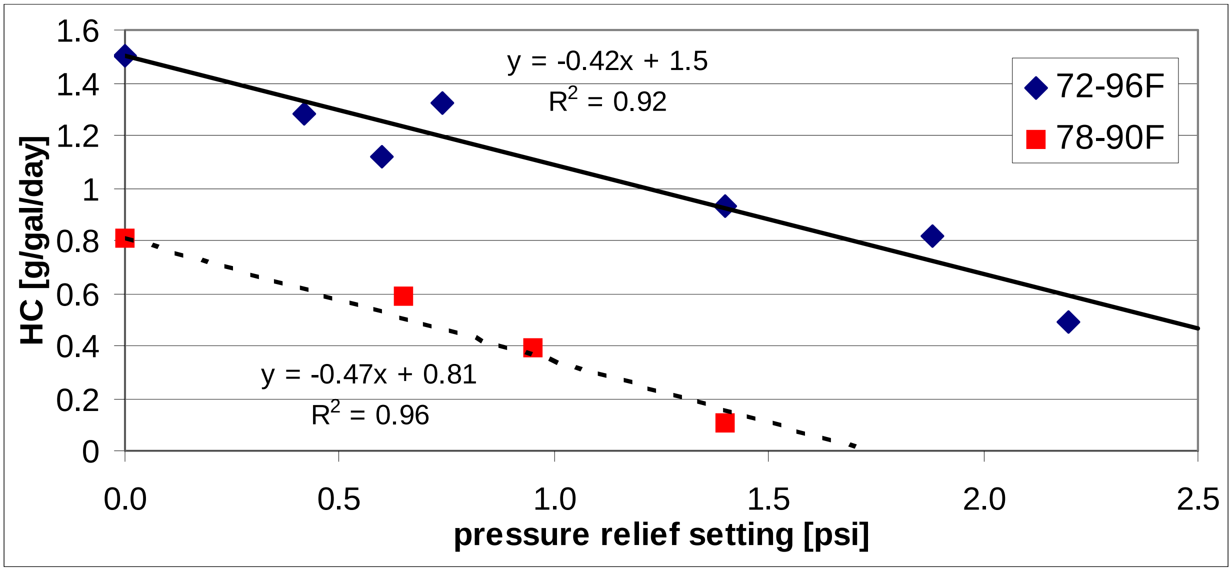
Manufacturers of larger plastic fuel tanks have expressed concern that their tanks are not designed to operate under pressure. For instance, although they will not leak at 3 psi, rotationally molded fuel tanks with large flat surfaces could begin deforming at pressures as low as 0.5 psi. At 2.0 psi, the deformation would be greater. This deformation would affect how the tank is mounted in the boat. Also, fuel tank manufacturers commented that some of the fittings or valves used today may not work properly under 2 psi of pressure. Finally, they commented that backup pressure-relief valves would be necessary for safety. For smaller fuel tanks, such as used in personal watercraft, portable fuel tanks, and Small SI equipment, pressure is less of an issue because of the smaller internal surface area of these fuel tanks. In addition, the construction of these fuel systems are generally vertically integrated which allows for more precise control of design parameters. For instance, personal watercraft manufacturers are already sealing their fuel systems to prevent fuel from spilling into the water. These systems generally have pressure relief valves ranging from 0.5 to 4.0 psi. In addition, portable fuel tanks are designed to be sealed without any pressure relief.

We looked at two types of pressure relief strategies: pressure relief valves and limited flow orifices. Because the Coast Guard requires that fuel systems not exceed 80 percent of their design capacity of 3 psi, we only looked at pressure relief strategies that would keep the pressure below 2.4 psi under worst case conditions.

For the pressure relief valve testing, we looked at several pressures ranging from 0.5 to 2.25 psi. The 2.25 psi valve was an off-the-shelf automotive fuel cap with a nominal 2 psi pressure relief valve and 0.5 psi vacuum relief valve. For the other pressure settings, we used another automotive cap modified to allow adjustments to the spring tension in the pressure relief valve. We performed these tests on the 17 gallon aluminum fuel tank to remove the variable of permeation. Emissions were vented through a hose to prevent diffusion losses from affecting the measurements. We operated over two temperature profiles. The first set of tests were performed in a variable temperature SHED with a 72-96°F air temperature profile. This temperature profile was based on the existing automotive cycle which is intended to represent a typical summer day on which a high ozone event may occur. The second set of tests were performed using a heating blanket to create a 78-90°F fuel temperature profile. This testing was intended to represent a fuel tank in a boat, where the tank may be inherently insulated, during the same ambient temperature profile. This inherent insulation creates a time lag on the heating and cooling of the fuel and reduces the amplitude of the temperature profile by half.

As shown in Figure 5.1-1, there was a fairly linear relationship between the pressure setting of the valve and the emissions measured over the proposed test procedure. In addition, the slopes of the lines are similar for both test temperature scenarios. This suggests that over a smaller temperature profile, a greater percent reduction in HC can be achieved at a given pressure setting. This is reasonable because, in each case, a constant amount of vapor is captured. In other words, regardless of the temperature profile, the same amount of vapor must be generated to create a given pressure. For instance, with a 1 psi valve, about 0.4 grams/gallon of HC are captured over each temperature profile. However, this represents a 50 percent reduction over a 78-90°F temperature profile while only about a 25 percent reduction over the 72-96°F temperature profile.

Figure 5.1-1: Effect of Pressure Cap on Diurnal Emissions



The California Air Resources Board tested a lawnmower in a SHED for diurnal emissions in a baseline configuration, a sealed system, and with various pressure relief settings.[31] Because the whole lawnmower was tested, permeation (and potentially leakages) were measured as well as diurnal venting emissions. The testing was performed over a 65-105°F temperature cycle with the fuel tank filled to 50 percent with 7 RVP fuel. For the system as a whole, they measured a 76 percent reduction in emissions when the tank was fully sealed compared to the open vent configuration. This suggests that diurnal venting made up about 76 percent of the evaporative emissions measured. Testing using 2, 3, and 4 psi pressure relief valves showed reductions of 43 percent, 43 percent, and 63 percent respectively. They also collected pressure data over various diurnal temperature cycles on a lawnmower fuel tank. Over the 65-105°F cycle, the measured a pressure increase of about 2.5 psi. Even under an extreme cycle of 68-121°F, the measured increase in tank pressure was about 3.6 psi.

5.1.5.2 Limited Flow Orifice

Another strategy for maintaining a design pressure is to use a limited flow orifice on the vent. In our testing, we are looked at three orifice sizes: 25, 75, and 1,000 microns in diameter. Again, we performed tests over a 72-96°F diurnal using a 17 gallon aluminum tank. To get these exact orifice sizes, we ordered from a company that specializes in boring holes with a laser device. These orifices were relatively inexpensive. It should be noted that a smaller tank would need a smaller orifice and a larger tank could use a larger orifice to build up the same pressure in the tank. The test results are presented in Table 5.1-15. For all of the tests with the limited flow orifices, no vent hose was attached.

Table 5.1-15: Diurnal Evaporative Emissions with Limited Flow Orifices

Orifice Diameter (microns)	*Peak Pressure [psi]*	*Evaporative HC [g/gallon/day]*
baseline (open vent with hose)	0.0	1.40
1000	0.0	1.47
75	1.6	1.16
25	3.1	0.24

By limiting the flow of the vapor from the tank, emissions were reduced with some pressure build up in the tank. However, because the vapor is flowing from the tank even at low pressure, this strategy is less effective for reducing diurnal emissions than a pressure relief valve. Generally, a higher peak pressure is necessary with the LFO for a given emission reduction. In addition, the limited flow orifice would have to be sized for worst case conditions to prevent the tank from reaching too high of a pressure. A LFO sized for worst case conditions would be less effective under typical conditions because the vapor flow out of the tank could be too low for the LFO to create a restriction. In comparison, a pressure relief valve would achieve higher percent reductions under typical conditions than for worst case conditions because the valve would open less often.

5.1.5.3 Vacuum Relief Valve

For some fuel tanks, pressure relief is not necessary. An example of this is portable marine fuel tanks which are currently equipped with a manual sealing valve. This valve can be sealed by the operator during storage to prevent vapor from escaping. Although pressure will build up during diurnal heating, the fuel tanks are designed to withstand this pressure. However, the valve must be opened by the operator during engine operation so that a vacuum does not form in the fuel tank as fuel is drawn to the engine. If this vacuum were to become too high, it could cause the engine to stall by restricting fuel to the engine.

The existing design requires that the operator close the valve whenever the engine is not running for diurnal emissions to be controlled. If an automatic vacuum relief valve were used, then the operator would not need to operate the sealing mechanism. It would always control diurnal (and other breathing loss) emissions. At the same time, the vacuum relief valve would allow air to be drawn into the fuel tank when the engine is operating to prevent a significant vacuum from being formed.

One manufacturer's approach to this automatic valve design is to use a diaphragm valve such as those used in automotive fuel systems.[32] This inexpensive design would be able to seal the tank under pressure, yet open at very low vacuums. This design (or other vacuum relief valve designs) could be used in any nonroad application where the fuel system is able to withstand pressure.

5.1.6 Selective Permeability Membrane

Another approach we investigated was fitting a molecular membrane in the vent line. The theory was that the membrane would allow oxygen and nitrogen to pass through, but block most longer-chain hydrocarbon molecules. We used a membrane fabricated using Teflon AF® which is an amorphous fluoropolymer. Because oxygen and nitrogen (and some smaller hydrocarbons) can pass through the membrane, hydrocarbons can be trapped in the fuel tank. However, the process for molecules passing through the membrane is slow, so it is important to size the membrane properly to prevent pressure build-up. This membrane could be placed in the vent line or directly in an opening in the top of the fuel tank.

Similar membranes are already used for several applications. One manufacturer provides membranes for a variety of uses such as oxygen or nitrogen enrichment of air or for separation of hydrocarbons from air.[33] One of these uses is to act as a vapor processor to prevent hydrocarbon vapor from escaping from retail gasoline stations in California.[34] Another membrane used for similar applications allows hydrocarbons to permeate but blocks smaller gases. This membrane is used in hydrocarbon recovery applications.[35] In the above noted applications, the membranes are typically used with a pump to provide a pressure drop across the membrane which causes permeation through the membrane. Typically, adequate mixing is needed to maintain an efficient diffusion rate.

We tested an amorphous fluoropolymer membrane with a surface area of about 40 cm^2 in the vent line of both a 30 and a 17 gallon aluminum fuel tank over three temperature cycles. The membrane was applied to a wire mesh in a cylindrical shape with the an outside diameter not much larger than the vent hose. Hydrocarbon emissions and fuel tank pressure were measured. Over these tests we consistently saw a pressure build up, even over a 24 hour test. To investigate the impacts of surface area, we increased the surface area by using 3 filters in parallel (single vent line to assembly). Our test results suggest that the pressures associated with this technology are comparable with the pressure relief valves needed to achieve the same reductions. However, this technology may have the potential for meeting our proposed standards if used in conjunction with a pump to provide a pressure differential across the filter without allowing pressure (and mixing) to build up in the fuel tank. Our test results are presented in Table 5.1-16.

Table 5.1-16: Diurnal Venting Emissions with Selective Permeable Membranes

Tank Size [gallons]	Venting	72-96°F		78-90°F		81.6-86.4°F	
		g/gal/day	psi	g/gal/day	psi	g/gal/day	psi
30	open	1.50	0	0.85	0	0.47	0
	1 filter	0.24	2.9	0.14	1.5	0.19	0.6
	3 filters	0.39	2.2	–	–	–	–
17	open	1.40	0	–	–	–	–
	3 filters	0.45	2.1	0.30	1.2	–	–

5.1.7 Volume Compensating Air Bag

Another concept for minimizing pressure in a sealed fuel tank is through the use of a volume compensating air bag.[36] The purpose of the bag is to fill up the vapor space in the fuel tank above the fuel itself. By minimizing the vapor space, less air is available to mix with the heated fuel and less fuel evaporates. As vapor is generated in the small vapor space, air is forced out of the air bag, which is vented to atmosphere. Because the bag collapses as vapor is generated, the volume of the vapor space grows and no pressure is generated.[3] Once the fuel tank cools as ambient temperature goes down, the resulting vacuum in the fuel tank will open the bag back up.

We tested a 6 gallon portable plastic fuel tank with a 1.5 gallon volume compensating bag made out of Tedlar. Tedlar is a light, flexible, clear plastic which we use in our labs for collecting exhaust emissions samples. In our testing, the pressure relief valve never opened because the volume compensating bag was able to hold the vapor pressure below 0.8 psi for each of the three days. This testing supports the theory that a volume compensating bag can be used to minimize pressure in a fuel tank, which in turn, reduces emissions when used in conjunction with a pressure relief valve.

We did see an emission rate of about 0.4 g/gal/day over the 3 day test. The emission rate was fairly constant, even when the ambient temperature was cooling during the test. This suggests that the emissions measured were likely permeation through the tank. Other materials

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

may be more appropriate than Tedlar for the construction of these bags. The bags would have to hold up in a fuel tank for years and resist permeation while at the same time be light and flexible. One such material that may be appropriate would be a fluorosilicon fiber.

5.1.8 Bladder Fuel Tank

Probably the most effective technology for reducing evaporative emissions from fuel tanks is through the use of a collapsible fuel bladder. In this concept, a non-permeable bladder would be installed in the fuel tank to hold the fuel. As fuel is drawn from the bladder, the vacuum created collapses the bladder. Therefore, there is no vapor space and no pressure build up. Because the bladder would be sealed, there would be no vapors vented to the atmosphere. In addition, because there is no vapor space, vapor is not displaced during refueling events. We have received comments that bladder tanks would be cost prohibitive because its use would increase tank costs by 30 to 100 percent depending on tank size. However, bladder fuel tanks have positive safety implications as well and are already sold by at least one manufacturer to meet market demand in niche applications. Information on this system is available in the docket.[37]

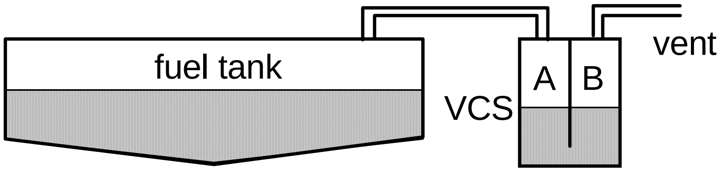
We tested a marine bladder fuel tank in our lab for both diurnal and permeation emissions. Over the diurnal test procedure we saw an emission rate of 0.2 g/gal/day. Because the system was sealed, this measured emission rate was likely due to permeation through the bladder and not due to diurnal losses. We later tested the bladder fuel tank for permeation emissions at 29°C and measured a permeation rate of 0.46 g/gal/day. The bladder used in our testing was constructed out of polyurethane. The manufacturer of this bladder tank is now working with a lower permeability material known as THV. THV is a fluoropolymer that can be used to achieve more than a 95 percent reduction in permeation from current bladder fuel tanks made out of polyurethane.[38] In addition, THV is resistant to ethanol. Permeation rates for these materials are presented in Appendix 5D.

5.1.9 Floating Fuel and Vapor Separator

Another concept used in some stationary engine applications is a floating fuel and vapor separator. Generally small, impermeable plastic balls are floated in the fuel tank. The purpose of these balls is to provide a barrier between the surface of the fuel and the vapor space. However, this strategy does not appear to be viable for fuel tanks used in mobile sources. Because of the motion of Small SI equipment and Marine SI vessels, the fuel sloshes and the barrier would be continuously broken. Even small movements in the fuel could cause the balls to rotate and transfer fuel to the vapor space. In addition, the unique geometry of many fuel tanks could case the balls to collect in one area of the tank. However, we do not preclude the possibility that some form of this approach could be made to work effectively in some mobile source applications.

5.1.10 Liquid Vapor Trap

Figure 5.1-2: Liquid Vapor Trap



One company has developed a liquid vapor trap that it refers to as a fuel vapor containment system (VCS).[39] The VCS behaves similar to a liquid trap used in sink drains in that trapped liquid creates a barrier to gases. This trap would be placed in the vent line to limit fuel vapor emitted from the fuel tank. Figure 5.1-2 presents an illustration of the basic concept.

When the temperature in the fuel tank increases, the vapor would expand in the fuel tank. The fuel vapor would enter chamber A and force more of the liquid into chamber B. This would provide room for the vapor to expand without allowing vapor to escape through the vent. As the fuel tank cools, the vapor would condense. This would cause the level of the liquid in chamber A to rise while the level of the liquid in chamber B would drop. Some pressurization may occur in the fuel tank with this system, but it would be much less than for a sealed fuel tank due to the expansion chamber. Any pressure or vacuum in the fuel system would be a function of the VCS design and would be expected to be less than 0.5 psi. In addition, a pressure relief valve could be added to the system to protect against any high pressure excursions.

In the initial testing of the VCS, the manufacturer has used water as the liquid barrier. However, they stated that ethylene-glycol or even oil could be used which would be more stable liquids and would resist freezing. Diurnal testing was performed on a 25 gallon fuel tank equipped with a roughly 3 gallon VCS unit.[40] Testing was performed in a mini-SHED over the EPA 72-96˚C diurnal cycle for two days. The tank was filled to 50 percent capacity with 9 RVP certification gasoline. The total weight loss was 1.1 grams on the first day and 2.6 grams on the second day. Using the higher of the two days, we get a diurnal emission rate of about 0.1 g/gal/day. The peak pressure during this testing was approximately 0.5 psi.

5.2 Running Loss Emissions

Running loss emissions are similar to diurnal emissions except that the fuel temperature rise is due to heat from the engine or other heat producing components, such as hydraulic systems, when the engine is running. This section summarizes the data and rationale supporting the running loss emission standard for Small SI equipment presented in the Executive Summary.

5.2.1 Baseline Emissions

To investigate running loss emissions, we instrumented seven riding lawnmowers, three walk-behind lawnmowers, two generators, and one pressure washer to measure the fuel temperature during typical operation. Many of the temperature measurements were made by a contractor.[41] Of the riding mowers, two had fuel tanks in front near the engine, three had fuel tanks in rear away from engine (but near the hydraulic system), and two were “zero-turn” mowers that had pairs of side saddle tanks that were relatively close to the rear mounted engine.

All of the riding mowers had plastic fuel tanks. One of the walk-behind mowers had a metal tank directly mounted to the block while the others had plastic tanks near the top/side of the engine. Both generators had plastic tanks mounted above the engine while the pressure washer had a metal tank mounted above the engine. All of the equipment vented through the fuel caps. The pressure washer had a metal fuel tank mounted above the engine. The equipment was operated in the field until the fuel temperature stabilized. For lawnmowers, the fuel temperature stabilized within 20 to 30 minutes while the larger equipment took up to an hour.

By measuring the increase in fuel temperature during operation, we were able to make a simple determination of the running loss emissions vented from the fuel tank. Other potential running loss emissions would be from the carburetor, due to permeation increases due to heating the fuel, or vibration-induced leaks in the fuel system. However, we believed that the majority of the running loss emissions would be due to breathing losses associated with heating the fuel. Table 5.2-1 presents the results of the temperature testing.

We contracted with an independent testing laboratory to test fuel tanks from most of the above pieces of equipment over the measured fuel temperature profiles.[42] For three of the tests on larger fuel tanks, we found that the measured emissions were inconsistent with theoretical predictions. An investigation of the test data suggested that the test had been ended too soon to see the full effect of the heat build. Repeat tests were performed with a longer sample time.[43] From this data we get the running loss emissions due to the breathing losses associated with the heating of the fuel tank. New tanks were purchased for this testing that had not been previously exposed to fuel so permeation emissions would not be included in the emission measurements. Table 5.2-1 also presents the test results for the above equipment.

Table 5.2-1: Fuel Temperature Measurements During Operation of Small SI Equipment and Hydrocarbons Measured Over This Temperature Profile

Equipment Type	Fuel Capacity [gallons]	Min. Temp °C	Max. Temp °C	HC [g/hr]
Riding mower front tank near engine	1.7 1.1	19.5 15.7	30.3 28.4	1.4 1.0
Riding mower rear tank away from engine	6.5 3.0 2.5	24.3 26.6 27.0	33.2 28.4 35.0	7.8 0.7 3.2
Zero-turn riding mower 2 saddle tanks near engine	6.5 x 2 1.4 x 2	20.5 21.9	23.9 29.7	3.4 2.5
Walk-behind mower (plastic)	0.34 0.25	23.3 28.7	33.0 46.7	0.3 1.2
Walk-behind mower (metal)	0.22	28.7	59.7	8.1
Generator set	8.5 7.0	20.6 25.8	25.8 50.0	1.8 69.3
Pressure washer	1.8	19.0	50.6	20.3

The California Air Resources Board performed running loss tests on several pieces of Small SI equipment.[44] This equipment included four lawnmowers (2 new and 2 old), one string trimmer, two generators, two ATVs, and two forklifts. To measure running loss emissions, the equipment were operated on California certification fuel in a SHED and the exhaust was routed outside the SHED. Running loss emissions were determined by measuring the HC concentration in the SHED. Therefore the measurements included all evaporative emissions during operation including those from fuel heating, permeation, carburetor losses, and, for the two older lawnmowers, liquid fuel leaks. Although the ATVs and forklifts are not considered to be small offroad engines, these data can be used as surrogates for equipment that were not tested. Table 5.2-2 presents this data.

Table 5.2-2: Results from ARB Running Loss Tests

Equipment Type	Model Year*	Running Loss [g/hr]
lawnmower	2000	0.8
	2001	2.6
	1994	27.0
	1989	12.1
string trimmer	1999	0.6
generator	1995	19.5
	2001	1.8
ATV	2001	21.4
	2001	1.3
forklift	1995	1.8
	1987	7.4

* the 2000 and 2001 equipment were new at the time of testing

5.2.2 Control Technology

Running loss emissions can be controlled by sealing the fuel cap and routing vapors from the fuel tank to the engine intake. In doing so, vapor generated heat from the engine will be burned by the engine. It may be necessary to use a valve or limited flow orifice in the purge line to prevent fuel from entering the line in the case of the equipment turning over and to limit the vapor to the engine during operation. 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 venting emissions. However, higher temperatures during operation would increase permeation somewhat. In addition, the additional length of vapor line would increase permeation. Considering these effects, we still believe that the system described here would result in more than a 90 percent reduction in running loss emissions from Small SI equipment.

A secondary benefit of running loss control for Small SI equipment has to do with diffusion emissions. As discussed above, venting a fuel tank through a hose (rather than through an open orifice) greatly reduces diffusion. In the system discussed above, all venting losses would occur through the vapor hose to the engine intake rather than through open vents in the fuel cap. Therefore, the diffusion effect should be largely eliminated.

Another approach to reducing running loss emissions would be to insulate the fuel tank or move it further from heat sources such as the engine or hydraulic system. With this approach, the fuel cap vent would likely still be used, but diffusion could be controlled using a tortuous vent path in the cap as described above.

For marine fuel tanks we are not considering running loss emissions. For portable fuel tanks and installed fuel tanks on larger vessels, we would not expect there to be significant heating of the fuel tanks during engine operation due to the distance from the engine and the cooling effect of operating the vessel in water. For personal watercraft, the fuel tanks have a sealed system with pressure relief that should help contain running loss emissions. For other installed fuel tanks, we would expect the diurnal emission control system to capture about half of any running losses as well.

5.3 Fuel Tank Permeation

The polymeric material (plastic) of which many gasoline fuel tanks manufactured generally has a chemical composition much like that of gasoline. As a result, constant exposure of gasoline to these surfaces allows the material to continually absorb fuel. Permeation is driven by the difference in the chemical potentials of gasoline or gasoline vapor on either side of the material. The outer surfaces of these materials are exposed to ambient air, so the gasoline molecules permeate through these fuel-system components and are emitted directly into the air. Permeation emissions continue at a nearly constant rate, regardless of how much the vehicle or equipment is used. Because of these effects, permeation-related emissions can therefore add up to a large fraction of the total emissions from nonroad equipment.

This section summarizes the data and rationale supporting the permeation emission standard for Small SI and Marine SI fuel tanks presented in the Executive Summary.

5.3.1 Baseline Fuel Tank Technology and Emissions

Fuel tanks may be constructed in several ways. Portable marine fuel tanks and some small, higher production-volume, installed marine fuel tanks are generally blow-molded using high-density polyethylene (HDPE). Larger, installed marine fuel tanks are generally either rotationally-molded using cross-link polyethylene (XLPE) or are constructed out of welded aluminum. Some boat builders even construct the fuel tanks out of fiberglass as part of the vessel construction. Fuel tanks on Small SI equipment may be injection molded, blow molded or rotationally molded. Blow-molded and injection-molded tanks are primarily made of HDPE, but nylon is used as well in some applications. Rotationally molded fuel tanks are generally made out of XLPE.

Blow molding is widely used for the manufacture of Small SI, portable marine, and PWC fuel tanks. Typically, blow molding is performed by creating a hollow tube, known as a parison, by pushing high-density polyethylene (HDPE) through an extruder with a screw. The parison is then pinched in a mold and inflated with an inert gas. In automotive applications, non-permeable plastic fuel tanks are produced by blow molding a layer of ethylene vinyl alcohol (EVOH) or nylon between two layers of polyethylene. This process is called coextrusion and requires at least five layers: the barrier layer, adhesive layers on either side of the barrier layer, and HDPE as the outside layers which make up most of the thickness of the fuel tank walls. However, multi-layer construction requires additional extruder screws which significantly increases the cost of the blow molding machine.

Injection molding can be used with lower production volumes than blow molding due to lower tooling costs. In this method, a low viscosity polymer is forced into a thin mold to create each side of the fuel tank. The two sides are then welded together. In typical fuel tank construction, the sides are welded together by using a hot plate for localized melting and then pressing the sides together. The sides may also be connected using vibration or sonic welding.

Rotational molding has two advantages over blow molding, which is widely used for forming automotive parts. First, the tooling cost is an order of magnitude lower than for blow-molding. Therefore, for small production volumes such as seen for marine applications, rotational molding is more cost-effective. Manufacturers of rotationally molded plastic fuel tanks have commented that they could not produce their tanks with competitive pricing in any other way. The second advantage of rotational molding is that larger parts can generally be molded on rotational molding machines than on blow-molding machines. Plastic marine fuel tanks can exceed 120 gallons.

Installed plastic marine fuel tanks are often produced in many shapes and sizes to fit the needs of specific boat designs. These fuel tanks tanks are generally rotationally-molded out of cross-link polyethylene. Cross-link polyethylene, which has a permeation rate comparable to HDPE, is used in larger marine applications because of its ability to pass the U.S. Coast Guard flame resistance requirements (33 CFR 183.590). Rotational-molding is also used in some Small SI applications where there are low production volumes of unique fuel tanks. XLPE is used in these fuel tanks as well because the fuel tank is often exposed and must be able to withstand impacts such as flying debris.

5.3.1.1 Baseline permeation test data

5.3.1.1.1 Marine fuel tanks

To determine the baseline permeation emissions from marine fuel tanks, we have collected permeation data on several plastic fuel tanks. Because gasoline does not permeate through aluminum, we did not perform permeation testing on aluminum fuel tanks.

We tested ten plastic fuel tanks that were either intended for marine use or are of similar construction. This permeation testing was performed at 29°C with gasoline. Prior to testing, the fuel tanks were stored with gasoline in them for about 20 weeks to ensure stable permeation rates. Table 5.3-1 presents the measured permeation rates for these fuel tanks in grams per gallon of fuel tank capacity. Where the internal surface area was either easily determined or supplied by the manufacturer, we also calculated the permeation rate in terms of grams per square meter of inside surface area. The 31 gallon tank showed much lower permeation than the other fuel tanks. This was likely due to the thickness of the walls in this tank. Even after stabilization, permeation is a function of material thickness. According to Fick's Law, if the wall thickness of a fuel tank were double, the permeation rate would be halved.[45]

Table 5.3-1: Permeation Rates for Plastic Marine Fuel Tanks Tested by EPA at 29°C

Tank Capacity [gallons]	Permeation [g/gal/day]	Permeation [g/m^2/day]	Construction	Application
3.3	0.96	12.7	HDPE	portable marine
6.0	0.61	6.8	HDPE	portable marine
6.0	1.18	13.1	HDPE	portable marine
6.0	0.75	8.4	HDPE	portable marine
6.6	0.83	9.1	HDPE	portable marine
6.6	0.77	8.4	HDPE	portable marine
6.0	0.60	8.3	cross-link	marine test tank
23	0.64	8.1	cross-link	installed marine
31	0.44	5.5	cross-link	installed marine

The Coast Guard tested three rotationally-molded, cross-link polyethylene marine fuel tanks at 40°C (104°F) for 30 days.[46] The results are presented in Table 5.3-2. Because permeation emissions are a function of surface area and wall thickness, there was some variation in the permeation rates from the three tanks on a g/gal/day basis. These results are not directly comparable to the EPA testing because of the difference in test temperature. However, we can adjust the permeation rates for temperature using Arrhenius' relationship[47] combined with empirical data collected on permeation rates for materials used in fuel tank constructions (described below). These adjusted permeation rates are shown in Table 5.3-2 and are consistent with the EPA test data.

Table 5.3-2: Permeation Rates for Cross-Link Marine Fuel Tanks at 40°C

Tank Capacity [gallons]	Measured Permeation Loss [g/gal/day]	Average Wall Thickness [mm]	Adjusted to 29°C [g/gal/day]
12	1.48	5.3	0.71
18	1.39	5.6	0.67
18	1.12	6.9	0.54

5.3.1.1.2 Small SI equipment fuel tanks

The California Air Resources Board (ARB) investigated permeation rates lawn & garden equipment fuel tanks. The ARB data is compiled in several data reports on their web site and are included in our docket.[48,49,50,51,52] Table 5.3-3 presents a summary of this data which was collected using the ARB Test Method 513.[53] Where multiple tests were run on a given tank or tank type, the average results are presented. Although the temperature in the ARB testing is cycled from 18 - 41°C rather than held at a constant temperature, the average temperature is 29˚C which is similar to the EPA testing. Therefore, the permeation results would likely be similar if the data were collected at the average temperature of 29°C used in the EPA testing.

Variation in permeation rates on a gram per square meter basis is likely due to differences in the wall thicknesses. Note that surface area measurements were not available for all of the fuel tanks. Smaller fuel tanks would be expected to have higher emissions on a gram per gallon basis due to the increased surface area to volume ratio. However, lower permeation rates were observed for the fuel tanks less than 1 quart, potentially due to relatively thicker walls or due to a difference in material used for these applications.

Table 5.3-3: Permeation Rates for Plastic Lawn and Garden Fuel Tanks Tested by ARB Over a 18-41°C Diurnal

Tank Capacity [gallons]	Permeation Loss [g/gal/day]	Permeation Loss [g/m^2/day]
0.06	0.20	5.39
0.08	0.26	6.67
0.09	0.12	--
0.09	0.19	5.88
0.10	0.28	--
0.12	0.53	9.01
0.15	0.42	7.32
0.16	0.29	4.79
0.25	1.32	11.56
0.25	0.73	10.65
0.25	0.67	9.75
0.25	0.74	10.75
0.25	0.86	12.54
0.25	0.68	9.91
0.25	1.06	9.24
0.25	1.24	10.84
0.25	0.99	8.68
0.25	0.67	9.80
0.25	0.66	9.65
0.25	0.62	9.07
0.25	1.39	12.17
0.25	1.26	11.03
0.29	1.27	15.00
0.38	0.27	--
0.38	1.30	10.66
0.38	0.92	9.18
0.38	0.08	--
0.50	1.39	12.69
0.50	1.04	8.53
0.55	1.24	--
0.74	1.82	--
1.4	1.72	7.81
1.7	1.14	--
1.8	1.47	6.19
3.9	3.28	4.84
5.0	3.20	--
5.0	2.75	--
5.0	3.82	8.80
7.5	2.07	2.86

Some handheld equipment, primarily chainsaws, use structurally-integrated fuel tanks where the tank is molded as part of the body of the equipment. In these applications the frames (and tanks) are typically molded out of nylon for strength. We tested structurally-integrated fuel tanks from four handheld equipment manufacturers at 29˚C on both gasoline and s 10 percent ethanol blend. The test results suggest that these fuel tanks are capable of meeting the proposed standards using their current materials. In the cases where the permeation rates were higher than the proposed standards, it was observed that the fuel cap seals had large exposed surface areas on the O-rings, which were not made of low permeation materials. Emissions could likely be reduced significantly from these tanks with improved seal designs. Table 5.3-4 presents the results of this testing. Note that permeation emissions are 20 to 70 percent higher on E10 than on gasoline for these fuel tanks.

Table 5.3-4: Permeation Rates for Nylon Handheld Fuel Tanks Tested by EPA at 29°C

Tank ID	Application	Material	Test Fuel	Permeation Loss [g/m^2/day]
R1	clearing saw	nylon 6	gasoline	0.34
R2	(0.24 gallons)		E10	0.42
R3			E10	0.48
B1	hedge clipper	nylon 6, 33% glass	gasoline	0.62
B2	(0.05 gallons)		E10	1.01
B3			E10	1.12
B4			E10	0.93
W1	chainsaw	nylon 6, 30% glass	gasoline	1.45
W2	(0.06 gallons)		E10	2.18
W3			E10	2.46
G1	chainsaw	nylon 6, 30% glass	gasoline	1.30
G2	(0.06 gallons)		E10	1.41
G3			E10	2.14

5.3.1.1.3 Portable fuel tanks

The California Air Resources Board (ARB) investigated permeation rates from portable fuel containers. Although this testing was not on Small SI or marine fuel tanks, the fuel tanks tested are of similar construction.[54,55] The ARB data is compiled in several data reports on their web site and is included in our docket. Table 5.3-5 presents a summary of this data which was collected using the ARB Test Method 513.[56] Due to the increasing surface to volume ratio with decreasing fuel tank sizes, data presented in terms of grams per gallon for smaller tanks would be expected to be higher for the same grams per surface area permeation rate. Although the temperature in the ARB testing is cycled from 18 - 41°C rather than held at a constant temperature, the results would likely be similar if the data were collected at the average temperature of 29°C which is used in the EPA testing.

Table 5.3-5: Permeation Rates for HDPE Portable Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Tank Capacity [gallons]	Permeation Loss [g/gal/day]
1.0	1.63
1.0	1.63
1.0	1.51
1.0	0.80
1.0	0.75
1.0	0.75
1.3	0.50
1.3	0.49
1.3	0.51
1.3	0.52
1.3	0.51
1.3	0.51
1.3	1.51
1.3	1.52
2.1	1.88
2.1	1.95
2.1	1.91
2.1	1.78
2.5	1.46
2.5	1.09
5.0	0.89
5.0	0.62
5.0	0.99
5.0	1.39
5.0	1.46
5.0	1.41
5.0	1.47
6.6	1.09

5.3.1.2 Effect of temperature on permeation rate

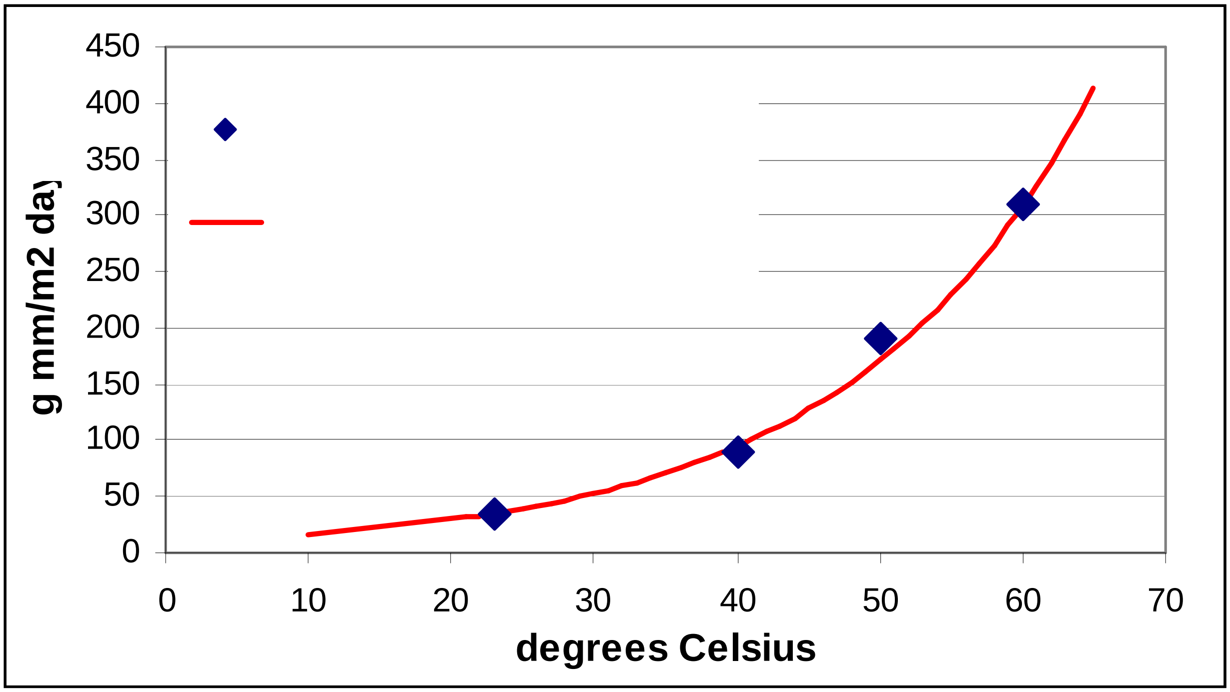
It is well known that the rate of permeation is a function of temperature. For most materials, permeability increases by about a factor of 2 for every 10°C increase in temperature.[57] To determine this relationship for nonroad fuel tanks, we performed permeation testing on nine HDPE Small SI fuel tanks at both 29°C and 36°C (85°F and 96°F).. This sample set included both baseline and surface treated fuel tanks. On average (excluding the outlier), the temperature effect was equivalent to nearly a factor of 2 increase in permeation per 10°C increase in temperature. The one outlier likely resulted from measurement error due to the very low permeation levels (0.5 grams lost over 2 weeks). Table 5.3-6 presents the test results.

Table 5.3-6: Effect of Temperature on Permeation from HDPE Small SI Fuel Tanks

Tank	Treatment	29°C [g/m²/day]	36°C [g/m²/day]	Increase per 10°C
A	untreated	11.5	17.1	92%
B		11.4	16.6	86%
C		11.2	17.0	97%
D	sulfonated	2.48	4.10	127%
E		2.73	3.98	85%
F		2.24	3.42	100%
H	fluorinated	0.56	0.75	60%
I		0.62	0.68	17%
J		0.22	0.31	80%

Published data collected on HDPE samples at four temperatures[58,59] suggest that the permeation of gasoline through HDPE increases by about 80 percent for every 10°C increase in temperature. This relationship is presented in Figure 5.3-1, and the numeric data can be found in Appendix 5D.

Figure 5.3-1: Effect of Temperature on HDPE Permeation



Another study was performed on the permeation from complete automotive fuel systems.[60] These fuel systems, which included fuel tanks, hoses, and other components, were tested at both 29°C and 40°C on three fuel types (gasoline, ethanol blend, and MTBE blend).

The effect of temperature on permeation did not appear to be significantly affected by fuel type. Table 5.3-7 presents this data for ten automotive fuel systems tested on gasoline. This data showed more than a factor of 2 increase in permeation per 10°C increase in temperature.

Table 5.3-7: Effect of Temperature on Permeation from Automotive Fuel Systems

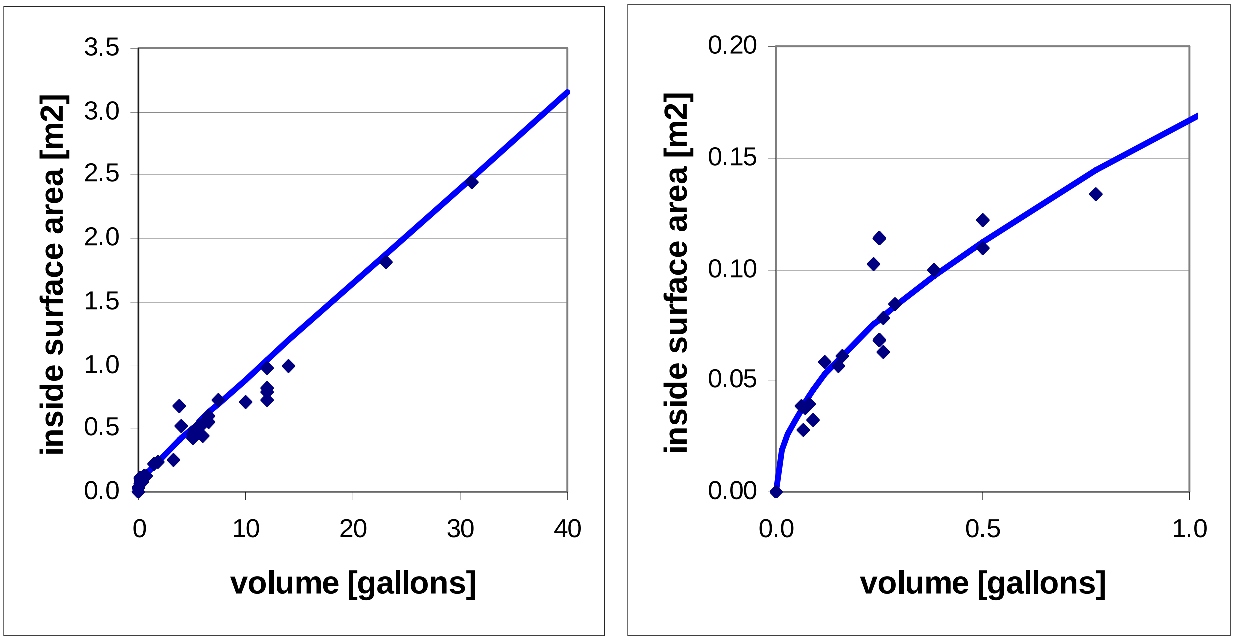
Fuel System	Fuel Tank	29°C [mg/hr]	40°C [mg/hr]	Increase per 10°C
2001 Toyota Tacoma	Metal	9	20	101%
2000 Honda Odyssey	Plastic (enhanced evap)	21	55	136%
1999 Toyota Corolla	Metal	10	24	124%
1997 Chrysler Town & Country	Plastic (enhanced evap)	23	52	110%
1995 Ford Ranger	HDPE	309	677	102%
1993 Chevrolet Caprice Classic	Fluorinated HDPE	95	255	143%
1991 Honda Accord LX	Metal	40	110	148%
1989 Ford Taurus GL	Metal	24	52	100%
1985 Nissan Sentra	Metal	53	148	152%
1978 Olds Cutlass Supreme	Metal	57	122	99%

5.3.1.3 Units for reporting the permeation rate (g/gal/day vs. g/m^2/day)

Much of the permeation data presented in this chapter is in units of grams of hydrocarbons lost in a day divided by the capacity of the fuel tank (g/gal/day). For diurnal emissions, these units are used because the vapor generation is a function of fuel tank volume. For permeation emissions, we considered using these units because the capacity of the fuel tank is generally readily available; either identified on the fuel tank or readily measured. However, although volume is generally used to characterize fuel tank emission rates, permeation is actually a function of surface area. Because the surface to volume ratio of a fuel tank changes with capacity and geometry of the tank, two similar shaped tanks of different volumes or two different shaped tanks of the same volume could have different g/gal/day permeation rates even if they were made of the same material and used the same emission control technology. For this reason, the final standards are based on units of grams per square meter of inside surface area (g/m^2/day).

This chapter presents permeation data for a large number of Small SI, marine, and other fuel tanks. For many of these fuel tanks, we had information on both the volume and inside surface area. Figure 5.3-2 presents the relationship between fuel tank volume in gallons and inside surface area in square meters. As a fuel tank becomes smaller, its surface to volume ratio increases. This relationship can be seen better in the chart to the right which presents only data for fuel tanks less than 1 gallon. A hyperbolic curve is fit through the data in Figure 5.3-2 to represent this relationship. This is seen better in the right-side chart which presents only smaller tank sizes. In addition to fuel tank volume, the surface to volume ratio is affected by geometry of the fuel tank. A long flat-fuel tank would have a higher surface to volume than a cube or spherical design. Larger plastic fuel tanks, used primarily in marine vessels, tend to have somewhat high surface to volume ratios for this reason.

Figure 5.3-2: Relationship Between Tank Volume and Inside Surface Area



5.3.1.4 Effect of fuel tank fill level on permeation

Permeation is driven by the chemical potential of the fuel or vapor in contact with the plastic. In a fuel tank, the vapor is essentially at equilibrium with the fuel in a fuel tank. Therefore, the permeation rate is the same through the surfaces in contact with saturated vapor as it is through the surfaces in contact with the liquid fuel. Because the permeation rate of saturated vapor and liquid fuel are the same, the fill level of the fuel tank during a permeation test does not affect the measured results.

The fact that liquid fuel and saturated fuel vapor result in the same permeation rates is supported by published literature.[61,62,63,64] In two of these studies, permeation was measured for material samples using the cup method illustrated in Figure 5.3-3. In these tests, no significant difference was seen between the permeation rates for material samples exposed to liquid fuel or to fuel vapor. To test for permeation with fuel vapor, the cup was inverted so that the fuel was on the bottom and the sample was taken off the top. Table 5.3-8 presents the data from these two reports. In both cases, the material being tested was a fluoroelastomer.

Figure 5.3-3: Cup Method

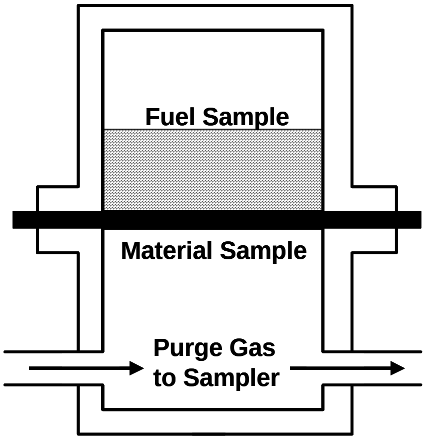


Table 5.3-8: Permeation Measured in Cup Method with Fuel Versus Vapor Fuel Exposure

Paper	Fuel	Temperature	Liquid Fuel Exposure	Fuel Vapor Exposure
SAE 2001-01-1999	CE10	40˚C	30.5 g/m^2/day	29.5 g/m^2/day
SAE 2000-01-1096	CE10	23˚C	0.3 g/test	0.3 g/test
		40˚C	2.6 g/test	2.5 g/test
	CM15	23˚C	3.1 g/test	2.9 g/test
		40˚C	9.5 g/test	8.5 g/test

One commenter presented test data suggesting that fill level may affect permeation emissions.[65] They tested four HDPE jugs, two filled to 40 percent and two filled to 100 percent with gasoline and saw a 15 percent difference in the average permeation results for the two fill levels (1.3 g/gal/day for 40 percent fill and 1.5 g/gal/day for 100 percent fill). Although this small measured difference was likely due to test variability, we performed our own testing to study the effect of fill level. For this testing, we used two 6-gallon HDPE portable marine fuel tanks. The fuel tanks were soaked with gasoline for 12 weeks to ensure a stabilized permeation rate. Each tank was tested at both 50 percent and 90 percent fill. No significant difference in permeation rate was observed for either tank. Table 5.3-9 presents the results in terms of g/gal/day at 29°C.

Table 5.3-9: Effect of Fuel Tank Fill Level on Permeation for Two Portable Marine Fuel Tanks [g/gal/day]

	50% fill	90% fill
Tank 1	1.16	1.21
Tank 2	0.77	0.78

Another study showed mixed results. Four automotive fuel systems (including fuel tank, hose, and other components) were tested for permeation with the fuel tanks filled with Fuel C to both 20 percent and 100 percent of capacity.[66] Prior to the testing, the fuel tanks were soaked with fuel at the specified fill levels until a stable permeation rate was achieved. It was not clear what fraction of the permeation came from the fuel tanks compared to other fuel system components or how the fuel level affected the exposure of the other components. In this study, two of the fuel systems saw no significant change in permeation as a result of a change in fill level. These two fuel system were on older vehicles, one with an untreated and one with a fluorinated HDPE fuel tank. Two other fuel systems, using fuel tanks that meet automotive enhanced evaporative emission requirements, showed significant reductions in fuel system permeation (32 percent and 49 percent) when tested with the fuel tank filled to only 20 percent capacity. The study presented no rationale for this effect; however, it should be noted that these were very low permeation systems and measurement error would presumably be larger. These data are presented in Table 5.3-10. In addition, it is possible that the change in fill level affected whether or not there was fuel in the hoses. As discussed later in this chapter, the vapor concentration in fuel hoses may be significantly lower than saturated when exposed only to vapor due to diffusion constraints.

Table 5.3-10: Effect of Fuel Tank Fill Level on Permeation for Four Automotive Fuel Systems at 29˚C [g/hour]

	Description of Fuel Tank	20% fill	80% fill
Rig 2	enhanced evap system	0.013	0.019
Rig 4	enhanced evap system	0.021	0.041
Rig 5	HDPE fuel tank	0.350	0.349
Rig 6	fluorinated HDPE fuel tank	0.095	0.094

The California Air Resources Board also performed testing on three pairs of portable fuel tanks.[67] All of the fuel tanks were identical 1 gallon tanks made out of HDPE. Each pair was filled to a different level with California certification fuel (30 percent, 50 percent and 70 percent fill). The fuel tanks were then sealed and subjected to five days of the California diurnal test (65-105˚F) and weight loss was measured daily. Over the five days of testing, the tanks with lower fill levels actually saw significantly higher permeation than the other tanks. Looking at the last day of testing, which represents some conditioning of the fuel tanks by the fuel resulting in more stabilized permeation rates, the permeation rates are similar regardless of the fill level. This data, which is presented in Table 5.3-11, suggests that the fuel vapor in the tanks permeated at the same rate as (or higher than) the liquid fuel.

Table 5.3-11: Effect of Fuel Tank Fill Level on Permeation for Three Pairs of Portable Fuel Tanks [g/day]

Tank	Fill Level	5-Day Permeation	Last Day Permeation
30a	30%	1.79	1.87
30b		1.57	1.91
50a	50%	1.53	1.91
50b		1.03	1.43
70a	70%	1.26	1.85
70b		1.08	1.43

5.3.1.5 Effect of background concentration on permeation

As discussed above, permeation is driven by the difference in chemical potential between the inside and outside of the tank. If the concentration of vapor outside the fuel tank were large enough, it could reduce the permeation rate of fuel through the tank. One commenter presented test data suggesting that, at very low concentrations of vapor in the boat around the fuel tank, that the permeation rate would be significantly reduced.[68] This test data was based on two three hour tests on 5 gallon HDPE bottles at 35°C. They measured 0.57 g/hr with a background concentration of 26 ppm and 0.36 g/hr with a background of 212 ppm. No repeat tests were run. It is not clear why the above results were measured. Compared to the concentration of the fuel vapor in the tank, this difference between 212 and 26 ppm is minuscule (about three orders of magnitude difference from saturated vapor). It is more likely that this effect was due to test variation.

To investigate this potential effect on permeation emissions further, we performed our own testing. First, we measured the concentration of fuel vapor around the fuel tank on a summer day in a runabout with the tank installed in the hull. This concentration was 1400 ppm. We then tested two different fuel tanks for permeation with different background concentrations. The background concentration was maintained by controlling the bleed of fresh air through the test container or SHED. Each test ran for about two weeks and the permeation rates were determined using the weight loss method. Prior to the testing, the tanks were soaked until a stable permeation rate was achieved, then new fuel was added to the tank just prior to beginning the test. The fuel tank was soaked until the fuel temperature stabilized at 29°C before the beginning weight was measured. The results, which are presented in Table 5.3-12, showed no significant difference in permeation as a function of background concentrations of hydrocarbon vapor.

Table 5.3-12: Effect of Background Concentration on Permeation

Fuel Tank	Background [ppmC]	Permeation [g/gal/day]
6 gallon HDPE	30	0.77
	1500	0.78
23 gallon cross-link PE	30	0.64
	150	0.67
	1350	0.66

5.3.2 Fuel Tank Permeation Reduction Technologies

There are several strategies that can be used to reduce permeation from plastic fuel tanks. This section presents data collected on five permeation control strategies: sulfonation, fluorination, non-continuous barrier platelets, coextruded continuous barrier, and alternative materials.

5.3.2.1 Sulfonation

Sulfonation is a process where the surface of the fuel tank is treated to minimize permeation. The sulfonation process uses sulfur trioxide is used to create the barrier by reacting with the exposed polyethylene to form sulfonic acid groups on the surface. Current practices for sulfonation are to place fuel tanks on a small assembly line and expose the inner surfaces to sulfur trioxide, then rinse with a neutralizing agent. However, sulfonation can also be performed off-line. Either of these processes can be used to reduce gasoline permeation by more than 90 percent from new tanks.[69]

We tested several sulfonated marine fuel tanks at 29°C for permeation. This testing included both HDPE blow-molded fuel tanks and cross-link polyethylene rotationally-molded tanks. Both gasoline and alcohol fuel blends were investigated. In some cases, the fuel tanks were exposed to durability testing as described in Section 5.6.2. The fuel tanks were stored with fuel in them (soaked) for preconditioning, then they were drained and then filled with fresh fuel prior to each permeation test. The purpose of the soak periods was to ensure that the fuel permeation rate had stabilized and the purpose of the pressure cycles and slosh testing was to evaluate the durability of the barrier treatment.

We also collected data from ARB and other sources on the effectiveness of sulfonation for reducing permeation emissions from plastic fuel tanks. Most of this research has been performed on blow-molded HDPE fuel tanks. As shown in these data, it is important that the resin formulation be matched to the sulfonation process. The following discussions look at sufonation results on HDPE and on cross-link polyethylene separately.

HDPE fuel tanks

We tested several HDPE fuel tanks that were sulfonated on the internal surfaces. These included three 6-gallon and one 3.3 gallon portable marine fuel tanks and three all-terrain vehicle (ATV) fuel tanks. These fuel tanks were sent to a sulfonater for barrier treatment. Multiple fuel tanks were used so that they could be tested on certification gasoline , E10 (10 percent ethanol), and M15 (15 percent methanol). The test results, presented in Table 5.3-13, showed more than a 90 percent reduction in permeation emissions from baseline. However, the two fuel tanks that were subjected to slosh testing saw emission levels above the proposed standard. This may have been a material compatibility issue as discussed below. The test results are consistent with similar data collected by the California Air Resources Board.

Table 5.3-13: EPA Permeation Data on Sulfonated HDPE Fuel Tanks at 29°C

Treatment	Fuel	Soak Period	g/gal/day	g/m^2/day
6 gallon portable marine fuel tanks				
baseline	gasoline	15 weeks	0.77	8.53
sulfonated	gasoline	16 weeks	0.04	0.45
sulfonated	gasoline, sloshed	12 weeks	0.39	4.30
sulfonated	E10	24 weeks	0.14	1.58
sulfonated	M15	24 weeks	0.08	0.84
4 gallon ATV fuel tanks				
sulfonated	gasoline	20 weeks	0.13	1.05
sulfonated	E10	24 weeks	0.06	0.45
sulfonated	M15	24 weeks	0.08	0.64
3.3 gallon portable fuel tank				
baseline	E10	14 weeks	0.96	12.7
sulfonated	E10	14 weeks	0.06	0.83
sulfonated	E10, sloshed	38 weeks	0.16	2.09

We performed slosh testing on the 6 and 3.3 gallon portable marine fuel tanks with E10 fuel. This slosh testing included 1 million cycles consistent with the proposed durability test procedure. After the slosh testing, the permeation rates were measured to be 2.0 and 4.3 g/m^2/day for the 3.3 and 6 gallon fuel tanks, respectively. As discussed below, we believe that the impact of the durability testing on the effectiveness of sulfonation can be minimized if the sulfonation process and material properties are matched properly. However, this data supports the need for the proposed durability testing requirements.

The California Air Resources Board (ARB) collected test data on permeation rates from sulfonated portable fuel containers using California certification fuel.[70] The results show that sulfonation can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 29°C. The average emission rate for the 32 sulfonated fuel tanks is 0.35 g/gal/day; however, there was a wide range in variation in the effectiveness of the sulfonation process for these fuel tanks. Some of the data outliers were actually higher than baseline emissions. This was likely due to leaks in the fuel tank which would result in large emission increases due to pressure built up with temperature variation over the diurnal cycle. Removing these five outliers, the average permeation rate is 0.17 g/gal/day with a minimum of 0.01 g/gal/day and a maximum of 0.64 g/gal/day. This data suggests that more than a 90 percent reduction in permeation from HDPE fuel tanks is possible through sulfonation. This data is presented in Table 5.3-14.

Table 5.3-14: Permeation Rates for Sulfonated Plastic Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Tank Capacity [gallons]	Permeation Loss [g/gal/day]
1	0.05
1	0.05
1	0.05
1	0.06
1	0.06
1	0.06
1	0.08
1	0.12
1	0.14
1	1.23
1	1.47
1	1.87
2	0.02
2	0.02
2	0.48
2	0.54
2	1.21
2.5	0.03
2.5	0.08
2.5	0.32
2.5	0.38
2.5	0.42
2.5	0.52
2.5	0.64
2.5	0.80
5	0.01
5	0.04
5	0.05
5	0.06
5	0.11
5	0.13
5	0.15

Variation can occur in the effectiveness of this surface treatment if the sulfonation process is not properly matched to the plastic and additives used in the fuel tank material. For instance, if the sulfonater does not know what UV inhibitors or plasticizers are used, they cannot maximize the effectiveness of their process. Earlier data collected by ARB showed consistently high emissions from sulfonated fuel tanks; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel tanks and that these issues have since been largely resolved.[71]

ARB also investigated the effect of fuel slosh on the durability of sulfonated surfaces. Three half-gallon fuel tanks used on Small SI equipment were sulfonated and tested for permeation before and after being sloshed with fuel in them 1.2 million times.[72,73] These fuel tanks were blow-molded HDPE tanks used in a number of Small SI applications including pressure washers, generators, snowblowers, and tillers. The results of this testing show that an 85 percent reduction in permeation was achieved on average even after the slosh testing was performed. Table 5.3-15 presents these results which were recorded in units of $g/m^2/day$. The baseline level for Set #1 is an approximation based on testing of similar fuel tanks, while the baseline level for Set #2 is based on testing of those tanks.

The sulfonater was not aware of the materials used in the fuel tanks sulfonated for the slosh testing. After the tests were performed, the sulfonater was able to get some information on the chemical make up of the fuel tanks and how it might affect the sulfonation process. For example, the UV inhibitor used in some of the fuel tanks is known as HALS. HALS also has the effect of reducing the effectiveness of the sulfonation process. Two other UV inhibitors, known as carbon black and adsorber UV, are also used in similar fuel tank applications. These UV inhibitors cost about the same as HALS, but have the benefit of not interfering with the sulfonation process. The sulfonater claimed that if HALS were not used in the fuel tanks, a 97 percent reduction in permeation would have been seen.[74] To confirm this, one manufacturer tested a sulfonated tank similar to those in Set #2 except that carbon black, rather than HALS, was used as the UV inhibitor. This fuel tank showed a permeation rate of 0.88 $g/m^2/day$ at 40°C[75] which was less than half of what the CARB testing showed on their constant temperature test at 40°C.[76] A list of resins and additives that are compatible with the sulfonation process is included in the docket.[77,78]

Table 5.3-15: Permeation Rates for Sulfonated Fuel Tanks with Slosh Testing by ARB Over a 18-41°C Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Set #1 Approximate Baseline	g/m²/day	10.4	10.4	10.4	10.4
Set #1 Sulfonated	g/m²/day % reduction	0.73 93%	0.82 92%	1.78 83%	1.11 89%
Set #1 Sulfonated & Sloshed	g/m²/day % reduction	1.04 90%	1.17 89%	2.49 76%	1.57 85%
Set #2 Average Baseline	g/m²/day	12.1	12.1	12.1	12.1
Set #2 Sulfonated	g/m²/day % reduction	1.57 87%	1.67 86%	1.29 89%	1.51 88%
Set #2 Sulfonated & Sloshed	g/m²/day % reduction	2.09 83%	2.16 82%	1.70 86%	1.98 84%

About a year and a half after the California ARB tests on the Set #2 fuel tanks, we performed permeation tests on these fuel tanks. During the intervening period, the fuel tanks remained sealed with California certification fuel in them. We drained the fuel tanks and filled them with fresh California certification fuel. We then measured the permeation rate at 29°C. Because this is roughly the average temperature of the California variable temperature test, similar permeation rates would be expected. The untreated fuel tanks showed slightly lower permeation over the constant temperature test. This difference was likely due to the difference in the temperature used for the testing. However, the sulfonated fuel tanks showed an increase in permeation. This increase in permeation appears to be the result of the 1.5 year additional fuel soak. After this long soak, the average permeation reduction changed from 84 to 78 percent. Table 5.3-13 presents this comparison.

Table 5.3-16: Permeation Rates [g/m²/day] for Sulfonated Fuel Tanks Tested by ARB and EPA on CA Certification Gasoline with a 1½ Year Fuel Soak Differential

Technology Configuration	Temperature	Tank 1	Tank 2	Tank 3	Average
Baseline, CARB testing	18-41°C	12.1	12.1	12.1	12.1
Baseline, EPA testing after 1.5 year additional fuel soak	29°C % change	11.5 -5%	11.4 -6%	11.2 -7%	11.4 -6%
Sulfonated, CARB testing	18-41°C	2.09	2.16	1.70	1.98
Sulfonated, EPA testing after 1.5 year additional fuel soak	29°C % reduction	2.48 78%	2.73 76%	2.24 80%	2.5 78%

After the above testing, we drained the fuel tanks and filled them with certification gasoline splash-blended with 10 percent ethanol (E10). We then soaked the fuel tanks for 20 weeks to precondition them on this fuel. Following the preconditioning, we tested these fuel tanks for permeation at 29˚C (85˚F). Table 5.3-17 presents these emission results compared to the emission results for three baseline tanks (untreated) that were subject to the same preconditioning. Percent reductions are presented based on the difference between the sulfonated fuel tanks and the average results of the three untreated fuel tanks.

Table 5.3-17: Permeation Rates for Sulfonated Fuel Tanks on E10 Fuel at 29˚C

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Baseline (untreated)	g/m²/day	13.9	13.7	14.4	14.0
Sulfonated	g/m²/day % reduction	3.91 72%	4.22 70%	2.92 79%	3.69 74%

An in-use durability testing program was also completed for sulfonated HDPE fuel tanks and bottles.[79] The fuel tank had a 25 gallon capacity and was removed from a station wagon that had been in use in southern California for five years (35,000 miles). The fuel tank was made of HDPE with carbon black used as an additive. After five years, the sulfonation level measured on the surface of the plastic fuel tank did not change. Tests before and after the aging both showed a 92 percent reduction in gasoline permeation due to the sulfonation barrier compared to the permeation rate of a new untreated tank. Testing was also done on 1 gallon bottles made of HDPE with 3 percent carbon black. These bottles were shown to retain over a 99 percent barrier after five years. This study also looked at other properties such as yield strength and mechanical fatigue and saw no significant deterioration.

One study looked at the effect of alcohol in the fuel on permeation rates from sulfonated fuel tanks.[80] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

XLPE fuel tanks

We tested eight sulfonated cross-link polyethylene (XLPE) fuel tanks for permeation emissions. These tanks were produced by marine fuel tank manufacturers specifically for this testing. The fuel tanks were then treated by a sulfonater. For the first four tanks tested, the fuel tanks were molded using the resin formulation and processes currently used by the fuel tank manufacturers. When the sulfonation was applied, we observed that the barrier was soft and could be scraped off easily. When tested, the barrier on these fuel tanks was not as effective as had been seen on HDPE fuel tanks.

Because the barrier could be scratched off, the sulfonater ascertained that the sulfonation had poor surface penetration and the darkness of the barrier suggested heavy oxidation. For the next batch of four test tanks, the sulfonater worked with the material supplier and roto-molder and attempted to develop a formulation that may be more compatible with sulfonation. They decided to use the same material, but bake it in the oven longer to remove more oxygen from the surface of the fuel tank. Four bake times were used to produce the four 6-gallon test tanks: 11, 12, 14, and 16 minutes. It was observed that the sulfonation barrier could not easily be scratched off these fuel tanks. We tested the four sulfonated on E10 (10 percent ethanol) using the same procedures as for the HDPE tanks discussed above. The test results did not show a significant improvement.

Another approach may be to mold an inner liner of HDPE inside a XLPE shell. These materials readily bond with each other and sulfonation has been demonstrated for HDPE. This construction, which is currently used in chemical storage applications, is performed in the oven through the use of a “drop box” in the mold containing the HDPE. This drop-box is opened part way through the oven cycle allowing for a HDPE layer to be molded on the inside of the fuel tank.

5.3.2.2 Fluorination

Another barrier treatment process is known as fluorination. The fluorination process causes a chemical reaction where exposed hydrogen atoms are replaced by larger fluorine atoms which form a barrier on the surface of the fuel tank. In this process, fuel tanks are generally processed post production by stacking them in a steel container. The container is then voided of air and flooded with fluorine gas. By pulling a vacuum in the container, the fluorine gas is forced into every crevice in the fuel tanks. As a result of this process, both the inside and outside surfaces of the fuel tank would be treated. As an alternative, fuel tanks can be fluorinated on-line by exposing the inside surface of the fuel tank to fluorine during the blow molding process.

However, this method may not prove as effective as off-line fluorination which treats the inside and outside surfaces.

We tested several fluorinated marine fuel tanks at 29°C for permeation. This testing included both HDPE blow-molded fuel tanks and cross-link polyethylene rotationally-molded tanks. Both gasoline and alcohol fuel blends were investigated. In some cases, the fuel tanks were exposed to durability testing as described in Section 5.6.2. The fuel tanks were stored with fuel in them (soaked) for preconditioning, then they were drained and then filled with fresh fuel prior to each permeation test. The purpose of the soak periods was to ensure that the fuel permeation rate had stabilized and the purpose of the pressure cycles and slosh testing was to evaluate the durability of the barrier treatment.

We also collected data from ARB and other sources on the effectiveness of fluorination for reducing permeation emissions from plastic fuel tanks. Most of this research has been performed on blow-molded HDPE fuel tanks. However, we believe that fluorination can also be applied effectively for injection-molded HDPE tanks as well. The following discussion looks at each material separately as well as rotationally-molded cross-link polyethylene.

Blow-molded HDPE fuel tanks

We tested one fluorinated HDPE fuel tank which we bought off the shelf and sent to a fluorinater for barrier treatment. The fuel tank type used was a 6-gallon portable marine fuel tank. The fuel tank was soaked for 20 weeks with certification gasoline prior to testing. We measured a permeation rate of 0.05 g/gal/day (0.56 g/m^2/day) which represents more than a 95 percent reduction from baseline. We then began soaking this fuel tank on E10, subjected it to the proposed pressure and slosh testing, and retested the fuel tank. The post durability testing result showed a permeation rate of 0.6 g/gal/day (6.8 g/m^2/day). As discussed below, we believe that the impact of the durability testing on the effectiveness of fluorination on can be minimized if the fluorination process and material properties are matched properly. In addition, this fuel tank was treated to a significantly lower level of fluorination than is now available. However, this data supports the need for the proposed durability testing requirements.

The California Air Resources Board (ARB) collected test data on permeation rates from fluorinated fuel containers using California certification fuel.[81,82] The results show that fluorination can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 30°C. For the highest level of fluorination, the average permeation rate was 0.04 g/gal/day which represents a 95 percent reduction from baseline. Earlier data collected by ARB showed consistently high emissions from fluorinated fuel tanks; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel tanks and that these issues have since been largely resolved.[83] The ARB data is presented in Table 5.3-18.

Table 5.3-18: Permeation Rates for Fluorinated Plastic Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Barrier Treatment*	Tank Capacity [gallons]	Permeation Loss [g/gal/day]
Level 4	1	0.05
	1	0.05
(average =0.09 g/gal/day)	1	0.06
	5	0.11
	5	0.11
	5	0.15
Level 5	1	0.03
	1	0.04
(average =0.07 g/gal/day)	1	0.05
	1	0.05
	1	0.07
	1	0.08
	1	0.11
	1	0.11
	1	0.12
	2.5	0.04
	2.5	0.04
	2.5	0.05
	2.5	0.07
	2.5	0.07
	5	0.05
	5	0.10
	5	0.11
SPAL	5	0.04
(average =0.04 g/gal/day)	5	0.04
	5	0.04

*designations used in ARB report; shown in order of increasing treatment

All of the data on fluorinated fuel tanks presented above were based on fuel tanks fluorinated by the same company. Available data from another company that fluorinates fuel tanks shows a 98 percent reduction in gasoline permeation through a HDPE fuel tank due to fluorination.[84]

ARB investigated the effect of fuel slosh on the durability of fluorinated surfaces. Two sets of three fluorinated fuel tanks were tested for permeation before and after being sloshed with fuel in them 1.2 million times.[85,86] These fuel tanks were 0.5 gallon, blow-molded HDPE tanks used in a number of Small SI applications including pressure washers, generators, snowblowers, and tillers. The results of this testing show that an 80 percent reduction in permeation was achieved on average even after the slosh testing was performed for Set #1. However, this data also showed a 99 percent reduction for Set #2. This shows the value of matching the barrier treatment process to the fuel tank material. Table 5.3-19 presents these results which were recorded in units of g/m^2/day. The baseline level for Set #1 is an approximation based on testing of similar fuel tanks, while the baseline for Set #2 is based on testing of those tanks.

Table 5.3-19: Permeation Rates for Fluorinated Fuel Tanks with Slosh Testing by ARB Over a 18-41°C Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Set #1 Approximate Baseline	g/m^2/day	10.4	10.4	10.4	10.4
Set #1 Fluorinated	g/m^2/day % reduction	1.17 89%	1.58 85%	0.47 96%	1.07 90%
Set #1 Fluorinated & Sloshed	g/m^2/day % reduction	2.38 77%	2.86 73%	1.13 89%	2.12 80%
Set #2 Approximate Baseline	g/m^2/day	12.1	12.1	12.1	12.1
Set #2 Fluorinated	g/m^2/day % reduction	0.03 >99%	0.00 >99%	0.00 >99%	0.01 >99%
Set #2 Fluorinated & Sloshed	g/m^2/day % reduction	0.07 99%	0.11 99%	0.05 >99%	0.08 99%

About a year and a half after the California ARB tests on the Set #2 fuel tanks, we performed permeation tests on these fuel tanks. During the intervening period, the fuel tanks remained sealed with California certification fuel in them. We drained the fuel tanks and filled them with fresh California certification fuel. We then measured the permeation rate at 29°C. Because this is roughly the average temperature of the California variable temperature test, similar permeation rates would be expected. The untreated fuel tanks showed slightly lower permeation over the constant temperature test. This difference was likely due to the difference in the temperature used for the testing. However, the fluorinated fuel tanks showed an increase in permeation. This increase in permeation appears to be the result of the 1.5 year additional fuel soak. Even after this long fuel soak, the fluorination achieves more than a 95 percent reduction in permeation. Table 5.3-20 presents this comparison.

Table 5.3-20: Permeation Rates [g/m^2/day] for Fluorinated Fuel Tanks Tested by ARB and EPA on CA Certification Gasoline with a 1½ Year Fuel Soak Differential

Technology Configuration	Temperature	Tank 1	Tank 2	Tank 3	Average
Baseline, CARB testing	18-41°C	12.1	12.1	12.1	12.1
Baseline, EPA testing after 1.5 year additional fuel soak	29°C % change	11.5 -5%	11.4 -6%	11.2 -7%	11.4 -6%
Fluorinated, CARB testing	18-41°C	0.07	0.11	0.05	0.08
Fluorinated, EPA testing after 1.5 year additional fuel soak	29°C % reduction	0.56 95%	0.62 95%	0.22 98%	0.47 96%

After the above testing, we drained the fuel tanks and filled them with certification gasoline splash-blended with 10 percent ethanol (E10). We then soaked the fuel tanks for 20 weeks to precondition them on this fuel. Following the preconditioning, we tested these fuel tanks for permeation at 29˚C (85˚F). Table 5.3-21 presents these emission results compared to the emission results for three baseline tanks (untreated) that were subject to the same preconditioning. Percent reductions are presented based on the difference between the fluorinated fuel tanks and the average results of the three untreated fuel tanks. The slight increase in permeation on the E10 fuel was similar for the baseline and fluorinated fuel tanks and still resulted in permeation rates well below the proposed standard.

Table 5.3-21: Permeation Rates for Fluorinated Fuel Tanks on E10 Fuel at 29˚C

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Baseline (untreated)	g/m^2/day	13.9	13.7	14.4	14.0
Fluorinated	g/m^2/day % reduction	0.43 97%	0.62 96%	0.62 96%	0.56 96%

Another study also looked at the effect of alcohol in the fuel on permeation rates from fluorinated fuel tanks.[87] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

Under their rule for small offroad equipment, California may issue executive orders to manufacturers with low emission products. As of August, 2006, ARB has issued 5 executive orders for low permeation fuel tanks.[88] Under these executive orders, three fluorination approaches have been approved. The California fuel tank permeation standard is 1.5 g/m^2/day tested at 40˚C on California certification fuel. Table 5.3-22 presents the test results for the fuel tanks with ARB executive orders. Note that the reported emissions are the average of five test samples.

Table 5.3-22: ARB Fuel Tank Executive Orders for Small Offroad Equipment

EO#	Test Fuel	g/m^2/day
C-U-05-015	Phase II	1.10
C-U-06-019	Phase II	0.30
C-U-06-006	Phase II	0.38

One automobile manufacturer used fluorination to reduce permeation on HDPE fuel tanks to meet the LEV I vehicle standards. This manufacturer used similar or more stringent requirements for fuel soak, durability, and testing than finalized today. At 40°C, this manufacturer stated that they measured 0.15-0.2 g/day for fluorinated tanks compared to over 10 g/day for untreated HDPE fuel tanks.[89]

Injection-molded HDPE fuel tanks

The issue has been raised by manufacturers that HDPE intended for injection-molding has a somewhat different composition than HDPE used for blow-molding. To address this concern, testing has been performed on fluorinated, injection-molded fuel tanks as well.[90] These fuel tanks were tested using California's TP-901 test procedures which preconditioning steps including fuel soak, slosh testing, and pressure-vacuum cycling. California Phase II gasoline was used for this testing.

Three similar fuel tanks were tested also over the proposed Federal test procedure.[91] Under this testing, E10 fuel was used. Weight loss tests were performed before and after the durability tests in 40 CFR 1501.515.[92] These durability tests included slosh testing, pressure vacuum cycling, and UV exposure. Results from this testing are presented in Table 5.3-23. The permeation was significantly higher when tested on E10 fuel, especially when accounting for differences in test temperature. In addition, permeation increased somewhat after the durability testing. However, the measured permeation rates were well below the proposed fuel tank permeation standard on E10 after the durability testing.

Table 5.3-23: Permeation Rates for Fluorinated, Injection-Molded Fuel Tanks [g/m^2/day]

Test Procedure	Test Temperature	Tank 1	Tank 2	Tank 3	Average
California TP-901	40˚C	0.28	0.26	0.27	0.27
Federal Baseline	28˚C	0.32	0.47	0.42	0.41
After Durability Testing	28˚C	0.30	0.92	0.57	0.60

XLPE fuel tanks

We tested several fluorinated cross-link polyethylene (XLPE) fuel tanks for permeation emissions. The first tank was a 6 gallon test tank produced by a marine fuel tank manufacturer specifically for this testing. The remaining fuel tanks were purchased on the open market. The fuel tanks were then treated by a fluorinater. We tested the first tank on certification gasoline. After a 20 week soak, we observed a permeation rate of 0.11 g/gal/day (1.52 g/m^2/day), which represented more than an 80 percent reduction in permeation.

The remainder of the fluorinated tanks were tested on E10 (10 percent ethanol) using the same procedures as for the HDPE tanks discussed above. These fuel tanks were treated at a level equivalent to what the fluorinater uses for automotive applications. All of the fuel tanks were treated both on the inside and outside. The test results, presented in Table 5.3-24, showed emission reductions of about 40 percent on average. Emission results from the sloshed fuel tanks were not significantly different than from the tanks that were not sloshed.

Table 5.3-24: EPA Permeation Data on Fluorinated Cross-Link Fuel Tanks at 29°C on E10

Fuel Tank	Capacity	Soak Period	g/gal/day	g/m^2/day	slosh test?
1	12 gallons	29 weeks	0.27 0.39 0.32 0.36 0.38	4.1 5.9 4.9 5.4 5.8	no no no no no
2	12 gallons	29 weeks	0.39 0.34 0.42 0.32	5.7 5.0 6.2 4.6	yes no no no
3	12 gallons	29 weeks	0.28 0.22 0.22	3.4 2.6 2.8	yes no no

5.3.2.3 Barrier Platelets

Another approach to creating a permeation barrier in a fuel tank is to blend a low permeable resin in with the HDPE and extrude it with a single screw. The trade name typically used for this permeation control strategy is Selar®. The low permeability resin, typically nylon or EVOH, creates non-continuous platelets in the HDPE fuel tank which reduce permeation by creating long, tortuous pathways that the hydrocarbon molecules must navigate to pass through the fuel tank walls. Although the barrier is not continuous, this strategy can still achieve greater than a 90 percent reduction in permeation of gasoline. EVOH has much higher permeation resistance to alcohol than nylon; therefore, it would be the preferred material to use for meeting our proposed standard which is based on testing with a 10 percent ethanol fuel.

We tested several portable gas cans and marine tanks molded with low permeation non-continuous barrier platelets 29°C. Six of fuel tanks tested were constructed using nylon as the barrier material. The remainder of the fuel tanks were constructed using ethylene vinyl alcohol (EVOH) as the barrier material. The advantage of EVOH is that it has much better resistance to alcohol than nylon. Five of the nylon based fuel tanks were tested on certification gasoline. The sixth tank was tested on E10 (10 percent ethanol) to evaluate the effectiveness of this material with alcohol blended fuel. The fuel tanks with the EVOH barrier were all tested on E10.

Testing was performed after the fuel tanks had been filled with fuel and stored at room temperature. The purpose of the soak period was to ensure that the fuel permeation rate had stabilized. Although 20 weeks was generally accepted as an acceptable period, we soaked the tanks with gasoline for 22 weeks and the tanks with E10 for 37 weeks. The fuel tanks were drained and then filled with fresh fuel prior to the permeation tests. Because the barrier platelets are integrated in the tank wall material, it did not seem likely that pressure or slosh testing would significantly affect the performance of this technology.

Table 5.3-25 presents the results of the permeation testing on the fuel tanks with barrier platelets. These test results show more than an 80 percent reduction for the nylon barrier tested on gasoline. However, the nylon barrier does not perform as well when a fuel with a 10 percent ethanol blend is used. Testing on a pair of 2 gallon tanks with nylon barrier showed 80 percent percent higher emissions when tested on E10 than on gasoline. We also tested fuel tanks that used EVOH barrier platelets. EVOH has significantly better resistance to permeation on E10 fuel than nylon (see Appendix 5D for material properties). For the fuel tanks blended with 6 percent EVOH, we observed an average permeation rate of about 1.4 g/m^2/day on E10 fuel which meets our proposed permeation standard.

Table 5.3-25: Permeation Rates for Plastic Fuel Containers with Barrier Platelets Tested by EPA at 29°C

Percent Selar®*	Tank Capacity [gallons]	Test Fuel	Fuel Soak [weeks]	g/gal/day	g/m^2/day
Nylon barrier platelets					
unknown**	2	gasoline	40	0.54	3.7
unknown**	2	E10	40	0.99	6.8
4%	5	gasoline	22	0.35	4.1
4%	5.3	gasoline	22	0.11	1.2
4%	6.6	gasoline	22	0.15	1.6
4%	6.6	gasoline	22	0.14	1.5
EVOH barrier platelets					
2%	6.6	E10	37	0.23	3.0
4%	6.6	E10	37	0.14	1.9
4%	6.6	E10	37	0.15	2.0
6%	6.6	E10	37	0.08	1.4
6%	6.6	E10	37	0.09	1.4

*trade name for barrier platelet technology used in test program
** designed to meet California permeation requirement

Manufacturers raised the concern about whether or not a tank using barrier platelets would have a stabilized permeation rate after 20 weeks. In other words, manufacturers were concerned that this technology may pass the test, but have a much higher permeation rate in-use. We tested one of the 4 percent and 6 percent EVOH tanks on E10 again after soaking for a total of 104 weeks (2 years). The measured permeation rates were 2.0 and 1.4 g/m^2/day for the 4 percent and 6 percent EVOH tanks, respectively, which represents no significant changes in permeation from the 37 week tests. In contrast we measured the 4 percent nylon tanks again after 61 weeks and measured a permeation rates of 2.8 and 2.7 g/m^2/day which represented about an 80-90 percent increase in permeation compared to the 22 week tests.

The California Air Resources Board (ARB) collected test data on permeation rates from portable fuel containers molded with low permeation non-continuous barrier platelets using California certification fuel. These fuel tanks all used nylon as the barrier resin. The results show that this technology can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 30°C. Because the data is reported in g/gal/day, we only include the data on fuel tanks here that are compatible in size with marine fuel tanks. This test data showed that more than a 90 percent reduction in permeation is achievable through the use of nylon barrier platelets. However, all of this testing was performed on California certification fuel which does not include ethanol.

Table 5.3-26: Permeation Rates for Plastic Fuel Containers with Barrier Platelets Tested by ARB Over a 18-41°C Diurnal

Percent Selar®*	Tank Capacity [gallons]	Permeation Loss [g/gal/day]
4%	5	0.08
	5	0.09
(average =0.12 g/gal/day)	5	0.13
	5	0.16
	5	0.17
	6	0.08
	6	0.10
6%	5	0.07
	5	0.07
(average =0.09 g/gal/day)	5	0.07
	5	0.08
	5	0.12
	5	0.17
	6	0.06
	6	0.07
8%	5	0.08
	5	0.10
(average =0.07 g/gal/day)	6	0.05
	6	0.06

*trade name for barrier platelet technology used in test program

Dupont, who manufacturers Selar®, has performed testing on HDPE with higher blends of EVOH (known as Selar RB®). Table 5.3-27 presents permeation rates for HDPE and three Selar RB® blends when tested at 60°C on xylene.[93] Xylene is a component of gasoline and gives a rough indication of the permeation rates on gasoline. This report also shows a reduction of 99 percent on naptha and 98 percent on toluene for 8 percent Selar RB®.

Table 5.3-27: Xylene Permeation Results for Selar RB® at 60°C

Composition	Permeation, g mm/m^2/day	% Reduction
100% HDPE	285	–
10% RB 215/HDPE	0.4	99.9%
10% RB 300/HDPE	3.5	98.8%
15% RB 421/HDPE	0.8	99.7%

5.3.2.4 Alternative Materials

Permeation can also be reduced from fuel tanks by constructing them out of a lower permeation material than HDPE. Examples of alternative materials are metal, various grades of plastic, and new fiberglass construction.

5.3.2.4.1 Metal

Gasoline does not permeation through metal. Therefore, the only permeation from a metal fuel tank would be through rubber gaskets or O-rings that may be used to seal connections on the fuel tank. Examples would be the gasket or O-ring in a fuel cap or a bolted-on component such as a sender unit for a marine tank. Presumably, the exposed surface area of the gaskets would be small enough that a metal fuel tank would be well below our proposed permeation standard. One issue with metal fuel tanks, however, is fuel leakage due to corrosion. A study sponsored by the Coast Guard in 1994 showed that aluminum (and even stainless steel) fuel tanks are prone to failure, both in salt water and fresh water applications., due to corrosion.[94] Fuel leakages would not only be an environmental issue, but could be a safety issue as well. Aluminum fuel tank manufacturers have stated that corroding fuel tanks are typically due to improper installation.

5.3.2.4.2 Alternative Plastics

There are grades of plastics other than HDPE that could be molded into fuel tanks. One material that has been considered by manufacturers is nylon; however, although nylon has excellent permeation resistance on gasoline, it has poor chemical resistance to alcohol-blended fuels. As shown in Appendix 5D, nylon could be used to achieve more than a 95 percent percent reduction in permeation compared to HDPE for gasoline. However, for a 10 percent ethanol blend, this reduction would significantly less depending on the grade of nylon. For a 15 percent methanol blend, the permeation would actually be several times higher through nylon than HDPE.

Some handheld equipment, primarily chainsaws, use structurally-integrated fuel tanks where the tank is molded as part of the body of the equipment. In these applications, the frames (and tanks) are typically molded out of nylon for strength. We tested structurally-integrated fuel tanks from four handheld equipment manufacturers at 29˚C on both gasoline and a 10 percent ethanol blend. The test results suggest that permeation emissions are 20 to 70 percent higher on E10 than on gasoline for these fuel tanks. Note these fuel tanks are capable of meeting the proposed standards using their current materials. In the cases where the permeation rates were higher than these standards, it was observed that the fuel cap seals had large exposed surface areas on the O-rings, which were not made of low permeation materials. Emissions could likely be reduced significantly from these tanks with improved seal designs. Table 5.3-28 presents the results of this testing.

Table 5.3-28: Permeation Rates for Nylon Handheld Fuel Tanks Tested by EPA at 29°C

Tank ID	Application	Material	Test Fuel	Permeation Loss [g/m^2/day]
R1	clearing saw	nylon 6	gasoline	0.34
R2			E10	0.42
R3			E10	0.48
B1	hedge clipper	nylon 6, 33% glass	gasoline	0.62
B2			E10	1.01
B3			E10	1.12
B4			E10	0.93
W1	chainsaw	nylon 6, 30% glass	gasoline	1.45
W2			E10	2.18
W3			E10	2.46
G1	chainsaw	nylon 6, 30% glass	gasoline	1.30
G2			E10	1.41
G3			E10	2.14

Other materials which have excellent permeation resistance even with alcohol-blended fuels are acetal copolymers and thermoplastic polyesters. These polymers can be used to form fuel tanks in the blow-molding, rotational-molding, and injection-molding processes. An example of an acetal copolymer is known as Celcon® which has excellent chemical resistance to fuel and has been shown to be durable based on exposure to automotive fuels for 5000 hours at high temperatures.[95] As shown in Appendix 5D, Celcon would result in more than a 99 percent reduction in permeation compared to HDPE for gasoline. On a 10 percent ethanol blend, the use of Celcon would result in more than a 95 percent reduction in permeation. Two thermoplastic polyesters, known as Celanex® and Vandar®, are also being considered for fuel tank construction and are being evaluated for permeation resistance by the manufacturer. Celcon has a more crystalline structure than Vandar resulting in lower permeation but less impact resistance.

We tested a 1-liter blow-molded Vandar fuel tank and three rotationally-molded 3-liter fuel tanks made of impact toughened Celcon for permeation at 29°C on E10 fuel. Prior to the permeation testing, the fuel containers were soaked in E10 for more than 20 weeks. These test results are included in Table 5.3-29 below. For the Celcon tank tests, higher emissions were observed in the second week than the first week. This behavior was seen in repeat tests and was likely due to deterioration of the epoxy seal used in this testing. Therefore, the actual emission rates of the material are likely lower than presented below. More detailed data on this testing is available in the docket.[96]

Table 5.3-29: Permeation Results Acetal Copolymer Fuel Tanks at 29°C on E10

Material Name		Material Type	g/gal/day	g/m^2/day
Vandar	V1	thermoplastic polyester	1.7	5.6
Impact	C10	modified	0.13	0.75
Resistant		acetal copolymer	0.09	0.53
C11			0.10	0.59
Celcon	C13			

Fuel tank manufacturers have expressed some concern that the acetal copolymer is not as tough as cross-link polyethylene. Thermoplastic polyesters have better impact resistance, but higher permeation. The impact toughened fuel tanks mentioned above were in response to these concerns. Also, the rotational molding process must be better controlled to use these materials in comparison to XLPE. The temperature profile must be tightly controlled to uses Celcon, or formaldehyde gases may form. The moisture level of Vandar must be kept low prior to molding.

Acetal copolymers are also used today to produce many fuel resistant automotive components such as low permeation fuel caps. This construction has been used for many years in automotive applications and now acetal copolymers are being used to manufacture low permeation fuel caps for nonroad equipment as well.

Another low permeation thermoplastic that can be used in the manufacture of fuel tanks is a polyester/polycarbonate alloy. One example is marketed under the trade name of Xenoy 6620. This engineered plastic is impact modified and is intended for the injection molding process. The polyester provides good chemical resistance and the polycarbonate provides the impact resistance. Permeation testing was performed on a fuel tank made of Xenoy 6620 following the California test procedures. At 40˚C on California Phase II CERT fuel, the measured permeation rate was 0.26 g/m^2/day.[97] The manufacturer of this material also has a version that is modified slightly so that it can be used in the blow-molding process.

5.3.2.4.3 Low Permeation Fiberglass

One manufacturer has developed a low permeation fiberglass fuel tank construction.[98] The composite tanks are fabricated using a glass fiber reinforced closed cell urethane composite sheet as substrate and assembled with structural urethane adhesive as a fastening medium. These fuel tanks may be hand constructed, or for larger volume production, they may be molded at lower cost. Once fully assembled with necessary fuel fittings the tank is coated with fiberglass reinforced resin, sufficient for H-24 ABYC (American Boat and Yacht Council) and 33 CFR 183.510 standards for fuel systems mechanical strength requirements. A final gel coat finish may was applied for aesthetics.

Permeation control is achieved by incorporating fillers into a resin system and coating the assembled tank interior and exterior. This filler is made up of nanocomposites (very small particles of treated volcanic ash)[4] which are dispersed into a carrier matrix. This construction creates a tortuous pathway for hydrocarbon migration through the walls of the fuel tank. We tested a 14 gallon fuel tank provided by this manufacturer and measured a permeation rate of 0.97 g/m^2/day on E10 fuel at 29°C. Other advantages of this technology are improved strength and flame resistance compared to plastic fuel tanks.

5.3.2.5 Multi-Layer Construction

Fuel tanks may also be constructed out of multiple layers of materials. In this way the low cost and structural advantages of traditional materials can be utilized in conjunction with higher grade materials which can provide effective permeation resistance. Today, fuel tanks are made in many ways including higher volume blow-molding, lower volume injection molding, and very low volume rotational-molding. The discussion below presents data on several multi-layer fuel constructions.

5.3.2.5.1 Blow-Molded Coextruded Barrier

Coextruded barrier technology has been long established for blow-molded automotive fuel tanks. Data from one automobile manufacturer showed permeation rates of 0.01-0.03 g/day for coextruded fuel tanks at 40°C on EPA certification fuel. They are using this technology to meet LEV II vehicle standards. For comparison, this manufacturer reported permeation rates of more than 10 g/day for standard HDPE fuel tanks.[99]

Another study looks at the permeation rates, using ARB test procedures, through multi-layer fuel tanks.[100] The fuel tanks in this study were 6 layer coextruded plastic tanks with EVOH as the barrier layer (3 percent of wall thickness). The outer layers were HDPE and two adhesive layers were needed to bond the EVOH to the polyethylene. The sixth layer was made of recycled polyethylene. The two test fuels were a 10 percent ethanol blend (CE10) and a 15 percent methanol blend (CM15). See Table 5.3-30.

Table 5.3-30: Permeation Results for a Coextruded Fuel Tank Over a 18-41°C Diurnal

Composition	Permeation, g/day	% Reduction
100% HDPE (approximate)	6 - 8	–
3% EVOH, 10% ethanol (CE10)	0.2	97%
3% EVOH, 15% methanol (CM15)	0.3	96%

The California Air Resources Board tested two sets of three 5-gallon portable fuel containers.[101] Each set was manufactured by a different company, but all of the fuel tanks were blow-molded with a coextruded barrier layer. Testing was performed over the California 18-41˚C temperature cycle with California Phase II gasoline. Testing was performed with and

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[4] Chemically modified montmorillonite for nanocomposite formulation

without the spouts removed. The test data presented in Table 5.3-31 was after 174 days of fuel soak with the spouts removed and the openings welded shut. California reported the test results in grams per gallon. Table 5.3-31 also presents approximate g/m^2/day values based on the relationship between tank capacity and inside surface area used in the NONROAD2005 emissions model.

Table 5.3-31: ARB Permeation Results for a Coextruded Portable Fuel Tanks

Fuel Tank	Permeation, g/gal/day	Approximate Rate in g/m^2/day
B1	0.01	0.09
B2	0.01	0.11
B3	0.01	0.11
Average	0.01	0.10
M1	0.01	0.14
M2	0.02	0.21
M3	0.02	0.18
Average	0.02	0.17

Another approach has recently been developed in which a multi-layer fuel tank can be blow-molded with only two layers.[102] In this construction, a barrier layer of a polyarylamide known as Ixef MXD6 is used on the inside of a HDPE fuel tank. Ixef has permeation properties similar to EVOH. Test results showed a permeation rate of 0.8 g-mm/m^2/day at 60˚C on CE10 for a test film of Ixef. Unlike EVOH, Ixef can be exposed directly to the fuel which removes the need for an inner layer of HDPE. In addition, a tie material can be blended into the HDPE which will allow the polyarylamide to bond directly to the HDPE rather than using an adhesive layer.

5.3.2.5.2 Rotational Molded Dual-layer Construction

As discussed above, an inner layer can be molded into the inside of a rotationally molded fuel tank through the use of a drop-box that opens after the XLPE tank begins to form. Through this method, a XLPE fuel tank could be molded with a low permeation inner barrier. With this construction, it may be possible to reduce the amount of XLPE used depending on the structural characteristics of the inner liner material. For instance, acetal copolymer can be rotationally molded and could be used as the inner liner. This way, the permeation characteristics of an acetal copolymer could be achieved through an inner liner while still retaining the toughness of XLPE . One issue would be that acetal copolymers do not readily adhere to XLPE. Therefore fitting designs would need to account for this.

Another material that could be used in a multi-layer approach is nylon which comes in many grades. Typical nylon grades used in Small SI fuel tank constructions may not perform well in marine applications because of the hygroscopic nature of these nylons. In other words, typical nylon adsorbs water which can make it brittle. In addition, E10 fuel permeates through nylon much more readily than gasoline.

One manufacturer is working with a nylon known as Rilsan® polyamide 11 (PA 11) in constructing low permeation multi-layer rotational-molded fuel tanks.[103] Rilsan® polyamide 11 has two advantages to traditional nylons in that it is not hygroscopic and it is more resistive to alcohol fuels. One manufacturer has manufactured fuel tanks using the PA11 as an inner liner in a polyethylene shell. The manufacturer using this approach reports a permeation rate of about 3 g-mm/m^2/day on fuel CE10 at 28°C compared to about 30 g-mm/m^2/day for XLPE. In addition, the nylon used in multi-layer constructions is formulated with a polyethylene graft that causes it to adhere well to XLPE. This prevents the layers from separating in use.

We tested two 10 gallon multi-layer rotational molded fuel tanks at 29°C with E10 fuel after a 35 week soak with two fuel changes during that period.[104] One of the tanks was molded with an outer shell of medium-density polyethylene while the other was molded with an outer shell of cross-link polyethylene. The long soak period was due to test equipment problems and the fuel was changed with each test attempt. However, it presents valuable data on the longer term effectiveness of this technology. This test data is presented in Table 5.3-31. The manufacturer reported that this tank design passed testing on the Coast Guard burn, pressure, shock, and impulse test requirements.[105,106,107,108] In addition, a tank of this construction was tested and passed the tank durability tests for snowmobiles specified in SAE J288.[109] These tests include cold (-40˚C) and hot temperature (60˚C) immersion and drop tests.

Typically, multi-layer rotational-molded fuel tanks are constructed with the use of a drop box which adds the inner-layer material into the mold after the first material sets. Other approaches are to use a meltable bag containing the inner-layer material or even to pull the mold from the oven to add the inner-layer material. However, one manufacturer, that participated in the SBREFA process, has stated that they have developed a method to mold the inner liner without the use of a drop box or other approach that lengthens molding cycle time. This fuel tank manufacturer is selling fuel tanks using this construction for use in Small SI equipment and is selling mono-layer XLPE rotational-molded tanks for use in boats.

Table 5.3-31: Permeation Results PA 11/PE Fuel Tanks at 29°C on E10

Tank	Outer Shell	g/gal/day	g/m^2/day
1	MDPE	0.05	0.71
2	XLPE	0.06	0.79

Under their rule for small offroad equipment, California may issue executive orders to manufacturers with low emission products. As of August, 2006, ARB has issued 5 executive orders for low permeation fuel tanks.[110] Under these executive orders, two basic multi-layer rotomolded (XLPE and nylon) approaches have been approved. The California fuel tank permeation standard is 1.5 g/m^2/day tested at 40˚C on California certification fuel. However, most of the testing was performed on fuel CE10 which is a significantly more aggressive fuel for permeation. Table 5.3-32 presents the test results for rotational-molded fuel tanks with ARB executive orders. Note that the reported emissions are the average of 3-5 test samples.

Table 5.3-32: ARB Fuel Tank Executive Orders for Small Offroad Equipment

EO#	Test Fuel	$g/m^2/day$
C-U-05-005	CE10 Phase II	0.81 0.18
C-U-06-014	CE10 CE10 CE10	0.10 0.00 0.09

There is another approach to dual-layer rotomolded fuel tanks under development that uses a "single shot" approach to molding.[111] In this method a material known as polybutylene terephthalate cyclic oligimor (CBT) is combined with the XLPE in the mold. Because of the different melt rates and viscosities of the two materials, during the mold process, the CBT® polymerizes into a thermoplastic known as polybutylene terephthalate (PBT) to form a barrier layer on the inside of the fuel tank. Adhesion between the PBT and XLPE comes from mechanical bonding between the two layers. This material can be used without lengthening the cycle time for rotational molding, and it does not require forced cooling.[112] Initial testing shows a permeation rate of <1 $g/m^2/day$ when tested with fuel CE10 at 40˚C for a sample with a 3.9 mm total wall thickness.[113] This wall thickness for this testing was composed of 0.9mm CBT and 3.0mm XLPE. PBT itself has a permeation rate on CE10 at 40˚C of less than 0.05 $g\text{-}mm/m^2/day$.

5.3.2.5.3 Injection-Molded Dual-Layer Construction

To add a barrier layer in the injection molding process, a thin sheet of the barrier material may be placed inside the mold prior to injection of the poleythylene. The polyethylene, which generally has a much lower melting point than the barrier material, bonds with the barrier material to create a shell with an inner liner.

5.3.2.5.4 Thermoformed Multi-Layer Construction

As an alternative, multiple layers can be created through thermoforming.[114] In this process, sheet material is heated then drawn into two vacuum dies. The two halves are then fused while the plastic is still molten to form the fuel tank. Before the halves are fused together, it is possible to add components inside of the fuel tank. Low permeation fuel tanks can be constructed using this process by using multi-layer sheet material. This multi-layer sheet can be extruded using similar materials to multi-layer blow-molded fuel tank designs. A typical barrier construction would include a thin EVOH barrier, adhesion layers on both sides, a layer of HDPE regrind, and HDPE layers on the outside surfaces.

This process has low capital costs compared to blow-molding and should be cost competitive with injection molding and rotational-molding. Manufacturers have indicated that this construction could be coated with an intumescent material which would help it pass the Coast Guard fire test. This coating could be applied directly to the multi-layer plastic sheets while they are still hot after extrusion. Once the plastic cools, it could be applied using flame ionization or electric arcing to increase the surface are of the plastic for adhesion.

EPA tested two, 5.6 gallon, thermoformed fuel tanks for permeation. These fuel tanks were constructed as described above with a thin EVOH barrier and were soaked with E10 for 27 weeks prior to testing. Due to test variability, testing was repeated at 35 and 44 weeks (fresh fuel was added prior to each weight loss test). From day to day, a constant weight loss was not always observed, and weight gains were occasionally seen. This variability in measured weight loss was likely due to the very low permeation rates combined with the effect of atmospheric conditions on measured weight. The highest variations in weight loss were observed when storms passed through suggesting that the changes in barometric pressure and relative humidity were affecting the buoyancy of the fuel tanks (discussed in more detail in Section 5.6.2.3). In the third round of testing (after 44 weeks), barometric pressure and humidity were measured and deemed to be relatively stable. In addition, a smaller tank with sand in it (rather than fuel) was measured simultaneously as a control to give some indication of the buoyancy effect. A small weight loss was measured for the control tank, suggesting that the measured test results may slightly overstate the permeation for the thermoformed fuel tanks. Table 5.3-33 presents the test results for each of the three tests.

Table 5.3-33: Permeation Results Multilayer Thermoformed Fuel Tanks at 29°C on E10

Soak (weeks)	Tank	g/gal/day	g/m^2/day
27	#16 #21	0.01 0.01	0.15 0.05
35	#16 #21	0.01 0.01	0.07 0.09
44	#16 #21	0.01 0.00	0.11 0.04
Average	#16 #21	0.01 0.01	0.11 0.06

5.3.2.5.5 Epoxy Barrier Coating

Another approach that has shown promising results is to coat a plastic fuel tank with a low permeation epoxy barrier coating. Early attempts at coating a plastic fuel tank resulted in coatings that eventually wear off due to the difficulty of bonding some materials to HDPE and XLPE. However, because fluorination increases the surface energy of the plastic, a low level of fluorination can be used to make it possible to apply an epoxy coating, even to XLPE. Because this approach is applied to the fuel tank post-molding, it can be used for any plastic fuel tank, regardless of the production molding method.

We performed permeation testing on six 12 gallon rotationally-molded XLPE fuel tanks with a thin, low-permeation epoxy coating. This coating was a two-part epoxy that was sprayed onto the tank and thermally cured in 45 minutes. Prior to the permeation measurements, the fuel tanks were soaked with E10 fuel at about 25°C for 15 weeks. The tanks were then drained and fresh E10 was added prior to the 29°C constant temperature permeation test. Inspection of the externally coated fuel tanks showed that the epoxy was unevenly applied and that some bare spots existed. This was reflected in the unsatisfactory permeation results. A more careful coating would be expected to result in similar results as the internal coatings. One of the externally coated fuel tanks was over-coated with a 1-part epoxy that was cured with a 45 second UV exposure. This tank was soaked for an additional 6 weeks prior to retesting. These test results, which are presented in Table 5.3-34, show that this technology can be used to reduce permeation emissions by more than 90 percent.

Table 5.3-34: EPA Permeation Data on Epoxy Coated XLPE Fuel Tanks at 29°C on E10

Fuel Tank Set	Coating	Soak Period	g/gal/day	g/m^2/day	slosh test?
1	Inside Thermocured	15 weeks	0.04 0.001 0.07	0.6 0.02 1.0	no no yes
2	Outside Thermocured*	15 weeks	0.13 0.23 0.23	1.9 3.3 3.3	no no yes
3	Outside UV cured	additional 6 weeks	0.03	0.4	no

* inspection showed uneven application of the coating which affected permeation results

Since the above testing was performed, the fluorinater and the epoxy manufacturer who developed this approach have performed more testing on their UV cured, 1-part epoxy. The testing was performed on epoxy coated HDPE bottles and 2 gallon fuel tanks using the California ARB test procedure of 40°C with California certification fuel.[115] At 29°C, we would expect the permeation rate to be about half of these levels due to the relationship between permeation and temperature discussed above in Section 5.3.1.2. The results for this testing were reported to be 0.3 g/m^2/day on average for both the bottles and tanks on gasoline. The bottles had a permeation rate of 0.5 g/m^2/day on gasohol (ethanol blend). This technology resulted in better than 95 percent reductions in permeation. Table 5.3-35 presents the test results after a 9 week fuel soak at 40°C.

Table 5.3-35: Permeation Data: Epoxy Coated HDPE Fuel Tanks at 40°C on CA Cert Fuel

Fuel Tank	g/gal/day	g/m²/day
1	0.04	0.25
2	0.02	0.09
3	0.02	0.11
4	0.08	0.49

Roto-molders of marine fuel tanks generally use cross-link polyethylene. The advantage of XLPE is that its cross-link structure causes it to behave like thermoset which helps the fuel tanks pass the Coast Guard fire test (33 CFR 183.590) by holding their shape longer under exposure to fire. If a flame retardant were included in the epoxy coating, a less expensive material, such as HDPE could be used to make fuel tanks that are subject to the flame test requirement. The manufacturers who have developed the above approach for permeation have developed an additive that provides an intumescent coating to allow the fuel tanks to be produced at a lower cost. Testing on the Coast Guard burn test showed that an HDPE fuel tank would fail around after being exposed to a flame for about 1.5 minutes (the standard is 2.5 minutes). With the intumescent coating, the fuel tank passed the flame test and survived more than 5 minutes.[116]

5.4 Fuel/Vapor Hose Permeation

The polymeric materials (plastic or rubber) used in the construction of gasoline fuel and vapor hoses generally have chemical compositions much like that of gasoline. As a result, constant exposure of gasoline to these surfaces allows the material to continually absorb fuel. Permeation is driven by the difference in the chemical potentials of gasoline or gasoline vapor on either side of the material. The outer surfaces of these materials are exposed to ambient air, so the gasoline molecules permeate through these fuel-system components and are emitted directly into the air. Permeation emissions continue at a nearly constant rate, regardless of how much the vehicle or equipment is used. Because of these effects, permeation-related emissions can therefore add up to a large fraction of the total evaporative emissions.

This section summarizes the data and rationale supporting the permeation emission standard for fuel lines presented in the Executive Summary.

5.4.1 Baseline Hose Technology and Emissions

5.4.1.1 Marine Fuel Hose Subject to 33 CFR part 183

The majority of marine fuel hoses are constructed primarily of nitrile rubber with a chloroprene cover for abrasion and flame resistance. Hoses are designed to meet the Coast Guard requirements in 33 CFR part 183 which reference SAE J1527.[117] Fuel hose for boats with gasoline engines (excluding outboards) must meet the Class 1, Type A requirements which specify a maximum permeation rate of 100 g/m^2/day at 23°C on ASTM Reference Fuel C[118] (50 percent toluene, 50 percent iso-octane). Class 1 refers to hose that is used where liquid fuel is normally continuously in the hose. Type A refers to hose that will pass a 2½ minute flame resistance test.

On a fuel containing an alcohol blend, permeation would likely be higher from these fuel hoses. In fact, the SAE J1527 standard also requires Class 1 hose to meet a permeation rate of 300 g/m^2/day on fuel CM15 (15 percent methanol). Although ethanol is generally less aggressive than methanol, ethanol in the fuel would still be expected to increase the permeation rate significantly through most fuel hoses. Based on the data presented in Appendix 5D, permeation through nitrile rubber is about 50 percent higher when tested on Fuel CE10 (10 percent ethanol) compared to testing on Fuel C.

Fuel fill neck hoses are subject to a less stringent permeation standard under the Coast Guard specifications because they are not normally continuously in contact with fuel (Class 2). This relaxed standard is 300 g/m^2/day on Fuel C and 600 g/m^2/day on Fuel CM15 at 23°C. Where marine fuel hose is typically extruded, fill neck hose is generally constructed by wrapped layers on a mandrill. Fill neck hose is constructed with a larger inner diameter (1.5-2") to accommodate higher fuel rates and with thicker, more heavily reinforced walls, to prevent buckling and pinching.

Marine fuel hose is typically designed to be somewhat lower than the SAE J1527 requirements. Confidential data by one manufacturer supplying baseline marine fuel hose suggested that their fuel feed hose is about 25 percent lower than the Class 1, Type A requirement on Fuel C and about 35 percent lower on Fuel CM15. In their comments on the 2002 proposal for marine evaporative emission control, Lawrence industries stated that the majority of their fill neck hose permeates in the range of 150 to 180 g/m^2/day which is about half of the 300 g/m^2/day requirement required by the Coast Guard.[119]

We collected test data on marine hose permeation through contracts with outside laboratories.[120,121,122,123,124] Data was also available on a fuel feed hose testing funded by the marine industry.[125] All of the hose were prepared by soaking with liquid fuel for long enough periods to stabilize the permeation rate. This data is presented in Table 5.4-1. Note that this data shows somewhat lower permeation than was reported by manufacturers based on their own testing. Especially in the case of the fuel feed hose, this may be a function of the hose construction. This hose was purchased by the contractor without any knowledge of the hose construction. Therefore, it is not known if this is a representative sample of a baseline hose construction or if it contains some sort of barrier material.

Table 5.4-1: Permeation Rates for Baseline SAE J1527 Marine Fuel Hose

Hose Type	I.D.	Fuel Type*	g/m^2/day	Test Temperature
fuel feed hose	3/8"	E10 Fuel CE10	43 88	23 ˚C
vent hose	5/8"	E10	37	28 ˚C
fill neck hose	1.5"	Fuel C	95 98 109	22-36 ˚C temperature cycle
fill neck hose	1.5"	Fuel C Fuel CE10	87 164	23 ˚C
fill neck hose	1.5"	Fuel C E10 Fuel CE10	123 123 274	23 ˚C

* E10 refers to gasoline with 10 percent ethanol

Although fuel hose used in personal watercraft is subject to 33 CFR part 183, personal watercraft manufacturers do not use hose specified in SAE J1527. Fuel hose specifications are contained in a separate recommended practice under SAE J2046.[126] Under this practice, the permeation requirement is 300 g/m^2/day with testing performed in accordance with SAE J1527.

5.4.1.2 Other Marine Fuel Hose

Fuel hose used with outboard engines is not subject to 33 CFR part 183. This hose includes the fuel line from the portable fuel tank to the engine and fuel hose on the engine itself and is generally either constructed out of nitrile rubber with an abrasion resistant cover similar to hose used in recreational vehicle applications or is constructed out of polyvinyl chloride (PVC). One manufacturer of marine hose for use in outboard marine engines supplied permeation data on five hose constructions tested at 23°C.[127] This data is presented in Table 5.4-2 for Fuel C, Fuel CE10, and Fuel CM15 (15 percent methanol). As shown by this data, hose permeation rates can increase dramatically when tested on fuel blended with alcohol. Fuel lines connected to a portable fuel tank are also generally fitted with a primer bulb which is also typically constructed from nitrile rubber.

Table 5.4-2: Permeation Rates for Baseline Fuel Hose [g/m^2/day at 23°C]

Fuel Hose	Fuel C	Fuel CE10	Fuel CM15	gasoline*	E10
C-464-D11	195	420	590	66	192
C-530-D2-CE	5	183	546	4	74
ECO/CPE	228	402	565	53	131
J30R7	426	279	433	27	126
OMC ES1763	141	290	314	43	103

* cited as Marathon 92

5.4.1.3 Small SI Equipment Hose

Fuel hoses produced for use in Small SI equipment are generally extruded nitrile rubber with a cover for abrasion resistance. This hose is often equivalent to SAE J30 R7 hose which as a permeation requirement of 550 g/m^2/day at 23°C[128] on ASTM Fuel C (50 percent toluene, 50 percent iso-octane). On a fuel containing an alcohol blend, permeation would likely be much higher for these fuel hoses. R7 hose is made primarily of nitrile rubber (NBR). Based on the data presented in Appendix 5D, permeation through NBR is 50 percent higher when tested on Fuel CE10 (10 percent ethanol) compared to testing on Fuel C.

One manufacturer performed a study of several hose samples and various fuel types.[129] Permeation testing was performed using the methodology in SAE J30. These hose samples included SAE J30 R7, R8, and R9 hose. The R7 hose samples were constructed with an acrylonitrile inner tube with a chlorosulfonated polyethylene cover layer. The R8 hose samples were constructed using a epichlorohydrin ethyleneoxide copolymer. The R9 hose used a fluoroelastomer barrier for the inner tube with an outer tube made of chlorosulfonated polyethylene compound reinforced with a polyester braid. Over the two week tests, the study showed a peak permeation rate after 4-6 days for R7 and R8 hose and a peak permeation rate after 10-12 days for the lower permeating R9 hose. Table 5.4-3 below presents the two week averages for each of the hose samples and test fuels. In this study, the hose manufacturers were not identified, but the hose samples were each given a letter designation.

Table 5.4-3: Permeation Rates for SAE J 30 Fuel Hose [g/m^2/day at 23°C]

Fuel Hose	Fuel C	Fuel CE10	Fuel CE15	Fuel CM15
SAE J30 R7 “mfr. D”	450	508	541	587
SAE J30 R7 “mfr. E”	330	501	433	707
SAE J30 R8 “mfr. B”	152	385	337	620
SAE J30 R8 “mfr. F”	130	355	308	545
SAE J30 R9 “mfr. A”	2	11	10	73
SAE J30 R9 “mfr. C”	2	6	4	55

Handheld equipment typically use smaller diameter hose made of a single material with no cover. This fuel hose may either be extruded straight run hose or may be more complex injection-molded designs. To determine baseline permeation emission rates from hose on handheld equipment, testing was performed by industry using a modified SAE J30 weight loss procedure.[130] In this modified procedure, E10 fuel was used and the testing followed a 30 day fuel soak intended to stabilize the permeation rate. Table 5.4-4 presents the test results.

Table 5.4-4: Handheld Product Fuel Line Permeation Test Data [E10 fuel at 23˚C]

Hose Identification	Construction	Material	$g/m^2/day$
90014	extruded	NBR	198
90015		NBR	192
90016		NBR	168
S3		NBR	165
S4		NBR	171
H1		NBR	360
H2		NBR	455
S1	injection-molded	NBR	198
S2		NBR/PVC	386

5.4.1.4 Fuel Effects on Hose Permeation

As shown in the data above, adding ethanol or methanol to the test fuel significantly affects the permeation rate through fuel hoses. Because the SAE guidelines typically specify Fuel C for testing, most of the hose data available in the literature is on Fuel C or some blend of Fuel C and ethanol or methanol.

One study looked at the effect of fuel composition on the permeation of several materials used in baseline hose constructions.[131] This data suggests that Fuel C is a more aggressive fuel with respect to permeation than gasoline. In addition, this data shows that permeation for these materials is very low with diesel fuel. Table 5.4-5 presents the data from this study. Appendix 5D includes a table spelling out the acronyms for the hose materials in this table.

Table 5.4-5: Permeation Rates by Fuel and Fuel and Hose Material [g/m^2/day at 21°C]

Material	Fuel C	CE10	CM10	Indolene*	IE10	IM10	Diesel
CFM	nil	35	nil	0.1	20	nil	3
CO	150	270	255	10	80	125	2
ECO	190	390	310	55	180	150	5
ETER	230	400	360	65	205	165	10
39% ACN NBR	300	420	360	110	200	200	15
CSM	490	575	665	210	240	300	nil
CR	640	690	740	320	340	385	10

* "Indolene" refers to a fuel meeting the EPA specifications for certification gasoline

This difference in permeation between Fuel C and gasoline is likely due to the higher aromatic content of Fuel C than of certification gasoline. A second study compared three common fuel system materials on Fuel C and certification gasoline.[132] Fuel C is made up of 50 percent toluene and 50 percent isooctane. As a result, it is half aromatics and half aliphatics. In this study, the certification gasoline was observed to be 29 percent aromatics, 67 percent aliphatics, and 4 percent olefins. The test results were indicative of the effect of aromatics on permeation. Table 5.4-6 presents the permeation rate reported in g-mm/m^2/day for three sample materials: a low permeation fluoroelastomer (FKM), two medium permeation epichlorohydrins (ECO) and two high permeation nitrile rubbers (NBR). This testing, which was performed at 24˚C, gives a good comparison of the effect of gasoline versus Fuel C on permeation.

Table 5.4-6: Fuel C Versus Gasoline Permeation by Hose Material [g-mm/m^2/day]

Material	Fuel C	Indolene*	% difference
FKM-1	3.3	1.2	-64%
ECO-1	180	33	-82%
ECO-3	282	45	-84%
NBR-1	570	255	-55%
NBR-2	705	510	-28%

* "Indolene" refers to a fuel meeting the EPA specifications for certification gasoline

5.4.1.5 Vent Hose Permeation

Permeation occurs not only through hose walls that are in contact with liquid gasoline, but also through surfaces exposed to fuel vapor. In the event that the fuel vapor represents a saturated mix of air and fuel, we would expect permeation to be the same as that for exposure to liquid fuel. In a fuel tank, the walls of the tank are readily exposed to saturated vapor as discussed earlier in Section 5.3.1.4. In a fuel system hose not continuously exposed to liquid fuel, the vapor concentration may be significantly lower than saturation for several reasons. Clearly, if a hose is open to atmosphere, such as vent hose, there would be a gradient through the hose ranging from saturated vapor in the fuel tank to fresh air outside of the fuel system. In addition, if the tank is venting and drawing in air due to diurnal (or other) temperature changes, then the fuel hose will regularly be exposed to varying vapor concentrations.

To investigate permeation rates for vent hose exposed to gasoline vapor, we contracted with an outside laboratory to measure the permeation of fuel through marine hoses under various venting configurations.[133,134] The marine hose used in this testing met the USCG requirements for SD/I vessels in specified in 33 CFR part 183 and SAE Recommended Practice J1527. Each section of hose was connected to a metal fuel reservoir and exposed to liquid fuel for 8 weeks at 40°C to stabilize the permeation rate. The test fuel was EPA certification gasoline blended with 10 percent ethanol (E10) Each section of hose was then soaked for an additional 2 weeks at 40°C in the planned test configuration. After the soak, fresh fuel was added to the reservoirs and permeation was measured in a mini-SHED. Hose sections were tested at constant temperature in three configurations.

One section of hose was tested exposed to liquid fuel. Two sections of hose (1.5 and 5/8" I.D.) were tested with one end connected to the fuel reservoir and the other opened to atmosphere through a fitting in the SHED. This configuration was intended to simulate vent hose at constant temperature. A third configuration was also tested where three sections of hose were configured as vent hose and tested over a 22.2-35.6°C one day diurnal sequence. This test was intended to simulate vent hose in a fuel system exposed to fuel tank breathing caused by temperature variation. The data in this testing, shown in Table 5.4-7, suggest that permeation rates for vent lines are much lower than for hose that is regularly exposed to liquid fuel. This result is likely due to a fuel concentration gradient in the hose which is largely due to one end being exposed to fresh air.

Table 5.4-7: Effect of Venting on Hose Permeation with E10 [g/m^2/day]

I.D. inches	Length feet	Temperature	Liquid Exposure	Vented to Atmosphere
1.5	1	28°C (84°F) constant	123*	3.3
0.625	3		37	5.8
0.625	3	22-36°C (72-96°F) diurnal	–	4.3
0.625	3			4.5
0.625	3			4.9

* taken from Table 5.4-1 on a similar hose for comparison

The marine industry also funded permeation testing on vent hose exposed only to fuel vapor and air.[135] The vent line hose was preconditioned by attaching the hose to a 55 gallon steel drum containing commercial gasoline containing 10 percent ethanol and setting the drum outside during the summer. A carbon canister was attached to the end of the hose to simulate a vent line with diurnal emission control. Permeation was measured after 90, 120, 150, and 180 days of preconditioning. Because of the large size of the test rig, weight loss testing could not be performed. Instead, a sleeve was fitted over the hose and nitrogen was flowed through the sleeve to a carbon trap. The change in the weight of the carbon trap was then measured to determine the permeation rate. As with the fill neck testing, the hose was configured to run vertically from the top of the fuel reservoir (55 gallon drum). Repeat testing was performed on this hose and both values for each hose are presented in Table 5.4-8. The permeation rates for this testing were lower than for similar hose exposed to liquid fuel. Fuel vapor stratification may have been caused by a number of factors including breathing of fresh air into the tank during ambient cooling periods, gravity, and a limiting diffusion rate.

Table 5.4-8: Industry Test Data on Marine Vent Hose Exposed to Fuel Vapor

Hose manufacturer	Permeation [g/m^2/day]
#1	2.7, 2.2 2.7, 2.8 8.9, 8.5 5.7, 6.6
#2	2.2, 2.0 2.5, 2.2 2.5, 2.6

5.4.1.6 Vapor Hose Permeation

Even in a vapor hose that is sealed at one end, stratification may occur for a fuel system due to gravity. An example of vapor hose would be fuel fill neck hose with a sealed cap. Because fuel vapor is heavier than air, even a large diameter hose may see stratification of fuel vapor concentration if it reaches high enough above the surface of the liquid fuel. The stratification of vapor molecules happens slowly but would likely be observed under static conditions. Another cause of low vapor concentration in fuel system hose may occur due to the properties of diffusion discussed above in Section 5.1.3. If the hose diameter is small compared to its length, diffusion of vapor into the hose may be the rate limiting step rather than the permeation rate through the hose. In other words, the fuel vapor may enter the hose much slower than rate at which it could permeate through the hose. This effect could be combined with the other effects discussed above to cause lower permeation for fuel hose exposed to vapor rather than liquid fuel.

The marine industry funded permeation testing on fill neck exposed only to fuel vapor.[136] For the fill neck hose, a three foot section of hose was attached to the top of a five gallon metal fuel reservoir and configured vertically. The fuel reservoir was filled half-way with gasoline containing 10 percent ethanol. Approximately every 30 days, this hose/reservoir assembly was weighed for five days in a row. After the fifth day, the fuel in the reservoir was replaced with fresh fuel. Testing was performed at 23˚C. The only liquid fuel exposure was a weekly inversion of the assembly for about 1 minute. No attempt was made to simulate fuel slosh that would be likely be seen in a boat in the water. Also the hose was configured straight up and down rather than in a more representative configuration as seen on a boat that would include more horizontal orientation for most of the length of the hose. Repeat testing was performed on the hose.[137] During this repeat testing, permeation was also measured for the same fill neck hose exposed to liquid fuel.

Four of the fill neck hose constructions were specified as meeting the A2 designation in SAE J1527. The other two fill neck hose samples were not identified except that they are made by a hose manufacturer that is known to offer fill neck hose with and without a fluoroelastomer barrier. Table 5.4-9 presents the test results which show much lower permeation rates for fill neck hose exposed vapor rather than liquid fuel. Because the end of the hose was not exposed to atmosphere, and because the hose was situated well above the surface of the liquid fuel in a vertical fashion, stratification may have occurred in the hose largely due to gravity. This stratification would be expected to lower the vapor concentration in the hose and therefore lower permeation.

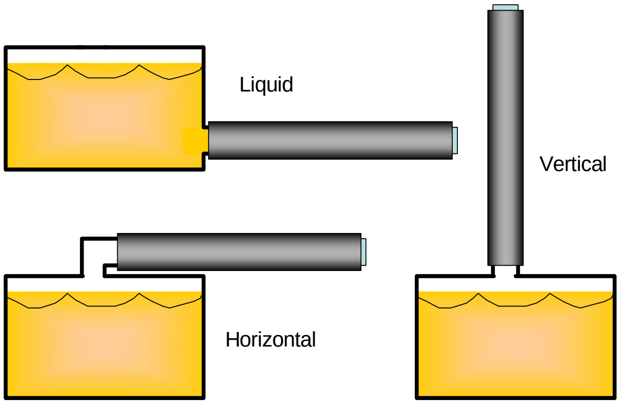
Table 5.4-9: Industry Permeation Data on Marine Fill Neck Hose [g/m^2/day]

Hose manufacturer	Vapor Exposure	Liquid Exposure
#1	4.8, 4.8 4.5, 4.4 4.7, 4.8 4.7, 4.7	129 114 113 121
#2	1.3, 1.1 0.6, 6.9	5.6 8.5

The marine industry testing was all performed on static test rigs with vertically oriented hose. No consideration was given to how sloshing the test configuration, as would be seen in a boat in the water, would have affected the results. For in-use equipment, especially boats in the water, the fuel is sloshed regularly due to operation or waves. This sloshing may mix up the vapor in the tank and hose. The industry test program also did not consider how a different hose configuration (i.e. more horizontally oriented) would have affected the results. Fill neck hose in boats often runs nearly horizontal from the tank to the edge of the boat, then runs more vertically near the fill port.

We contracted with an outside test lab to investigate the effects of fuel slosh and hose configuration on permeation through marine fill neck hose.[138] All of the testing was performed on 3 foot sections of 1.5" I.D. marine fill neck hose. Testing was performed in each of the three configurations shown in Figure 5.4-1. For each fuel vapor exposure test, the hose was first preconditioned by subjecting it to liquid fuel for 5 weeks followed by fuel vapor for an additional 5 weeks. For the liquid fuel exposure tests, the hose was soaked with liquid fuel for

Figure 5.4-1: Hose Test Configurations



10 weeks. Fuel soaking was performed at 40˚C.

A total of eleven tests were run. For each configuration, testing was performed on three fuels: Fuel C, CE10, and E10. The liquid fuel exposure tests were performed in the static position, while the fuel vapor exposure tests were performed with the fuel tanks on a slosh table. Sloshing was performed at 15 cycles per minute with a deviation of +7˚ to -7˚ from level to simulate movement that might be seen on a boat. An additional two tests were performed to measure permeation through vapor hose in the vertical and horizontal positions without sloshing. Permeation was measured similar to the industry testing using weight loss measurements of the entire test rigs at 23˚C.

The test results from this testing are presented in Table 5.4-10. It was observed that permeation was much lower for vapor fuel exposure than for liquid fuel exposure. Fuel permeation was significantly higher for the horizontal hose configuration than for the vertical hose configuration. This suggests that a large amount vapor stratification was occurring for the vertical hose, while some fuel vapor was collecting in the horizontal hose. The fuel sloshing applied in this testing doubled the permeation through the horizontal hose. Regardless of fuel slosh, no measurable permeation was observed through the vertically oriented hose. Permeation emissions were observed to be about twice as high on fuel CE10 than on Fuel C or E10.

Table 5.4-10: Effect of Hose Configuration, Vapor Exposure, and Test Fuel on Marine Fill Neck Hose Permeation at 23˚C

Hose Configuration	Vapor Exposure	Test Fuel	Permeation [g/m^2/day]
horizontal	stationary	CE10	4.6
	sloshed	CE10	9.1
	sloshed	E10	4.6
	sloshed	Fuel C	9.1
vertical	stationary	CE10	0.0
	sloshed	CE10	0.0
	sloshed	E10	0.0
	sloshed	Fuel C	0.0
liquid soak		CE10	273.7
		E10	123.2
		Fuel C	123.2

In another study, the effects of liquid fuel versus vapor were studied in which the vapor hose was not open to atmosphere.[139] The fuel hose used for this testing was purchased over the counter and was labeled as SAE J30 R7. Further investigation of the hose revealed that this particular grade is made of lower permeation materials than typical Small SI hose constructions. It was constructed of NBR with a relatively high ACN blend (39 percent) and an ECO cover was used. This construction was originally intended to allow the hose to be painted with a lacquer-based paint, then dried in an oven. Although this is a somewhat atypical hose construction, the test results should still reflect the effects of liquid versus vapor on permeation.

In this testing, all of the fuel hose was preconditioned by soaking in liquid fuel for 5 weeks at about 40˚C. This soak was then repeated, except that half of the hose sections were then exposed only to fuel vapor resulting from attaching the hose to the top of a metal fuel reservoir. Three fuels were used; California certification gasoline (CARB II), EPA certification gasoline (gasoline), and EPA gasoline blended with 10 percent ethanol (E10). After the soak period, the fuel was refreshed and weight loss testing was performed at 23˚C. Table 5.4-11 presents the test results. Note that each data point in this table is the average of three hose samples. In this testing, the end of the hose was plugged and the hose was configured horizontally. The lower permeation rates for vapor exposure were likely the result a low vapor concentration in the hose. This low vapor concentration may have been caused because the diffusion into the long narrow hose may have been the rate limiting effect rather than the permeation rate through the hose.

Table 5.4-11: Fuel Hose Permeation with Vapor vs. Liquid Exposure [g/m^2/day]

Test Fuel	Liquid Exposure	Vapor Exposure
CARB II	35.8	0.3
Gasoline	44.5	0.1
E10	80.3	0.7

5.4.2 Hose Permeation Reduction Technologies

Materials used in current automotive fuel lines are two to three orders of magnitude less permeable than nitrile hoses.[140] In automotive applications, multilayer plastic tubing, made of fluoropolymers is generally used. An added benefit of these low permeability lines is that some fluoropolymers can be made to conduct electricity and therefore can prevent the buildup of static charges.[141] Although this technology can achieve more than an order of magnitude lower permeation than barrier hoses, it is relatively inflexible and may need to be molded in specific shapes for each Small SI application. For marine applications, this tubing would not likely meet the Coast Guard or ABYC durability specifications for fuel and vent hose.

Thermoplastic fuel lines for automotive applications are generally built to SAE J2260 specifications.[142] Category 1 fuel lines under this specification have permeation rates of less than 25 g/m^2/day at 60°C on CM15 fuel (15 percent methanol). One thermoplastic used in automotive fuel line construction is polyvinylidene fluoride (PVDF). Based on the data presented in Appendix 5D, a PDVF fuel line with a typical wall thickness (1 mm) would have a permeation rate of 0.2 g/m^2/day at 23°C on CM15 fuel. However, manufacturers involved in the boat building industry have commented that this fuel line would not be flexible enough to use in their applications because they require flexible rubber hose to fit tight radii and to resist vibration. They also commented that the hose they use must pass the Coast Guard flame resistance requirements.[143,144]

Recreational vehicle manufacturers are required to use hose that meets a permeation standard of 15 g/m^2/day at 23°C on gasoline blended with 10 percent ethanol (E10). Low permeation hose constructions that have been identified for these applications could also be used in Small SI equipment. We believe that the same barrier materials that will be used for recreational vehicle hose can also be used for marine hose constructions. Marine hose constructions generally meet the Coast Guard flame resistance requirements either through the use of a flame-resistant cover, or by increasing the wall thickness. Therefore, the addition of an inner permeation barrier would not be expected to affect the flame resistance of the hose. Several low permeation hose constructions are discussed below. Even though most of this data is on hoses not designed for marine applications, the barrier technology can be used in marine hose.

We are proposing that fuel and vapor hose meet our standards on E10 fuel for two reasons. First, ethanol is commonly a component of in-use fuels. Second, for many materials used in hose constructions, permeation would likely be much higher for fuel containing ethanol. For instance, a typical barrier material used in barrier hose constructions is FKM. Based on the data presented in Appendix 5D for FKM, the permeation rate is 3-5 times higher on Fuel CE10 than Fuel C. Therefore, a hose meeting 15 g/m^2/day at 23°C on Fuel C may actually permeate at a level of 40-50 g/m^2/day on fuel with a 10 percent ethanol blend.

There are lower permeation fuel hoses available today that are manufactured for automotive applications. These hoses are generally used either as vapor hoses or as short sections of fuel line to provide flexibility and absorb vibration. One example of such a hose[145] is labeled by General Motors as “construction 6" which is a multilayer hose with an inner layer of a fluoroplastic known as THV sandwiched in inner and outer layers of a rubber known as ECO.[5] A hose of this construction would have less than 8 g/m^2/day at 40°C when tested on CE10.

Permeation data on several low permeation hose designs were provided to EPA by an automotive fuel hose manufacturer.[146] This hose, which is as flexible as non-barrier hose, was designed for automotive applications and is available today. Table 5.4-12 presents permeation data on three hose designs that use THV 800 as the barrier layer. The difference in the three designs is the material used on the inner layer of the hose. This material does not significantly affect permeation emissions through the hose but can affect leakage at the plug during testing (or connector in use) and fuel that passes out of the end of the hose which is known as wicking. The permeation testing was performed using the ARB 18-41°C diurnal cycle using a fuel with a 10 percent ethanol blend (E10).

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[5] THV = tetrafluoroethylene hexafluoropropylene, ECO = epichlorohydrin/ethylene oxide

Table 5.4-12: Hose Permeation Rates with THV 800 Barrier over ARB Cycle (g/m^2/day)

Hose Name	Inner Layer	Permeation	Wicking	Leaking	Total
CADBAR 9610	THV	0.16	0.00	0.02	0.18
CADBAR 9710	NBR	0.17	0.29	0.01	0.47
CADBAR 9510	FKM	0.16	0.01	0.00	0.18

The data presented above shows that there is hose available that can easily meet the proposed hose permeation standard on E10 fuel. Although hose using THV 800 is available, it is produced for automobiles that will need to meet the tighter evaporative emission requirements in the upcoming Tier 2 standards. Hose produced in mass quantities today uses THV 500. This hose is less expensive and could be used to meet the proposed hose permeation requirements. Table 5.4-13 presents information comparing hose using THV 500 with the hose described above using THV 800 as a barrier layer.[147] In addition, this data shows that permeation rates more than double when tested on CE10 versus Fuel C.

Table 5.4-13: Comparison of Hose Permeation Rates with THV 500 and 800 (g/m^2/day)*

Hose Inner Diameter, mm	THV 500		THV 800	
	Fuel C	Fuel CE10	Fuel C	Fuel CE10
6	0.5	1.4	0.2	0.5
8	0.5	1.4	0.3	0.5
10	0.5	1.5	0.2	0.5

* Calculated using data from Thwing Albert materials testing (may overstate permeation)

We contracted with an independent testing laboratory to test several samples of SAE J30 R9 hose and a sample each of automotive vent line and fill neck hose for permeation.[148,149,150,151,152,153] The fuel and vapor hoses had a six mm inner diameter. The test lab used the SAE J30 test procedures for R9 hose with both Fuel C and Fuel CE10. Most of the R9 fuel hose was supplied by recreational vehicle manufacturers who also supplied information on the materials used in the construction of the hose as well. We purchased one sample of the R9 hose (which was labeled as such) from a local auto parts store without knowing its construction. Two additional R9 hoses were tested by a fuel hose manufacturer on fuel CE10 after a four week soak.[154] The SAE permeation specification for R9 hose is 15 g/m^2/day at 23˚C on Fuel C. The R9 hose tested all met this limit, even on ethanol blend fuels which typically result in higher permeation. The automotive vent line showed similar results, but the automotive fill neck showed much lower permeation. Table 5.4-14 presents the test data on the above hose samples.

Table 5.4-14: Test Results on Commercially Available Hose Samples (g/m^2/day)

Hose Sample	Construction	Fuel C	Fuel CE10
SAE J30 R9	FKM/ECO	–	7.6
SAE J30 R9	FKM/ECO	–	2.1
SAE J30 R9	FKM/NBR/CM	–	4.2
SAE J30 R9	FKM/ECO	–	10.9
SAE J30 R9	FKM/ECO	–	5.2
SAE J30 R9	PVC/EEC	–	11.6
SAE J30 R9	FKM barrier	–	6.6
SAE J30 R9	fluorine/hydrin	–	9.0
SAE J30 R9	unknown	10.1	12.1
SAE J30 R9	FKM barrier	–	4.2
SAE J30 R9	FKM barrier	–	6.7
Automotive vent line	unknown	10.9	9.0
Automotive fill neck	unknown	0.33	0.49

Another hose construction that can be used to meet the marine hose permeation standards is known as F200 which uses Teflon® as a barrier layer. Teflon® has a permeation rate of 0.03-0.05 g-mm/m^2/day on 15 percent methanol fuel. F200 hose is used today to meet SAE J30 R11 and R12 requirements for automotive applications. Table 5.4-15 presents data on permeation rates for several F200 constructions.[155]

Table 5.4-15: F200 Typical Fuel Permeation

Film Thickness [mils]	Hose Diameter [in.]	Fuel	g/m^2/day @23°C	g/m^2/day @40°C
2	0.375	TF-2	--	0.7
2	0.275	TF-2	--	1
2	0.275	M25	0.5	4
2	0.470	CE10	--	3
2	0.625	CE10	--	3
1	0.625	CE10	--	4
1	1.5	CE10	1.5	--

Low permeability hoses produced today are generally constructed with a barrier material layer. There are hoses used in some marine applications with a thermoplastic layer (either nylon or EVOH) between two rubber layers to control permeation. Because the thermoplastic layer is very thin, on the order of 0.1 to 0.2 mm, the rubber hose retains its flexibility. Through contract with two independent labs, we tested three samples of marine barrier hose that was available prior to our initial proposal for marine permeation emissions. This hose included two 3/8" samples and one 5/8" sample which all used nylon as the permeation barrier. These hose constructions are used in some sterndrive and inboard applications. Table 5.4-16 presents the permeation test results at 23°C.[156,157,158,159,160,161]

Table 5.4-16: Test Results on Available Barrier Marine Hose Samples (g/m^2/day)

Hose Description	Lab 1		Lab 2*
	Fuel C	Fuel CE10	Fuel C
3/8" marine barrier fuel hose	0.80 --	5.2 11.6	0.36 --
5/8" marine barrier fuel hose	--	3.4	0.76

* average of three tests

Similar testing was performed by the marine industry on commercially available low permeation marine hose.[162] In this testing, the 3/8" I.D. fuel hose samples were connected to metal fuel reservoirs and soaked with gasoline containing 10 percent ethanol at 23˚C for 180 days. The weight of the container/hose assembly was measured for five days in a row approximately every 30 days. The fuel was replaced with fresh fuel after each series of weight measurements. The test report did not specify details on the hose constructions. However, based on the manufacturer part numbers, several of the hoses in this test program were determined to use a nylon barrier layer. One of the hoses included was a baseline rubber construction meeting Coast Guard requirements for SD/I fuel hose. Repeat testing was performed on the hose.[163] During this repeat testing, permeation was also measured for the same hose exposed to fuel CE10. Although the permeation rate was generally higher on fuel CE10, the barrier hose permeation rates were still well below the proposed standard. Table 5.4-17 presents the results of this testing.

Table 5.4-17: Permeation Results for Commercially Available Marine Barrier Hose Tested at 23˚C with Gasoline Containing 10% Ethanol (g/m^2/day)

Hose Construction	Gasoline with 10% Ethanol	CE10
SAE J1527 A1 constructions with nylon barrier	6.2, 5.2 5.6, 5.1 4.4, 3.8 4.4, 3.2	6.1 6.7 10.0 12.1
not reported	0.4, 0.1	0.0

After the initial proposal for marine permeation emissions, two marine hose manufacturers developed hose samples using the F200 hose construction. In addition, other hose manufacturers supplied samples of barrier hose using the F200 hose construction and using THV800 as a barrier layer. These manufacturers stated that they could make marine hose using the same barrier construction. We contracted to have these hose samples permeation tested on fuel CE10 at 23°C following a four week soak.[164] These test results are presented in Table 5.4-18.

Table 5.4-18: Permeation Test Results on New Marine Barrier Hose Constructions

Application	Barrier Material	I.D. [inches]	$g/m^2/day$
marine fill neck	Teflon (F200)	1½	0.2
marine fuel hose	Teflon (F200)	3/8	5.0
fuel hose	Teflon (F200)	1/4	3.8
fuel hose	THV 800	1/4	5.1

Currently, the Coast Guard requires that fuel pumps on engines be located on or near the engine to minimize the length of high pressure fuel lines on the vessel. However, at least one manufacturer sells boats with the high pressure fuel pump in the fuel tank. They received a waiver from the Coast Guard by using fuel lines that use either a glass fiber or stainless steel braid cover and quick connect end fittings that are designed to withstand very high pressures (much higher than would be seen on a boat).[165] This particular fuel line construction also uses Teflon® as a barrier layer. Table 5.4-19 presents permeation test data on this hose.[166]

Table 5.4-19: Permeation Test Data on Reinforced Fuel Hose

Application	I.D. [inches]	Temperature	Fuel	$g/m^2/day$
Marine	0.31 0.25 0.19	23°C	CE10	0.05 0.08 0.05
Outdoor Power Equipment	0.31 0.25 0.19	60°C	CM15	0.52 0.93 1.08

Primer bulbs are typically injection-molded out of nitrile rubber. Fuel lines for some handheld equipment are manufactured in a similar manner. Low permeation primer bulbs and fuel lines could be manufactured using a similar process by molding them from a fluoroelastomer such as FKM. Fluoroelastomers, such as FKM, have similar physical properties as nitrile rubber but are much more fuel-resistant. If the primer bulb or fuel line were molded out of a FKM with a sufficient flurorine concentration, the permeation rate would be less than proposed fuel line permeation standard. Alternatively, primer bulbs could be manufactured to meet the proposed standards by molding a fluoroelastomer inner liner with a nitrile shell to reduce costs. Other materials may be applicable as well (see tables of material properties in Appendix 5D).

Under their rule for small offroad equipment, California may issue executive orders to manufacturers with low emission products. As of August, 2006, ARB has issued 24 executive orders for low permeation fuel lines.[167] The California fuel line permeation standard is 15 $g/m^2/day$ tested at 40˚C on California certification fuel. However, many of the manufacturers tested their products on CE10 fuel which results in significantly higher permeation rates. Some manufacturers even tested at 60˚C. In all cases, the test results were below the 15 $g/m^2/day$ standard, even under the more challenging test conditions. Table 5.4-20 presents the test results for the fuel lines with ARB executive orders. Note that the reported emissions are the average of 5-6 test samples.

Table 5.4-20: ARB Fuel Hose Executive Orders for Small Offroad Equipment

EO#	I.D. [mm]	Test Fuel	Temperature	$g/m^2/day$
C-U-06-016	4.8	CE10	40	3.75
C-U-06-001	6.0	CE10	40	1.42
G-05-016	6.4	CE10	40	4.62
G-05-017	6.4	CE10	40	5.97
G-05-019	6.4	CE10	40	0.02
C-U-05-004	6.4	CE10	40	12.3
C-U-05-010	6.4	CE10	40	10.6
G-05-019*	6.4	CE10	60	0.26
G-05-015a	7.9	CE10	60	11.1
C-U-05-001	8.0	CE10	60	8.22
C-U-06-001*	6.0	CM15	40	3.77
C-U-06-001*	6.0	Fuel C	40	0.78
C-U-06-020	4.5	Indolene	40	3.20
C-U-05-014	6.4	Indolene	40	8.20
C-U-06-021	6.4	Indolene	40	7.40
C-U-06-002	6.4	Indolene	40	5.00
C-U-06-011	6.4	Indolene	40	12.7
C-U-05-011	2.0	Phase II	40	4.63
C-U-06-017	3.5	Phase II	40	10.8
C-U-05-013	4.0	Phase II	40	1.22
C-U-05-006	4.0	Phase II	40	10.3
C-U-05-012	4.0	Phase II	40	7.33
C-U-05-003	4.5	Phase II	40	12.3
G-05-018	4.8	Phase II	40	0.87
C-U-05-009	4.8	Phase II	40	3.94
C-U-06-010	4.8	Phase II	40	4.69
C-U-05-002	6.4	Phase II	40	3.76

* fuel tube

5.4.3 Low Temperature Hose Materials

In some applications, molded fuel hoses are used rather than simple extruded fuel hose. These fuel hoses are typically molded out of nitrile rubber (NBR) or a fluoroelastomer such as FKM. FKM is essentially rubber impregnated with fluorine which results in good fuel permeation resistance. Manufacturers of handheld equipment that may be used in very cold weather have stated that they must use nitrile rubber because the FKM material may become brittle at very low temperatures.[168] Examples of such equipment are ice augers and chainsaws.

Industry has not raised an issue with the capability of using extruded multi-layer hose in cold temperature applications. This type of hose construction has been demonstrated for low temperature use in automobiles and snowmobiles. Extruded fuel hose meeting SAE and ASTM standards is available today which meets a widespread set of safety and durability requirements. Industry has stated that for some applications, such as chainsaws, that extruded fuel hose will not work. In these applications, injection molding is used to manufacture complex fuel hose geometries designed to account for high vibration of the equipment. This vibration generally results in different motion patterns for the carburetor and fuel tank resulting in variable distances between the two.

Industry presented information on FKM fuel lines that became brittle and cracked at very low temperatures.[169,170] However, this information was was based on an FKM compound without a low temperature additive package. There are a wide range of FKM products available on the market. Many of these fluoroelastomers are designed for use at low temperatures.[171,172] For instance, low temperature o-rings are common in automotive applications.[173,174,175] Low temperature grade FKM products are available with a glass transition temperature as low as -40˚C and a brittleness point as low as -60˚C.[176] However, low temperature grade FKM products typically cost several times as much as FKM products intended for less severe temperatures. In addition, these materials have not been demonstrated for use in molded fuel lines for handheld applications.

A lower cost option may be to blend a standard fluorosilicone such as FVMQ with a standard grade FKM. The fluorosilicone brings very low temperature characteristics to the blend. However, the permeation resistance is not nearly as good as for FKM products. The blended product would be intended to create a balance between cost, permeation, and low temperature properties.[177] This product is currently used in automotive o-rings. However, it is not clear if this material could be molded into fuel lines that would meet the appropriate design criteria for handheld applications.

A new material, called F-TPV, has been developed that is a dynamically vulcanized combination of fluorothermoplastic resin and fluoroelastomer compound.[178] The mix of the two materials can be varied to trade-off permeation resistance with material hardness. This material has been shown to have a permeation rate ranging from 3 to 30 g-mm/m^2/day on fuel CE10 at 60˚C. Rubber hose molded out of even the softest version of this material would be expected to be capable of achieving a permeation rate well below the proposed standard. In addition, the impact brittleness temperature is below -50˚C for the full range of material blends discussed above. Finally, the cost of this material is much lower than for low-temperature FKM products. Further development efforts would be necessary to determine the suitability of this material for fuel lines on handheld equipment.

Table 5.4-4, above, presents permeation data on several samples of NBR fuel lines used on handheld equipment today. The permeation rates from these fuel lines range from 165 to 455 g/m^2/day with E10 fuel at 23˚C. Later discussions with industry revealed that the NBR hose with the lower permeation rates had higher acrylonitrile (ACN) contents. Although high ACN rubber cannot achieve the same low permeation rates as FKM or F-TPV, some permeation reductions could still be achieved with this material.

5.5 Other Evaporative Emissions

5.5.1 Other Venting Losses

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

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

In automotive applications, the carbon canister is sized not only to capture diurnal emissions, but refueling, hot soak, and running loss emissions as well. With an engine purge, the canister would effectively capture running loss emissions and hot soak emissions because the canister would presumably be nearly empty after a short period of operation. For the canister to be effective at collecting refueling emissions, it would need to be purged before the refueling event. However, even without a purged canister, refueling emissions could be minimized by matching the geometry of the fuel fill opening to the fuel pump nozzle. By minimizing the open space in the fuel fill opening around the nozzle, less air will be entrained which will minimize vapor generation during the refueling event. This will not help control the expulsion of vapor that is displaced by liquid fuel.

5.5.2 Refueling Spitback/Spillage

Installed fuel systems on boats are typically open vented. The exception to this is PWC which have sealed fuel tanks with pressure relief valves, largely to prevent spillage of fuel during operation. For larger boats, fuel spillage during operation is less of an issue; however, it is common for fuel to be lost to the environment during refueling or shortly thereafter.[179,180] There are several mechanisms that lead to fuel loss due to a refueling event. These mechanisms include restrictions in the fill neck, fuel flowing out the vent line, and expansion of fuel in the tank.

The American Boat and Yacht Council (ABYC) has a voluntary refueling standard designed to help prevent fuel from backing up the fill neck during a refueling event.[181] This test requires that no fuel back up the fill neck when a fuel tank in a boat is filled from 25 to 75 percent full at a fill rate of 9 gallons per minute. This test is apparently designed to make sure that the fill neck does not have a restriction that may cause fuel to back up the fill neck during refueling. To prevent fill from backing up the fill neck, fill necks are typically made of large diameter hose which is reinforced to prevent kinking. In addition, the fuel fill opening is typically positioned higher than the vent line. This test does not consider fuel overflow that may occur from filling a marine tank to 100 percent full. In addition, the full rate may be too low to require a design that would work in typical in-use situations. One survey on 19 marinas saw a range of 8 to 25 gallons per minute for gasoline fill nozzles with an average of 14 gallons per minute.[182]

The most common refueling spillage today is overflow out the vent line. Typically the vent line is the path of least resistance for fuel overflow. Boats typically do not have a mechanism that prevents fuel tanks from filling all the way to the top. In fact, the fill and vent hose are attached to the top of the fuel tank and are often filled with fuel in addition to the tank. Because the vent hose exits the boat lower than the fill neck opening, the tank can be filled until fuel begins to exit through the vent hose. In addition, fuel may expand in the fuel tank when cool fuel is pumped into the fuel tank on a warm day. This expansion can cause additional fuel overflow out the vent line.

A number of devices have been produced to help control fuel spillage during refueling. These devices include liquid/vapor separators, combination deck fills and vents, and fuel flow monitoring systems. A study was performed by Boat US Foundation to evaluate the effectiveness of several of these systems which are currently available on the market.[183] The results of this study are discussed below.

Liquid/vapor separators are valves that are installed in the fuel line. The typical design is for the valve to contain a ball that rises when liquid fuel reaches it which closes the vent to liquid fuel. As the tank fills, fuel backs up the fill neck, allowing the automatic shut-off on the nozzle to stop the fuel flow. The study found that these systems typically worked best at lower fuel fill rates and that the larger units were more effective. The effectiveness of the larger units was probably because they essentially included a reservoir, allowing extra room for fuel expansion. For the smaller units, the testing consistently showed fuel backing up the fill neck too quickly for the automatic shut-off valve to engage and fuel spit back out of the deck fill.

In a vented deck fill design, the vent line is routed back to the top of the fill neck. The intent is that the fuel surging out of the vent line would return to the fill neck and back to the tank. The study found that the combination vented deck fills significantly reduced spitback/spillage, but still needed to be used with some caution. One issue was that even when the fuel came back up and shut off the nozzle, pressure in the fuel tank would cause fuel to continue to rise in the line and spill onto the deck. Another manufacturer has a similar device except that a clear section of tubing that redirects the fuel overflow from the vent line to the fill neck. The operator only attaches this tubing during refueling. Because the tubing is clear, the operator can see when the fuel is coming out of the vent and can manually slow down or stop the fuel flow.

Fuel flow monitoring systems are designed to keep track of fuel usage by measuring fuel flowing to the engine. The study did not present definitive results for the use of flow meters to accurately refuel the tank without overfill.

Where a carbon canister is used in the vent line for diurnal vapor control, it would be important to include a device to prevent liquid fuel from entering the canister. This device could take the form of a floating ball valve, limited flow orifice, or other liquid/vapor separation mechanism. In addition, this device could be positioned in such a way as to prevent the tank from filling all the way to the top. For instance, the vent fitting could reach down into the fuel tank. Leaving a vapor space in the fuel tank would give room for fuel in the tank to expand.

In automotive applications, carbon canisters have been used for many years in vehicles that also meet fuel spit-back standards set by EPA. In typical automotive fuel systems, the fuel shut-off on the nozzle is tripped before the fuel comes back out the fill neck. It is common to have a narrow tube parallel to the fill neck reach into the fuel tank at the desired peak fill level of the tank. The narrow tube connects to the fill neck near the top where the small hole on the nozzle would be. When fuel splashes on this small hole, the vacuum draw is broken and the shut-off device is triggered. Fuel travels up the narrow tube more quickly than up the fill neck and triggers the nozzle shut-off well before fuel spit-back can occur.

At least one company is developing a similar design for use in boats. Testing has been performed on one system by an independent laboratory that also performs ABYC and Coast Guard tests for the marine industry. During the testing, a fuel tank was filled 30,000 times, using this fuel system configuration, without any spillage.[184] Also, this fuel system configuration creates a vapor space in the top of the tank which allows fuel to expand during heating, thereby preventing fuel spillage due to expansion of the fuel in the tank.[185] This system has since been modified to be adaptable to any fuel tank with a fuel sending unit based on the standard SAE 5-hole pattern. The updated system was tested using a similar methodology as in the Boat US study discussed above and underwent 25,000 refueling events at 15 gallons per minute without experiencing any spills.[186] Pictures and video of this system are included in the docket.

5.6 Evaporative Emission Test Procedures

This section discusses test procedures for measuring fuel line permeation, fuel tank permeation, and diurnal emissions.

5.6.1 Hose Permeation Testing

We propose for hose permeation to be measured at a temperature of 23 ± 2°C using the weight loss method specified in SAE J30.[187] In this method, one end of a specified length of hose is connected to a metal reservoir while the other end is plugged. Test fuel is then added to the reservoir at a volume high enough to ensure that the hose is filled with fuel. Once any air bubbles have been removed from the hose, the reservoir is sealed and the entire system is weighed. Permeation is determined by weighing the system every 24 hours and noting the weight loss. After each weighing, the fuel is mixed by inverting the assembly, then returning it to its original position.

We are proposing two modifications to SAE J30 that are consistent with our current requirements for recreational vehicles and highway motorcycles. First, the test fuel must be ASTM Fuel C[188] (50 percent toluene, 50 percent iso-octane) blended with 10 percent ethanol. This fuel is known as CE10 and is commonly used in industry standards and test procedures such as in SAE recommended practices. Section 5.4, and Appendix 5D presents permeation data for several hose constructions and materials used in hose constructions on fuels with and without ethanol. As shown in this data, adding ethanol to the test fuel significantly increases permeation. Standard recommended practice for hose testing uses Fuel C, or some blend of Fuel C and either ethanol or methanol. This test fuel is generally more aggressive than standard gasoline. Although hoses are not generally exposed to Fuel C in use, the level of the standard was based on testing using Fuel C and Fuel C blends. In addition, most of the test data on low permeation hose presented in this Chapter is based on fuel CE10. For these reasons, we believe that it is appropriate to allow Fuel CE10 for hose testing.

The second modification is that the hose must be preconditioned by filling the hose with fuel and soaking long enough to ensure that the permeation rate has stabilized. We are proposing a soak period of 4 weeks at 23 ± 5°C. If a longer time period is necessary to achieve a stabilized permeation rate for a given hose design, we would expect the manufacturer to use a longer soak period (and/or higher temperature) consistent with good engineering judgement. For instance, thick-walled marine fuel hose may take longer to reach a stable permeation rate than thinner-walled hose used in Small SI applications.

Alternatively, for purposes of submission of data at certification, permeation could be measured using alternative equipment and procedures that provide equivalent results. To use these alternative methods, manufacturers would have to apply to us and demonstrate equivalence. Examples of alternative approaches that we anticipate manufacturers may use are the recirculation technique described in SAE J1737,[189] enclosure-type testing such as in 40 CFR part 86, or weight loss testing such as described in SAE J1527.[190]

Coast Guard standards for marine fuel hoses (33 CFR part 183) cite SAE recommended practice J1527[191] which, among other things, includes test procedures for measuring permeation from marine fuel hoses. In this test procedure, a short section of hose is attached to a nonpermeable container (i.e. metal fuel can) and plugged. Fuel is added to the container and the mass of the entire unit is measured every 24 hours for 15 days and the peak fuel loss is determined. This testing is performed at 23 ± 2°C on both reference fuel “C” for the version of the SAE standard referenced in 33 CFR part 183. However, SAE J1527 was revised in 1993 to include permeation standards for hoses tested on a fuel blend with 15 percent methanol. This test procedure is simple; however, it is sufficient for marine hoses because they have high permeation rates ranging from 100 to 600 $g/m^2/day$ depending on the hose class and the fuel used.

Recommended practice for automotive fuel tubing is defined in SAE J2260.[192] The permeation requirements in this standard are one to two orders of magnitude lower than those defined for marine hoses. These permeation requirements are based on the same fuels as the revised SAE J 1527, but at a much higher temperature (60°C). At 60°C, permeation rates for a given material may be 16 times as high or higher than at 23°C based on the rule of thumb that permeation doubles for every 10°C increase in temperature. SAE J2260 refers to the permeation test procedures in SAE J1737.[193]

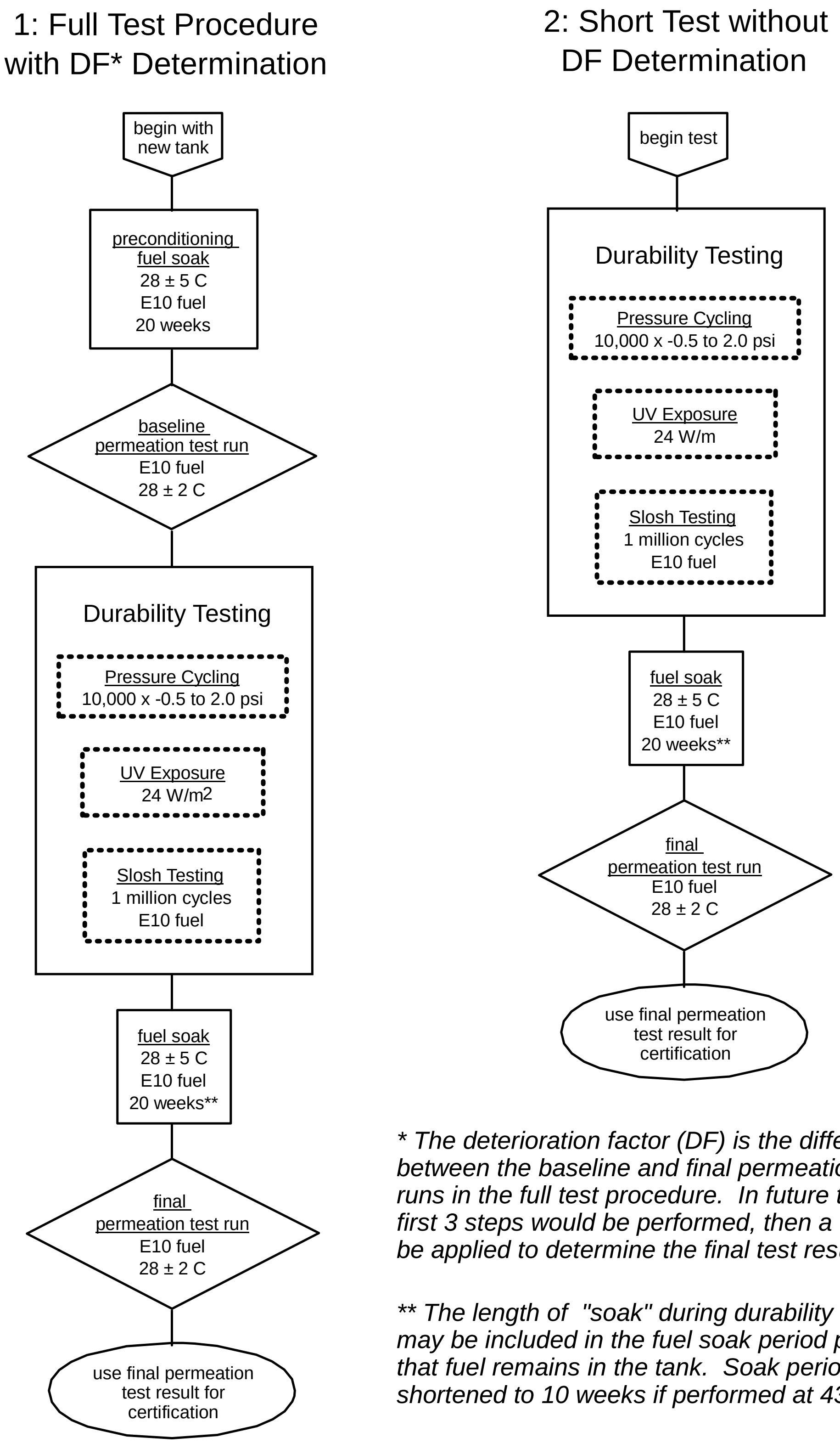
The procedures in SAE J1737 were designed to measure the low permeation rates needed in automotive applications to meet EPA evaporative emission requirements. There was concern that the weight loss measurement, such as used in SAE J1527, was not sensitive enough to measure these low permeation rates.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

Some manufacturers of low permeability product are finding that as their emission rates decrease, they need more refined test procedures to accurately measure permeation. These manufacturers are finding that the weight of the charcoal canisters are much higher than the permeate being measured. As an alternative to the gravimetric approach used in the above two procedures, even very low permeation emissions can be measured by a flame ionization detector and a SHED. As discussed earlier, SHED testing is generally used to measure evaporative emissions from whole automobile systems as well.

5.6.2 Fuel Tank Permeation Testing

We are proposing to apply a similar fuel tank permeation test procedures to Small SI equipment and Marine SI vessels as we currently use for recreational vehicles. This testing includes preconditioning, durability testing, and permeation measurement. The proposed differences in the test procedure compared to recreational vehicles are minor and are intended to simplify the testing. For instance, the durability testing would be performed during the preconditioning soak period prior to the weight loss testing rather than testing the tank twice; once before durability testing, and once after. Figure 5.6-2 provides flow charts for this testing compared to the recreational vehicle test which includes the calculation of a deterioration factor.

Figure 5.6-2: Flow Chart of Fuel Tank Permeation Test with and without a Deterioration Factor (DF) Determination



1: Full Test Procedure with DF* Determination

2: Short Test without DF Determination

** The deterioration factor (DF) is the difference between the baseline and final permeation test runs in the full test procedure. In future tests, the first 3 steps would be performed, then a DF could be applied to determine the final test result.*

*** The length of "soak" during durability testing may be included in the fuel soak period provided that fuel remains in the tank. Soak periods can be shortened to 10 weeks if performed at 43* ± 5 C

For the purpose of this testing, “fuel tank” includes the fuel cap and other components directly mounted to the tank that become part of the barrier for the fuel and vapor. During testing, fittings and openings in the fuel tank intended for hose connections (or petcock) would be sealed with an impermeable plug. An opening containing a fuel petcock could also be plugged with an impermeable fitting because this is an opening to the fuel hose which will be required to meet permeation standards. In many installed marine fuel tanks, the fuel cap is not directly mounted on the fuel tank. Instead, the fuel cap is usually linked to the fuel tank by a fill neck hose. In this case, the fill neck opening in the fuel tank may be sealed with an impermeable plug during permeation testing.

5.6.2.1 Durability Testing

Prior to the weight loss test, the fuel tank must be preconditioned to ensure that the hydrocarbon permeation rate has stabilized. Under this step, the fuel tank must be filled with a 10 percent ethanol blend (E10), sealed, and soaked for 20 weeks at a temperature of 28 °C ± 5 °C. Once the permeation rate has stabilized, the fuel tank is drained and refilled with E10, sealed, and tested for a baseline permeation rate. The permeation rate from the fuel tank is determined by measuring the weight difference the fuel tank before and after soaking at a temperature of 28 °C ± 2 °C over a period of at least 20 weeks. The soak periods could be shortened to 10 weeks if performed at 43 °C ± 5 °C. The durability testing described below may be performed during the soak period. During the slosh testing, a lower tank fill level, consistent with the proposed slosh test, would be acceptable.

To determine a permeation emission deterioration factor, we are proposing three durability tests: slosh testing, pressure-vacuum cycling, and ultra-violet (UV) light exposure. The purpose of these deterioration tests is to help ensure that the technology is durable and the measured emissions are representative of in-use permeation rates. For slosh testing, the fuel tank is filled to 40 percent capacity with E10 fuel and rocked for 1 million cycles. The pressure-vacuum testing contains 10,000 cycles from -0.5 to 2.0 psi. The slosh testing is designed to assess treatment durability as discussed above. These tests are designed to assess surface microcracking concerns. These two durability tests are based on a draft recommended SAE practice.[194] The third durability test is intended to assess potential impacts of UV sunlight (0.2 µm - 0.4 µm) on the durability of the surface treatment. In this test, the tank must be exposed to a UV light of at least 0.40 W-hr/m^2 /min on the tank surface for 15 hours per day for 30 days. Alternatively, it can be exposed to direct natural sunlight for an equivalent period of time in exposure hours.

The order of the durability tests is optional. However, we require that the fuel tank be soaked to ensure that the permeation rate is stabilized just prior to the weight loss test. If the slosh test is run last, the length of the slosh test may be considered as part of this soak period. Where possible, the deterioration tests may be run concurrently. For example, the fuel tank could be exposed to UV light during the slosh test. In addition, if a durability test can clearly be shown to not be appropriate for a given product, manufacturers may petition to have this test waived. For example, a fuel tank that is only used in vehicles where an outer shell prevents the tank from being exposed to sunlight may not benefit from UV testing.

After the durability testing, once the permeation rate has stabilized, the fuel tank is drained and refilled with fresh fuel, sealed, and tested for a final permeation rate. The final permeation rate from the fuel tank is determined using the same measurement method as for the baseline permeation rate. The final permeation rate would be used for the emission rate from this fuel tank. The difference between the baseline and final permeation rates could be used to determine a deterioration factor for use on subsequent testing of similar fuel tanks.

5.6.2.2 Test Fuel

As discussed in Chapter 3, about 30 percent of fuel sold in the U.S. contains ethanol and this percentage is expected to increase to about 45-50 percent in 2012 and later. We are proposing the use of E10, which is a blend of 90 percent certification gasoline (as specified in 40 CFR 1065.210) blended with 10 percent ethanol for permeation testing of fuel tanks. As an alternative, we are proposing that ASTM Fuel C blended with 10 percent ethanol (Fuel CE10) may be used. Fuel CE10 is commonly used in industry standards and test procedures such as in SAE recommended practices.

5.6.2.2.1 Effect of ethanol on fuel tank permeation

Most plastic nonroad fuel tanks today are made out of high-density polyethylene (HDPE) or cross-link polyethylene (XLPE). For Small SI and Marine SI markets, plastic is much more widely used than metal for fuel tank constructions. For HDPE, E10 fuel has little effect on permeation emissions and may even result in slightly lower emissions according to one study.[195] We tested three 0.5 gallon Small SI fuel tanks for permeation using both certification gasoline and E10 and found a slight increase in permeation due to ethanol. ARB also tested several Small SI fuel tanks on both gasoline and ethanol blends [196,197,198,199] and saw a small increase in permeation. Permeation data was collected on two XLPE marine fuel tanks on E10. The measured permeation rates were within the range of data from other XLPE marine fuel tanks tested on gasoline presented earlier in Table 5.3-1. This data is presented in Table 5.6-1.

Table 5.6-1: Effect of Ethanol on Permeation for HDPE Fuel Tanks

Material	Test Equipment	Tank gallons	Test Temp(s)	gasoline [g/m^2/day]	E10 [g/m^2/day]	Increase in Permeation
HDPE	material sample	NA	40˚C	90*	69*	-23%
HDPE	Small SI fuel tanks (EPA Testing)	0.5 0.5 0.5	29˚C	11.5 11.4 11.2	13.9 13.7 14.4	21% 21% 28%
HDPE	Small SI fuel tanks (ARB Testing)	0.25 0.25 0.25 0.25 0.25 0.5 3.9	18-41˚C	11.6 10.7 12.5 9.9 9.2 12.7 4.8	13.6 11.6 11.4 10.3 10.3 14.8 5.0	18% 7% -9% 4% 12% 17% 4%
XLPE	marine tanks (EPA testing)	12 12	29˚C	**	7.5 8.5	minimal

*ASTM Fuel C was used as gasoline (50% toluene, 50% isooctane). Units are per mm of thickness

** See Table 5.3-1 for data on similar tanks tested on gasoline.

Although E10 does not have a large effect on permeation through polyethylene, it does have a large effect on most other materials used in fuel systems, especially those designed for low permeation. This is supported by the data presented in Appendix 5D of permeation rates for several fuel system materials on fuel C, CE10, and C15. In addition, ethanol is commonly blended into fuels in-use and alcohol fuels may be used more in the future in an effort to use alternative energy sources. Therefore, we are proposing E10 as a test fuel to ensure that the proposed permeation standard will be met on in-use fuels.

A recent study found that permeation from automotive fuel systems increased significantly when gasoline containing ethanol was used compared to gasoline without ethanol.[200] In this case the ethanol fuel was specifically blended to achieve two weight percent oxygen. This test fuel represents California reformulated fuel and contains 5.7 percent by volume ethanol. Table 5.6-2 presents the test results at 29°C. The average increase in permeation due to using E5.7 was 60 percent. Presumably, this effect would have been higher on E10. Because most of the fuel tanks are metal, the effect is largely due to fuel hose/tubing permeation. The highest effect of ethanol in gasoline on permeation probably occurs when 10-30 percent ethanol is blended into the gasoline. We are just beginning a contract for testing to study permeation rates at various ethanol fuel blends as part of our on-highway inventory modeling efforts.

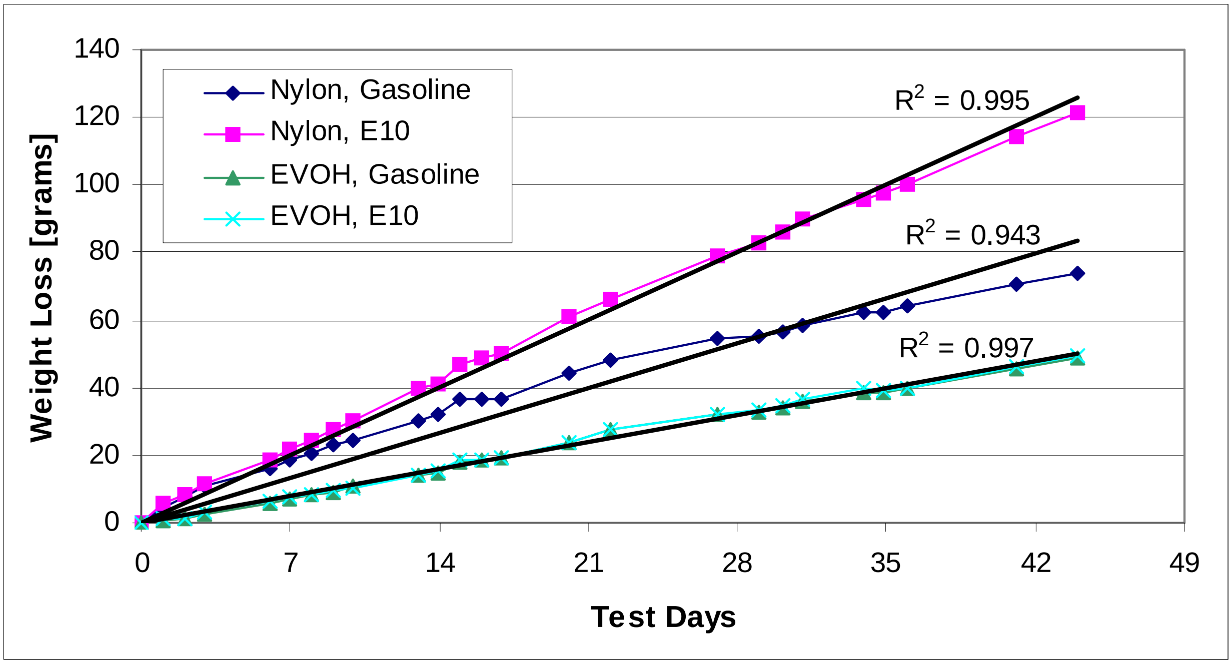
Table 5.6-2: Effect of Ethanol on Permeation from Automotive Fuel Systems

Fuel System	Fuel Tank	Gasoline	E5.7	Increase
2001 Toyota Tacoma	Metal	10	32	220%
2000 Honda Odyssey	Plastic (enhanced evap)	19	53	179%
1999 Toyota Corolla	Metal	11	57	418%
1997 Chrysler Town & Country	Plastic (enhanced evap)	40	66	65%
1995 Ford Ranger	HDPE	348	342	-2%
1993 Chevrolet Caprice Classic	Fluorinated HDPE	94	137	46%
1991 Honda Accord LX	Metal	39	100	156%
1989 Ford Taurus GL	Metal	28	73	161%
1985 Nissan Sentra	Metal	73	177	142%
1978 Olds Cutlass Supreme	Metal	73	139	90%

One significant finding with the above study was that switching from one fuel to another affects the permeation rate within a few weeks. Although operating on gasoline with ethanol changes the fuel tank material in such a way that permeation increases, this effect is reversible when gasoline is used in the fuel tank for a long enough period of time. This study found that the permeation rate at 40°C typically approached a stabilized level within 1 to 2 weeks of switching from one fuel to another.

To investigate the potential effects of fuel switching, we tested two pairs of 6.6 gallon portable marine fuel tanks. These fuel tanks used the barrier platelet technology discussed above. The first pair used nylon as a barrier material which is highly sensitive to ethanol while the second pair used EVOH which is much less sensitive to ethanol. All four tanks were soaked on E10 fuel, then the fuel was drained and replaced for testing. For each pair, one tank was tested on EPA certification gasoline and the other was tested on E10 fuel (10 percent ethanol, 90 percent gasoline). We continued the test for more than six weeks to observe the effects of fuel switching on the permeation rates. The results suggest that switching to gasoline significantly reduces the permeation rate for the nylon barrier tanks, but has no significant effect on the fuel tanks using EVOH as a barrier. Note that the nylon tanks had permeation rates near the proposed standards when soaked and tested on gasoline, but have much higher permeation rates when tested on E10. This data is presented in Figure 5.6-1. The R-squared values for linear fits to the data are also presented. The fuel tank with a nylon barrier that experienced fuel switching had a lower R-squared value than the other fuel tanks.

Figure 5.6-1: Effect of Fuel Switching on Permeation from Barrier Platelet Fuel Tanks



Fuel tank permeation data on both gasoline and E10 fuel were presented earlier in this chapter for nylon handheld tanks, fluorinated and sulfonated Small SI tanks, portable tanks with non-continuous nylon barrier platelets, and rotationally molded tanks with a nylon inner barrier. This data is repeated here in Table 5.6-3 to better focus on the effect of ethanol on fuel tank permeation. As shown by this data and the previous discussion, ethanol in the test fuel tends to increase permeation. However, the effect of ethanol on permeation appears to be highly variable depending on the materials or surface treatments used in constructing the fuel tank.

Table 5.6-3: Permeation Rates on Gasoline and E10 for Barrier Fuel Tanks

Permeation Control	Capacity [gallons]	Gasoline [g/m^2/day]	E10 [g/m^2/day]	% Increase
nylon 6	0.24	0.34	0.42 0.48	32%
nylon 6, 33% glass	0.05	0.62	1.01 1.12 0.93	65%
nylon 6, 30% glass	0.06	1.45	2.2 2.5	60%
nylon 6, 30% glass	0.06	1.30	1.4 2.1	37%
fluorination	0.5	0.56 0.62 0.22	0.43 0.62 0.62	19%
sulfonation	0.5	2.5 2.7 2.2	3.9 4.2 2.9	49%
non-continuous nylon platelets	2.0	3.7	6.8	84%
Rotomolded with PA11 liner*	1mm barrier thickness	0.17 0.24 0.12	0.91 0.72 0.78 0.81	350%

* based on testing for California (California Phase II gasoline and fuel CE10)

5.6.2.2.2 Effect of CE10 versus E10 on fuel tank permeation

As discussed above, we are proposing to allow the use of fuel CE10 as an alternative to E10 for fuel tank permeation testing. The primary fuel, E10 is representative of in-use fuel and is consistent with the certification fuel used for recreational vehicles. However, fuel CE10 is widely used by industry for materials testing. Data presented earlier in this chapter suggests that permeation is generally significantly higher on fuel CE10 for fuel hoses. We were therefore interested in the effect of fuel CE10 versus E10 on fuel tank permeation. We tested several fuel tanks and found that permeation was only slightly higher on CE10 than E10 for most of the fuel tanks tested.

To study the effects of CE10 versus E10 on permeation, we used fuel tanks that had been previously tested on fuel E10. All of these tanks were drained and refueled with fresh test fuel. Most of the tanks were filled with fuel CE10; however, with some exceptions, one of each tank type was filled with fresh E10 for comparison. These fuel tanks were then preconditioned by soaking them for 12 weeks with the new test fuel. Note that all of the test tanks had been soaking with E10 fuel for more than a year (and in some cases multiple years) prior to beginning this preconditioning soak. Following the soak period, each tank was drained, refilled with fresh fuel, and sealed. Permeation was measured over two weeks at 29˚C. The fuel tanks were weighed on each weekday during this period.

Table 5.6-4 presents the results of this testing. In most cases, emissions were only slightly higher on CE10 than E10. The exceptions were the nylon 6 and the acetal copolymer fuel tanks which showed much higher permeation on CE10. However, the permeation rates for these fuel tanks were still below the proposed standard when tested on fuel CE10. The fuel tank with a continuous EVOH barrier was well below the proposed standard on fuel CE10. No comparison was made to E10 results for this technology.

Table 5.6-4: Permeation Rates on Gasoline and E10 for Barrier Fuel Tanks

Permeation Control	Capacity [gallons]	E10 [g/m^2/day]	CE10 [g/m^2/day]	% Increase
nylon 6	0.24	0.69	1.4 1.2	90%
HDPE	0.5	12.5	13.3 13.5	7%
fluorination	0.5	0.41	0.49 0.52	21%
sulfonation	0.5	3.1	4.2 2.9	16%
non-continuous platelets (4% nylon)	6.6	4.5	5.3	16%
non-continuous platelets (2% EVOH)	6.6	3.0*	3.3	10%
non-continuous platelets (4% EVOH)	6.6	2.2	2.3	6%
non-continuous platelets (6% EVOH)	6.6	1.3	1.4	6%
continuous EVOH barrier	5.6	--	0.05 0.01	NA
acetal copolymer	0.8	0.25	0.55 0.65	140%

* based on previous testing (presented earlier in this chapter)

5.6.2.3 Reference Tank

In cases where the permeation of a fuel tank is low, and the sample tank is properly sealed, the effect of air buoyancy can have a significant effect the measured weight loss. Air buoyancy refers to the effect on air density on the perceived weight of an object. As air density increases, it will provide an upward thrust on the fuel tank and create the appearance of a lighter tank. Air density can be determined by measuring relative humidity, air temperature, and air pressure.[201]

One testing laboratory presented data to EPA on their experience with variability in weight loss measurements when performing permeation testing on portable fuel tanks.[202] They found that the variation was due to air buoyancy effects. By applying correction factors for air buoyancy, they were able to greatly remove the variation in the test data. A technical brief on the calculations they used is available in the docket.[203]

A more direct approach to accounting for the effects of air buoyancy is to use a reference fuel tank. In this approach, an identical fuel tank to that being tested for permeation would be tested without fuel in it and used as a reference fuel tank. Dry sand would be added to this tank to make up the difference in mass associated with the test tank being full of fuel. The reference tank would then be sealed so that the buoyancy effect on the reference tank would be the same as the test tank. The measured weight loss of the test tank could then be corrected by any measured changes in weight in the reference tank. The California Air Resources Board has proposed this approach for measuring portable fuel tank emissions, and they refer to the reference tank as a “trip blank.”[204]

5.6.2.4 Engineering Design-Based Certification

Fuel does not permeate through metal and automotive style EVOH barrier tanks have very low permeation through the walls of the tank. We are proposing to allow design-based certification for metal tanks and co-extruded high-density polyethylene fuel tanks with a continuous ethylene vinyl alcohol barrier layer. The EVOH barrier layer would be required to be at least 2 percent of the wall thickness of the fuel tank.

To address the permeability of the fuel cap, seals, and gaskets used on metal and co-extruded tanks, we are proposing that the design criteria include a specification that seals and gaskets that are not made of low-permeation materials must have a total exposed surface area less than 1000 mm^2. A low-permeation material would have a permeation rate not more than 10 g-mm/m^2/day at 23°C on CE10 fuel as tested under the procedures specified in SAE J2659.[205] A metal or co-extruded fuel tank with seals that meet this design criterion would reliably pass the standard.

5.6.3 Diurnal Emission Testing

The proposed test procedure for diurnal emissions is to place the fuel tank in a SHED[6], vary the temperature over a prescribed profile, and measure the hydrocarbons escaping from the fuel tank. The final result would be reported in grams per gallon where the grams are the mass

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[6] Sealed Housing for Emission Determination

of hydrocarbons escaping from the fuel tank over 24 hours and the gallons are the nominal fuel tank capacity. The proposed test procedure is based on the automotive evaporative emission test described in 40 CFR part 86, subpart B, with modifications specific to marine applications. If we were proposing diurnal emissions standards for Small SI applications, the test procedures would be similar and would be based on a 72-96°F temperature profile.

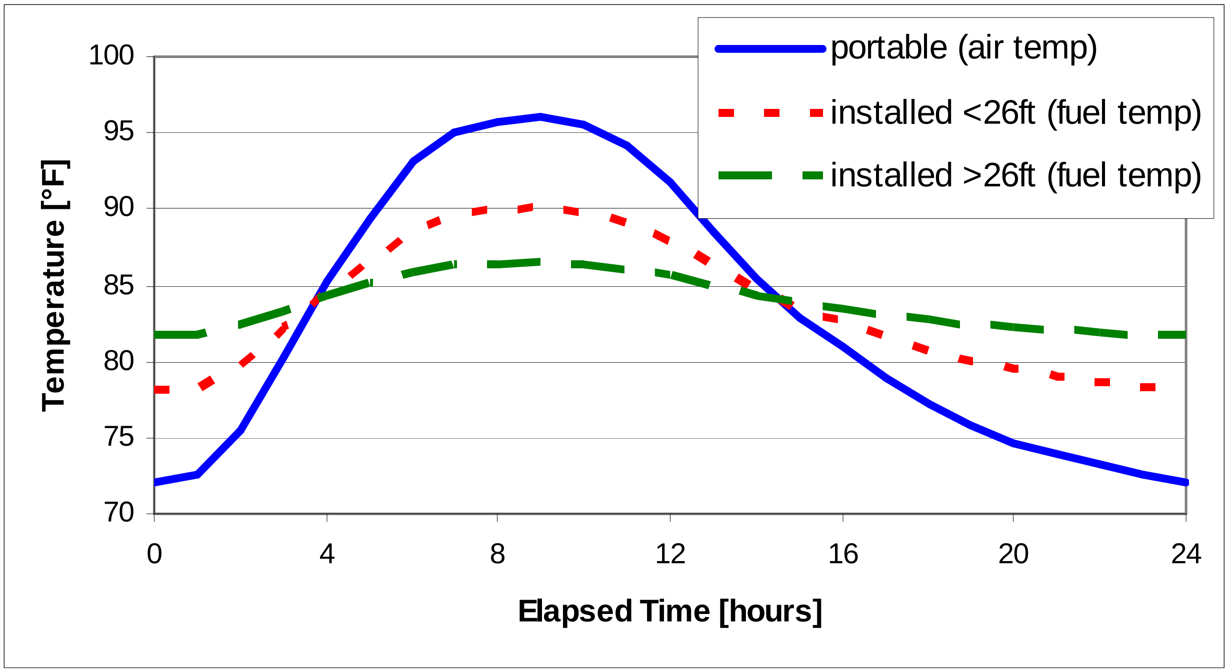
5.6.3.1 Temperature Profile

We are proposing that portable marine fuel tanks would be tested over the same 72-96°F (22.2-35.6°C) temperature profile used for automotive applications. This temperature profile represents a hot summer day when ground level ozone emissions (formed from hydrocarbons and oxides of nitrogen) would be highest. This temperature profile would be for the air temperature in the SHED.

For installed marine fuel tanks, we believe that the fuel temperature profile observed in the tank would have a lower variation in temperature due to the inherent insulation provided by the boat hull. Data discussed earlier in this chapter, and presented in Appendix 5A, suggest that the fuel temperature in an installed marine tank would see a change in temperature less than that of ambient air. Based on this data, the fuel temperature change in boats stored on trailers would be expected to be about half of ambient. For boats stored in the water, the fuel temperature change would be expected to be about 20 percent of ambient. Based on discussions with industry, we use a boat length as a surrogate for determining if a boat is a trailer boat. We are proposing to consider a boat below 26 feet (7.9 m) in length as a trailer boat and larger boats as being primarily stored in the water.

To account for the differences between ambient and fuel temperature, we are proposing a test temperature profile of 78-90°F (25.6-32.2°C) for marine fuel tanks installed in boats less than 26 feet in length. For larger boats, we are proposing a test temperature profile of 81.6-86.4˚F (27.6-30.2˚C). These test temperature profiles would be based on fuel rather than ambient temperature. Figure 5.6-3 presents the three temperature profiles over 24 hours. Numerical values are presented in Appendix 5E.

Figure 5.6-3: Proposed Diurnal Temperature Profiles



The automotive diurnal test procedure includes a three day temperature cycle. The purpose of this test length is to ensure that the carbon canister can hold at least three days of diurnal emissions without vapor breaking-through the canister. For vessels using carbon canisters as an evaporative emission control strategy, we are proposing a multiple day cycle here as well so that the passive purging can be observed. In the automotive test, the canister is loaded, then purged during an engine test prior to the first day of testing. Because we are anticipating canisters on marine applications to be passively purged we are proposing a different approach. Prior to the first day of testing, the canister would be loaded to full working capacity, then run over the diurnal test temperature cycle to allow one day of passive purging. The test result would then be based on the highest recorded value in the following three days.

For fuel systems using a sealed system (or sealed-system with pressure relief), we do not believe that a three day test would be necessary. Prior to the first day of testing, the fuel would be stabilized at the initial test temperature. Following this stabilization, the SHED would be purged and a single diurnal temperature cycle run. Because this technology does not depend on purging or storage capacity of a canister, multiple days of testing should not be necessary. Therefore, we are proposing a one-day test for the following technologies: sealed system without pressure relief, sealed system with a pressure relief valve, sealed bladder fuel tanks, sealed fuel tanks with a volume compensating air bag.

5.6.3.2 Test Fuel

Consistent with the automotive test procedures, we are proposing that the test take place using certification gasoline with a vapor pressure of 9.0 RVP. We are not proposing to require ethanol to be blended into the test fuel. Although ethanol has a significant effect on permeation, it would not be expected to affect diurnal emissions except in that it may affect fuel vapor pressure.

Diurnal emissions are not only a function of temperature and fuel volatility, but of the size of the vapor space in the fuel tank as well. Consistent with the automotive procedures, we are proposing that the fill level at the start of the test be 40 percent of the nominal capacity of the fuel tank. Nominal capacity of the fuel tank would be defined as the volume of fuel, specified by the manufacturer, to which the fuel tank can be filled when sitting in its intended position. The vapor space that normally occurs in a fuel tank, even when “full,” would not be considered in the nominal capacity of the fuel tank.

5.6.3.3 Tank Configuration

Personal watercraft and other installed marine fuel tanks are typically equipped with a vent line. As shown above, this vent line can impact the emissions determined over the test procedure because it largely restricts diffusion losses. Therefore, for open vent marine fuel tanks that are designed with a connection for a vent line, we propose that the be equipped with a one meter fuel line to more accurately reflect real world emissions. This should only be necessary for baseline configurations.

The majority of marine fuel tanks are made of plastic. Even plastic fuel tanks designed to meet our proposed standards would be expected to have some amount of permeation. However, over the length of the diurnal test, if it were performed on a new tank that had not been previously exposed to fuel, the effect of permeation on the test results should be insignificant. For fuel tanks that have reached their stabilized permeation rate (such as testing on in-use tanks), we believe that it would be appropriate to correct for permeation. In such a case, we propose that the permeation rate could be measured from the fuel tank and subtracted from the final diurnal test result. The fuel tank permeation rate would have to be stabilized on the 9 RVP test fuel used for the diurnal test and measured either over the diurnal temperature cycle or at a constant temperature (28 ± 2°C). This test measurement would have to be made just prior (within 24 hours) to the diurnal emission test to ensure that the permeation rate does not change prior to the diurnal test. In addition, the test fuel would need to remain in the fuel tank between the permeation and diurnal tests to ensure a stable permeation rate. The fuel tank could be emptied to change test fuels and test set ups; however, this period would not be allowed to exceed one hour. As an alternative to stabilizing the permeation rate prior to testing, the permeation could be measured immediately before and after the diurnal test, and the lower permeation rate used to correct the diurnal test results. In this case, the test fuel would not be removed after the diurnal test, and the second permeation test would begin within 8 hours of the end of the diurnal test.

5.6.3.4 Carbon Canister Engineering Design

We are proposing to allow design-based certification as an option to performing the above test. For vessels using a carbon canister to control diurnal emissions, it is important to ensure that the canister design is sufficient to achieve the proposed standards. The following discussion outlines the requirements that would be necessary to ensure adequate canister design. These design parameters and their associated test procedures are largely based on our understanding of current industry practices for marine grade carbon.[206]

5.6.3.4.1 Carbon canister capacity

In a passive purge system, the storage capacity of the carbon canister must be properly matched to the fuel system. Ideally, the canister would be large enough to take full advantage of the passive purge caused by cooling of the fuel tank. By creating more open sites in the canister, greater vapor collection is possible during the next heating event. If a canister is undersized, then the vessel would not likely meet the proposed standards. On the other hand, after a certain point, increasing the size of the canister offers little additional emission control. Once the system reaches a stabilized purge/load condition, the emission reduction potential is based on the portion of the canister that purges and loads rather than the full volume of the canister.

The storage capacity of a carbon canister is based both on the volume of the canister and the working capacity of the carbon. Butane working capacity (BWC) is a measure of the vapor storage capacity of the carbon and is expressed in units of mass of butane per unit of volume. We are proposing that the BWC of the carbon be at least 9 g/dL based on the test procedures specified in ASTM D5228-92.[207] Under this test procedure, butane vapor is fed through a carbon sample at a specified rate, until the mass of the carbon sample reaches equilibrium. The butane is then purged off with dry air. BWC of the carbon sample is calculated from the difference in the measured mass of the carbon sample before and after the purge.

Using the ASTM test procedure, the BWC represents the full saturated capacity of the canister and not the amount of vapor that the canister will hold before breakthrough occurs. Under the EPA automotive test procedure in 40 CFR 86.134-96, the canister capacity is based on the amount of butane loaded in the canister until 2 grams of breakthrough is measured. However, we are proposing to use the ASTM procedure because it gives a repeatable measure that is currently used by industry. The design standard of 9 g/dL is based on this test procedure and therefore accounts for the differences in the ASTM and existing EPA automotive procedure.

Based on the data presented earlier in this chapter, we are proposing that the volume of the carbon canister must be a minimum of 0.04 liters of carbon per gallon of fuel tank capacity for fuel tanks installed in boats less than 26 feet in length. For larger boats, the fuel temperature may be less affected by diurnal temperature swings for two reasons. First, these fuel tanks would be in larger vessels which are more likely to be stored in the water and therefore, subject to smaller temperature fluctuations. Second, these fuel tanks would likely be larger and have larger thermal inertia in the fuel which may lead to lower temperature fluctuation. Therefore, for fuel tanks installed on boats greater than or equal to 25 feet, we are proposing a design minimum volume of 0.016 liters of carbon every gallon per gallon of fuel tank capacity.

5.6.3.4.2 Carbon humidity resistance

In a marine environment, the carbon may be exposed to more humid air, on average, than in land-based applications such as cars and trucks. Traditional carbons used in automotive applications can adsorb water, thereby closing sites off to hydrocarbons. With active purge and carbon heating during refueling vapor collection, the water vapor is easily purged off the carbon. Under this proposed rule, we are basing the design specification on a passive purge canister design and are not requiring onboard refueling vapor recovery. Therefore, we believe that the carbon should be resistant to moisture in the air. In the in-use program discussed above, marine grade carbon was used that was developed specifically for high humidity applications.[208]

We proposing design-based certification requirements for humidity resistance based on the specifications of the humidity-resistant carbon used in the in-use demonstration program. This carbon meets a moisture adsorption capacity maximum of 0.5 grams of water per gram of carbon at 90 percent relative humidity and a temperature of 25±5˚C. This limit is based on a test procedure where dried carbon is exposed to water vapor and the pressure in the sample chamber is controlled to achieve the correct partial pressure of the water to achieve the desired relative humidity. The adsorption of water in the carbon is calculated based on the reduction in pressure in the sample chamber. More detail on this test procedure is available in the docket.[209]

5.6.3.4.3 Carbon durability

Another issue that has been raised with regard to canister use in marine applications is the durability of the canister under the shocks that can be observed on a marine vessel. Automotive applications see shocks and vibration as well and the carbon is protected by packing it under pressure in the canister. To address the concern of carbon durability, however, we are proposing to include a carbon strength requirement. This strength requirement is consistent with the specifications for the carbon used in the in-use test program described above, which was designed to have a higher hardness value and lower dust attrition rates than typical automotive carbons.

The industry procedure for carbon pellet strength is to determine the average pellet size in a sample of carbon before and after a pan hardness test. Pellet size is determined by separating the carbon by size using sieves. The pan hardness test involves shaking the carbon in a pan with steel balls over a fixed period of time. The pellet strength is determined by taking the ratio of the average pellet size of the carbon before and after the pan and ball attrition test. We are proposing a pellet strength of at least 85 percent. The proposed test procedure is ASTM D3802-79[210] with two variations. First, as discussed above, hardness is defined as the ratio of mean particle diameter before and after the attrition test. Second, the attrition test would use twenty ½" steel balls and ten ¾" steel balls rather than fifteen of each as specified in ASTM D3802-79. These proposed variations on the ASTM procedure reflect common industry practice for pelletized carbons in contrast to the original test procedure which were intended for granular carbons.[211]

5.6.3.4.4 Canister design

The design of the canister itself is important in building an effective and durable carbon canister system. The canister should be made of a material that is compatible with the application. For instance, the material should be fuel resistant and durable. Where a flame test is required by the Coast Guard, the material should be able to pass this test on its own or with a protective cover. In addition, the canister material must have good structural integrity at temperatures that it would be exposed to in a boat. If the material changes in dimension at temperature, that flexing may loosen the carbon packing, allowing the carbon to move and eventually deteriorate. The canister should be installed in the boat in such a way that undue stress is not placed on the canister. It should also be properly constructed so that there are no leaks in the canister.

The canister must be packed in such a way that the carbon does not move inside the canister in-use. If the carbon were able to move, it would eventually break down under vibration. Over time the carbon could deteriorate into dust which could eventually escape from the canister. This is not an issue with a carbon canister that uses a properly designed and installed volume compensator. The basic design of a volume compensator is that compression is held on the carbon bed with a spring. A mesh or foam cover is used on the volume compensator that will allow air to pass through, but will hold the carbon pellets in place.

The carbon should be packed into the canister in such a way that there is a consistent size of carbon pellets throughout the canister. If the carbon settles in the storage hopper, it would be possible for some canisters to be filled largely with the smallest diameter carbon pellets (or dust) which would increase the pressure restriction of the canister. Also, if the carbon is not packed properly when placed into the canister, it could later settle leading to a volume reduction of the carbon that is too large for the volume compensator to address.

The carbon canister design must allow for a proper flow path of vapor and air through the carbon bed. In current carbon canister designs, an air gap is typically installed upstream of the carbon bed. Flow directors may be molded into this air gap. The purpose of the air gap is to allow the vapor or purge air to disperse and flow through the entire carbon bed. Even with a small air gap, the vapor will disperse because it will attempt to follow the path of least resistance through the canister. Without the air gap, the flow could be predominately in the center of the carbon (or wherever the intake hose connection is located).

The geometry of a carbon canister can affect the effectiveness of the control system. For instance, a long, narrow canister will have higher efficiency than a short wide canister. This is because some breakthrough can occur if the pathway is too short for the flow of vapor. Based on one study, the effectiveness of the carbon canister increases notably until a length to diameter ratio of about 3.5 is achieved.[212] At higher ratios, less of an impact on efficiency was observed. At too high of a length to diameter ratio, significant back pressure may occur in the system.

5.6.3.4.5 Integration with Fuel System

It would be important that a carbon canister system be appropriately integrated into the fuel system. For instance, the canister would need to be positioned in the vent line, and potentially a liquid separation valve added, to ensure that liquid fuel would not reach the canister during refueling. We would also expect the fuel system design to minimize spit-back out of the fill neck during refueling. A design that caused fuel to stream out the fill neck during refueling, even with a fuel nozzle shut-off mechanism, would not be acceptable.

5.7 Impacts on Noise, Energy, and Safety

The Clean Air Act requires EPA to consider potential impacts on noise, energy, and safety when establishing the feasibility of new emission standards for marine vessels.

5.7.1 Noise

In this case, we would not expect evaporative emission controls to have any impact on noise from Small SI equipment or marine vessels because noise from the affected parts of the fuel system is insignificant.

5.7.2 Energy

We anticipate that the proposed evaporative emission standards will have a positive impact on energy. By capturing or preventing the loss of fuel through evaporation, we estimate that the lifetime average fuel savings would be about 1.2 gallons for an average piece of Small SI equipment and 31 gallons for an average boat. This translates to a fuel savings of about 44 million gallons for Small SI equipment and 26 million gallons for Marine SI vessels in 2030 when most of the affected equipment used in the U.S. would be expected to have evaporative emission control.

5.7.3 Safety

As part of the development of this proposed rule, EPA performed a technical study on the safety of emission control technology for Small SI equipment and Marine SI vessels.[213] The conclusions of this study are presented below. Although the study focuses on equipment with engines less than 37 kilowatts, the conclusions drawn for marine apply to boats with larger engines as well as ABYC, USCG, UL, and SAE requirements do not distinguish between engine sizes.

EPA has reviewed the fuel hose and fuel tank characteristics for NHH and HH equipment and evaluated control technology which could be used to reduce evaporative emissions from these two subcategories. This technology is capable of achieving reductions in fuel tank and fuel hose permeation without an adverse incremental impact on safety. For fuel hoses and fuel tanks, the applicable consensus standards, manufacturer specific test procedures and EPA requirements are sufficient to ensure that there will be no increase in the types of fuel leaks that lead to fire and burn risk in use. Instead, these standards will reduce vapor emissions both during operation and in storage. That reduction, coupled with some expected equipment redesign, is expected to lead to reductions in the risk of fire or burn without affecting component durability.

We also conducted a design and process Failure Mode and Effects Analyses (FMEA) comparing current Phase 2 and Phase 3 compliant engines and equipment to evaluate incremental changes in risk probability as a way of evaluating the incremental risk of upgrading Phase 2 engines to meet Phase 3 emission standards.[214] This is an engineering analysis tool to help engineers and other professional staff on the FMEA team to identify and manage risk. In a FMEA, potential failure modes, causes of failure, and failure effects are identified and a resulting risk probability is calculated from these results. This risk probability is used by the FMEA team to rank problems for potential action to reduce or eliminate the causal factors. Identifying these causal factors is important because they are the elements that a manufacturer can consider reducing the adverse effects that might result from a particular failure mode.

Our FEMA evaluated permeation and running loss controls on nonhandheld engines. We found that these controls would not increase the probability of fire and burn risk from those expected with current fuel systems, but could in fact lead to directionally improved systems from a safety perspective. Finally, the running loss control program being proposed for nonhandheld equipment will lead to changes that are expected to reduce risk of fire during in-use operation. Moving fuel tanks away from heat sources, improving cap designs to limit leakage on tip over, and requiring a tethered cap will all help to eliminate conditions which lead to in-use problems related to fuel leaks and spillage. Therefore, we believe that the application of emission control technology to reduce evaporative emissions from these fuel hoses and fuel tanks will not lead to an increase in incremental risk of fires or burns and in some cases is likely to at least directionally reduce such risks.

EPA has reviewed the fuel hose and fuel tank characteristics for marine vessels and evaluated control technology which could be used to reduce evaporative emissions from boats. With regard to fuel hoses, fuel tanks, and diurnal controls, there are rigorous USCG, ABYC, UL, and SAE standards which manufacturers will continue to meet for fuel system components. All of these standards are designed to address the in-use performance of fuel systems, with the goal of eliminating fuel leaks. The low permeation fuel hoses and tanks needed to meet the Phase 3 requirements would need to pass these standards and every indication is that they would pass.

Furthermore, the EPA permeation certification requirements related to emissions durability will add an additional layer of assurance. Low permeation fuel hoses are used safely today in many marine vessels. Low permeation fuel tanks and diurnal emission controls have been demonstrated in various applications for many years without an increase in safety risk. Furthermore, a properly designed fuel system with fuel tank and fuel hose permeation controls and diurnal emission controls would reduce the fuel vapor in the boat, thereby reducing the opportunities for fuel related fires. In addition, using improved low permeation materials coupled with designs meeting USCG and ABYC requirements should reduce the risk of fuel leaks into the vessel. EPA believes that the application of emission control technologies on marine engines and vessels for meeting the proposed evaporative emissions standards would not lead to an increase in incremental risk of fires or burns, and in many cases may incrementally decrease safety risks in certain situations..

APPENDIX 5A: Diurnal Temperature Traces

Figure 5A-1: Temperature Trace for Personal Watercraft on Trailer

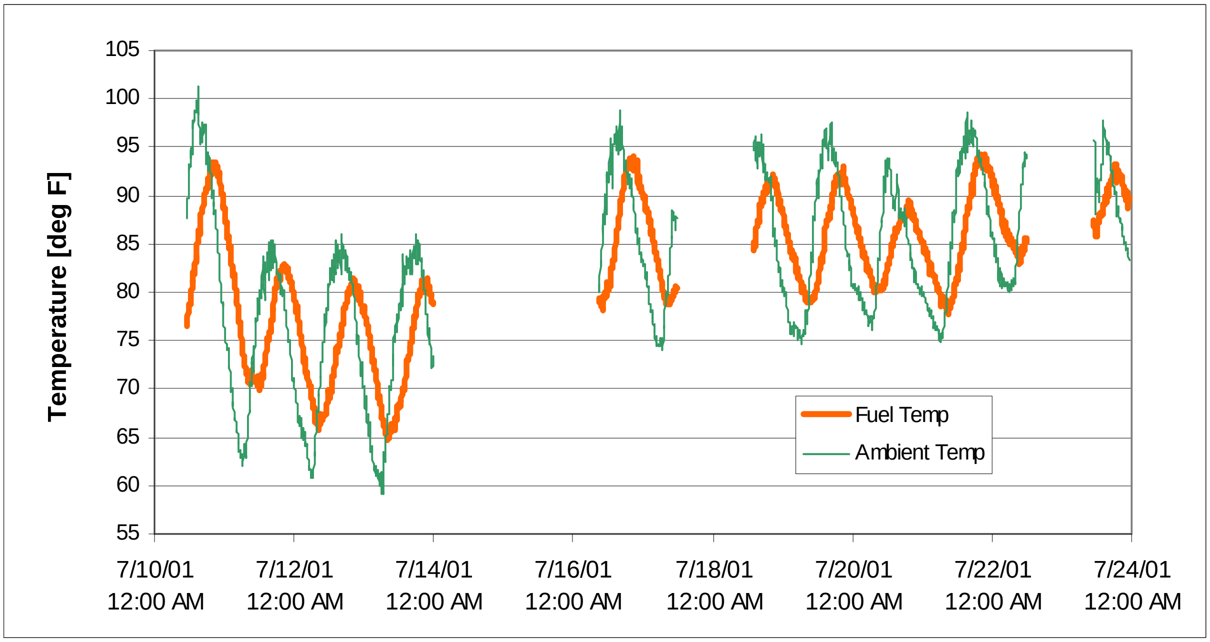


Figure 5A-2: Temperature Trace for Jet Boat on Trailer

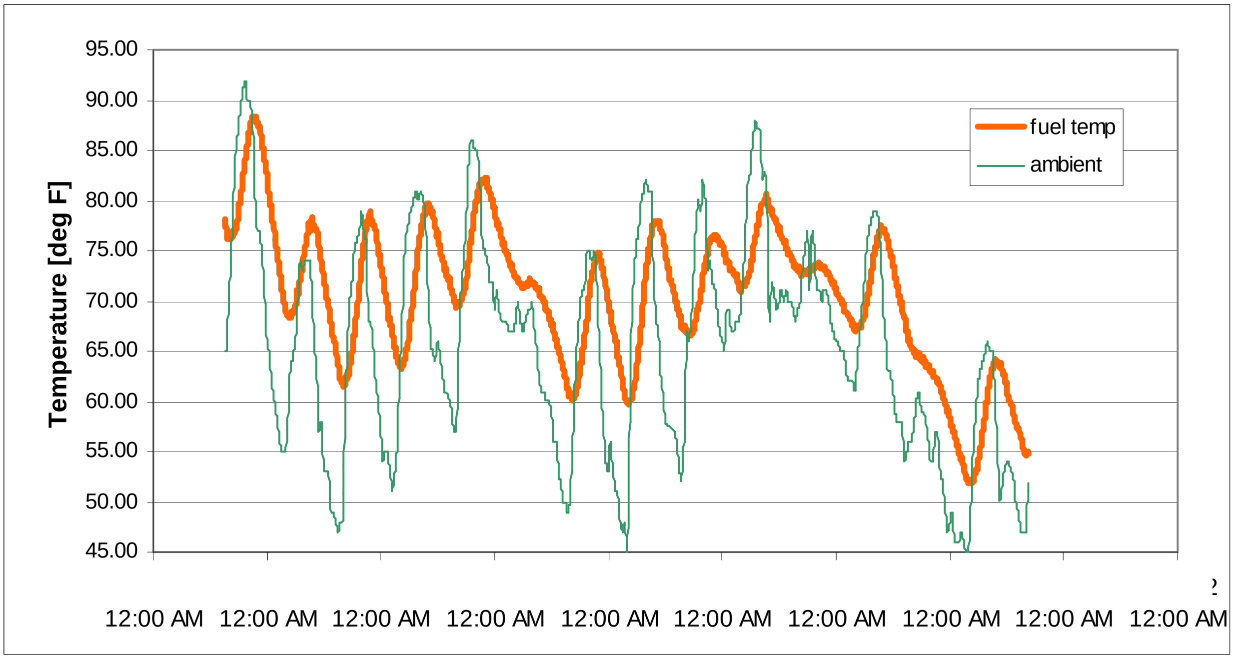


Figure 5A-3: Temperature Trace for Runabout on Trailer

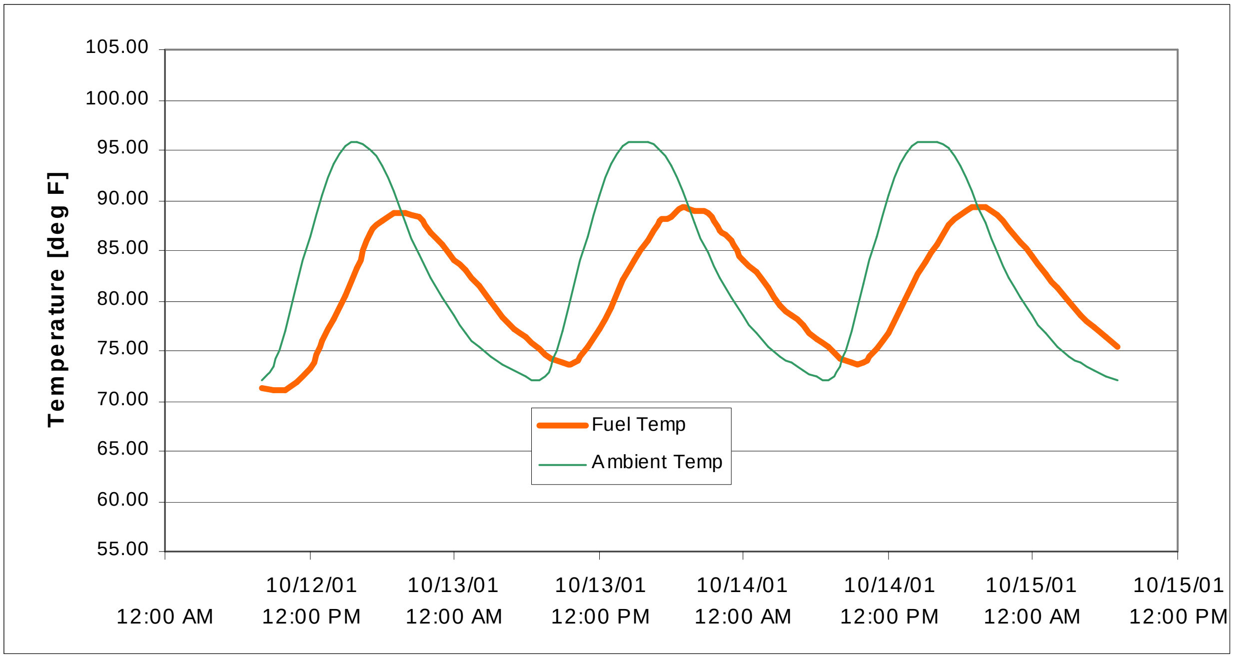


Figure 5A-4: Temperature Trace for Jet Boat on Trailer

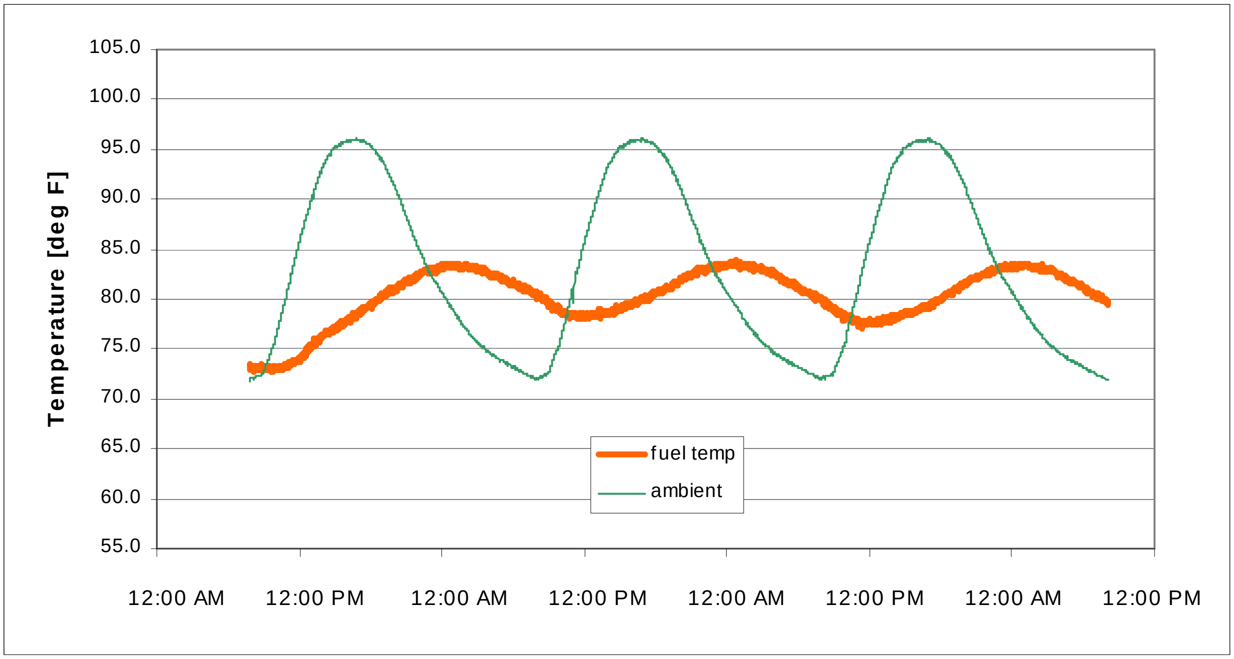


Figure 5A-5: Temperature Trace for Runabout in Water

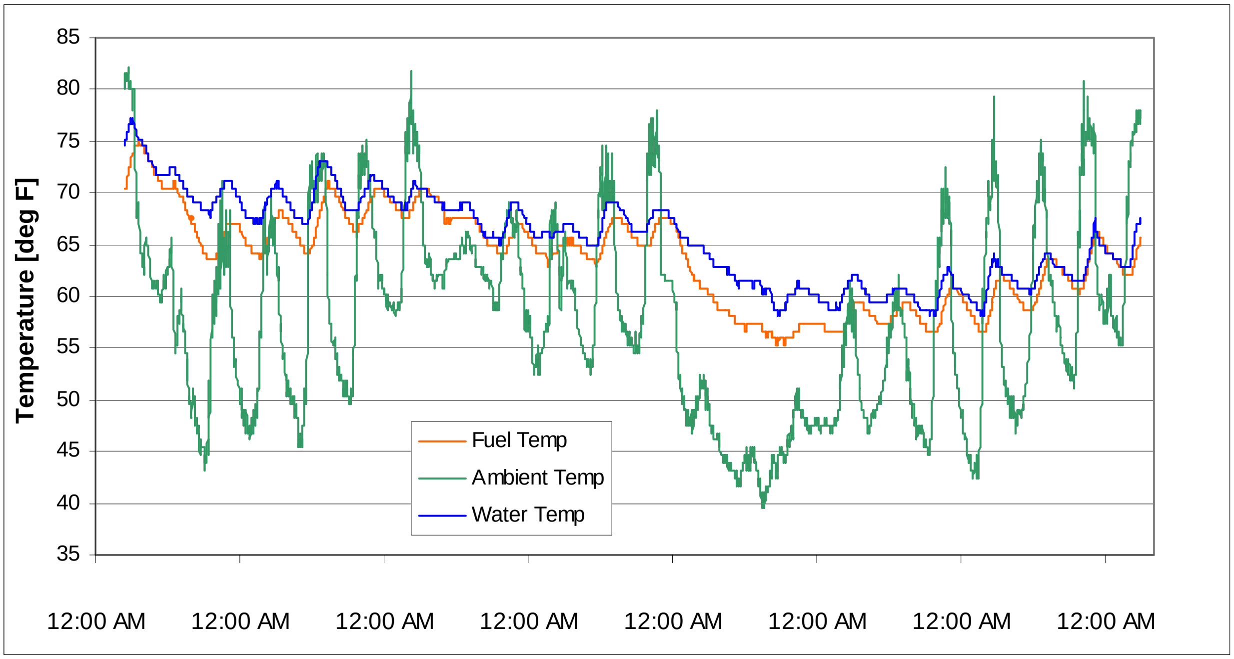
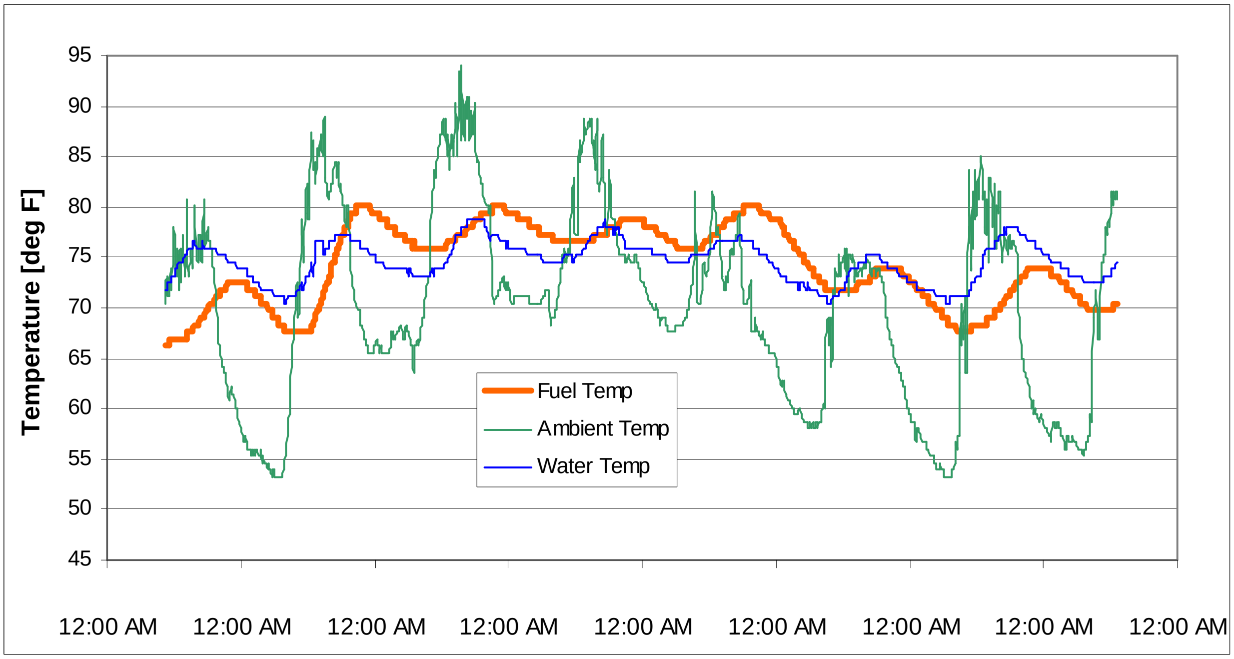


Figure 5A-6: Temperature Trace of Deckboat in Water



APPENDIX 5B: Emission Results for Small SI Equipment Fuel Tanks Showing Effect of Venting on Diffusion

5B.1 Diffusion Effects from Variable Temperature Diurnal Testing

Figure 5B-1: Diurnal/Diffusion Test Results for BM Metal Fuel Tank (2 Labs)

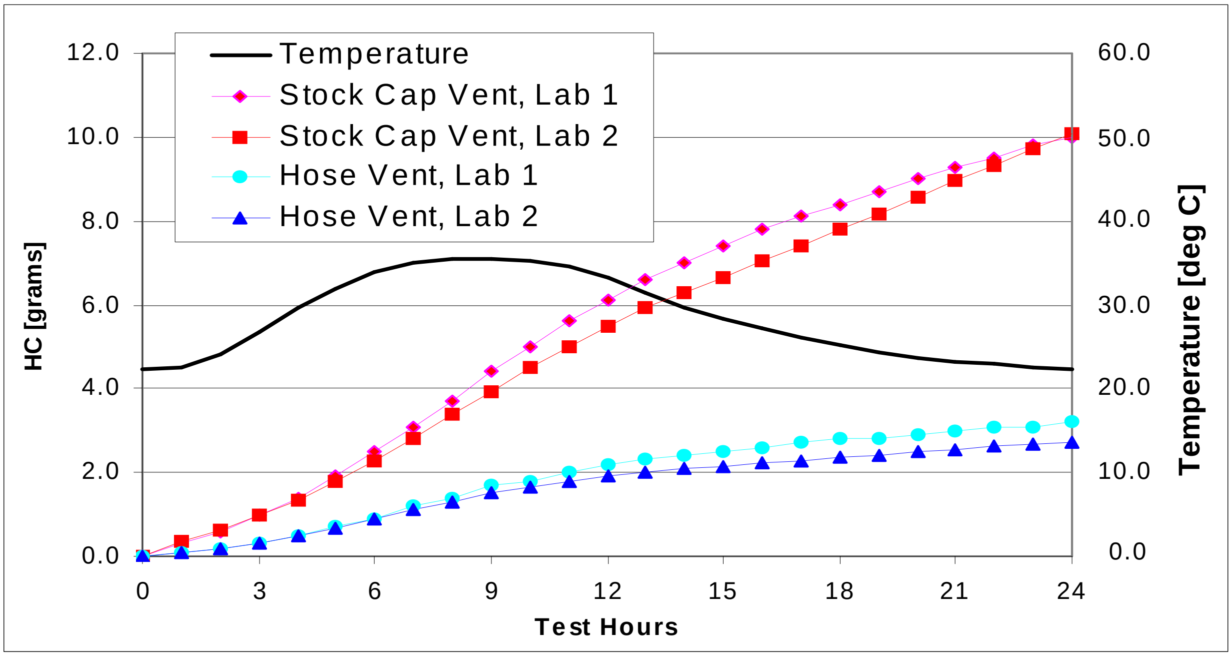


Figure 5B.1-2: Diurnal/Diffusion Test Results for BP Plastic Fuel Tank

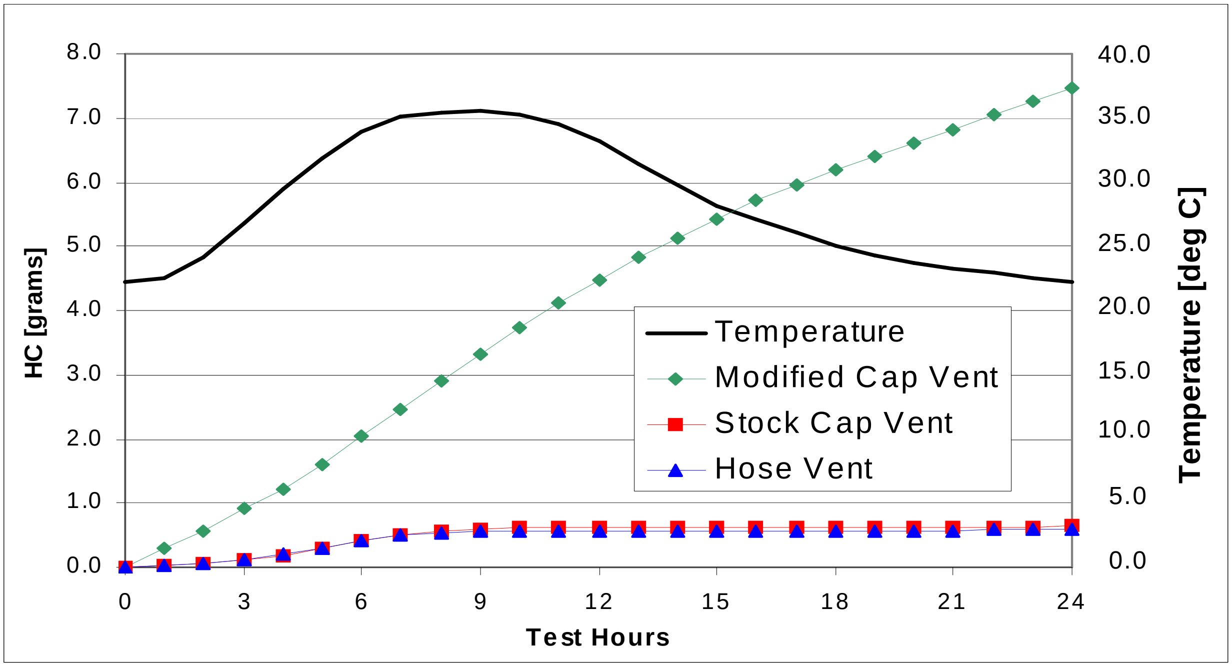


Figure 5B.1-3: Diurnal/Diffusion Test Results for HP Plastic Fuel Tank

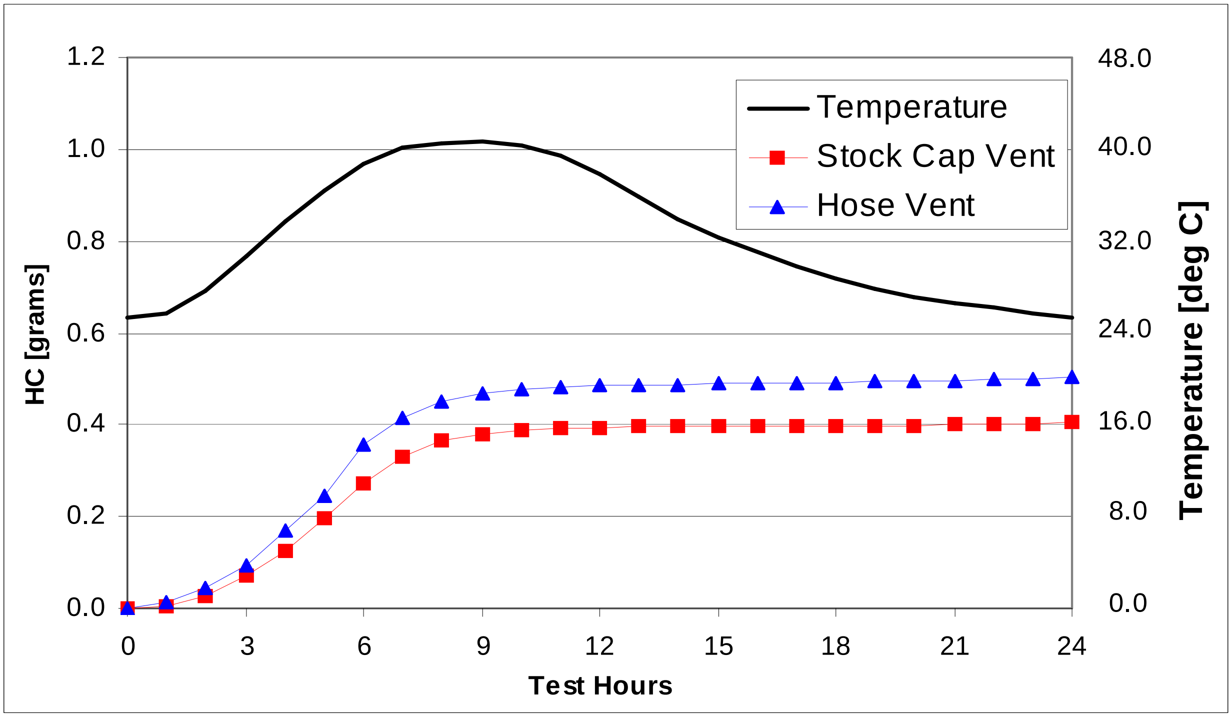
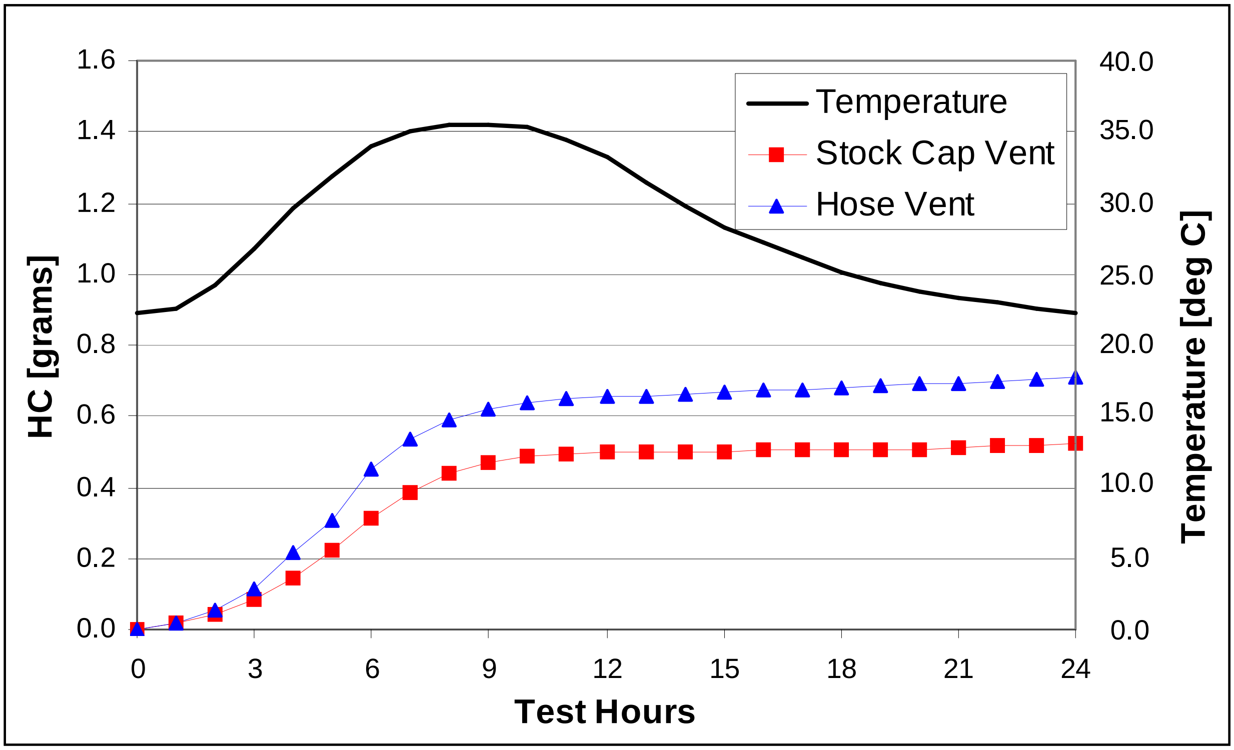


Figure 5B.1-4: Diurnal/Diffusion Test Results for TP Plastic Fuel Tank



5B.2 Isothermal Results for Small SI Equipment Fuel Tanks Showing Effect of Venting on Diffusion

Figure 5B.2-1: Isothermal Diffusion Test Results for BM Metal Fuel Tank

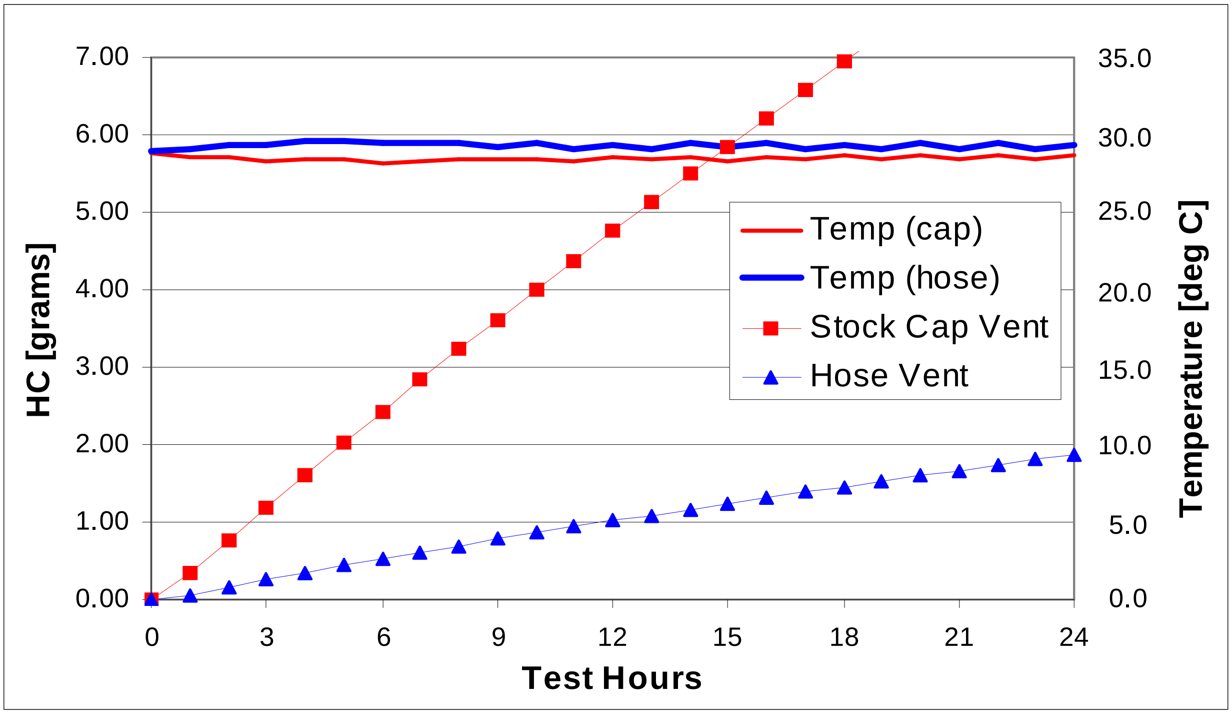


Figure 5B.2-2: Isothermal Diffusion Test Results for BP Plastic Fuel Tank

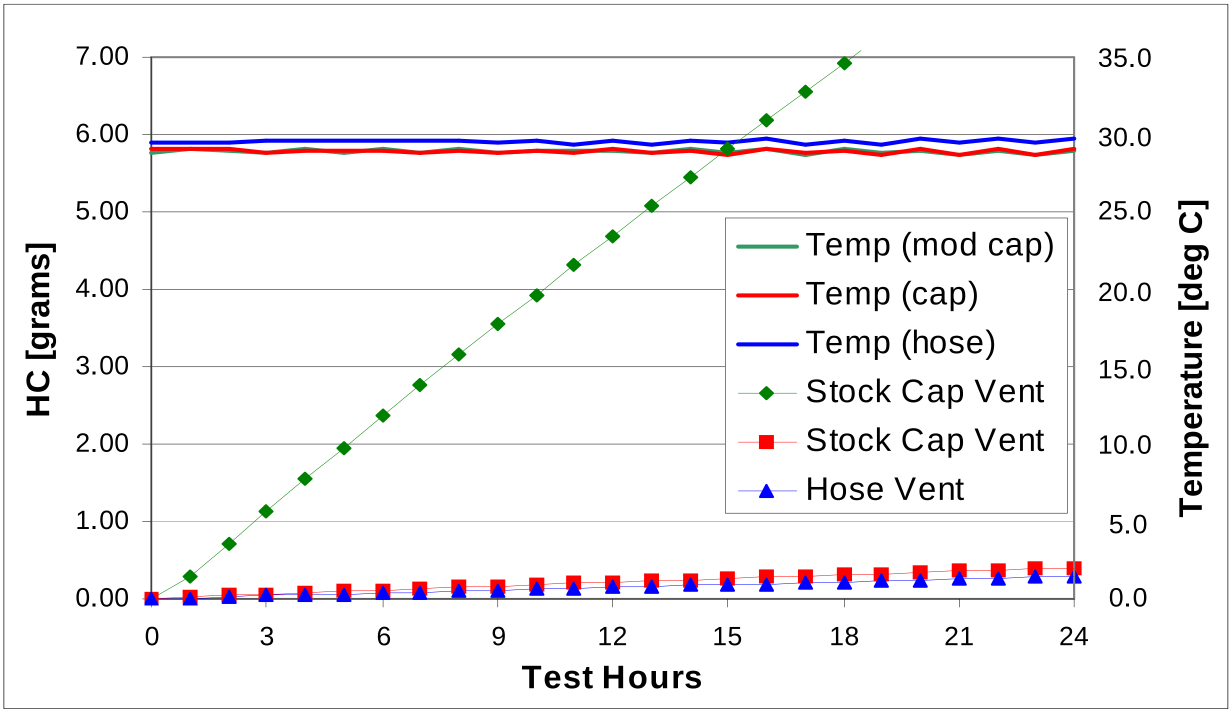


Figure 5B.2-3: Isothermal Diffusion Test Results for HP Plastic Fuel Tank

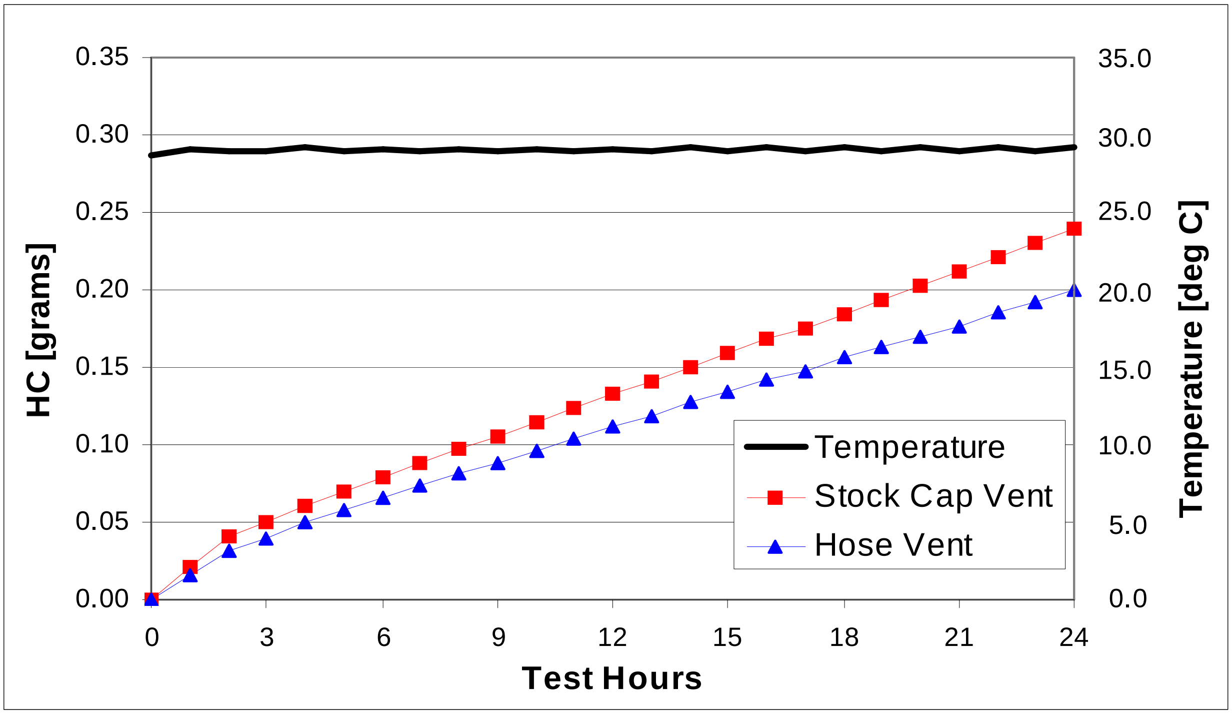
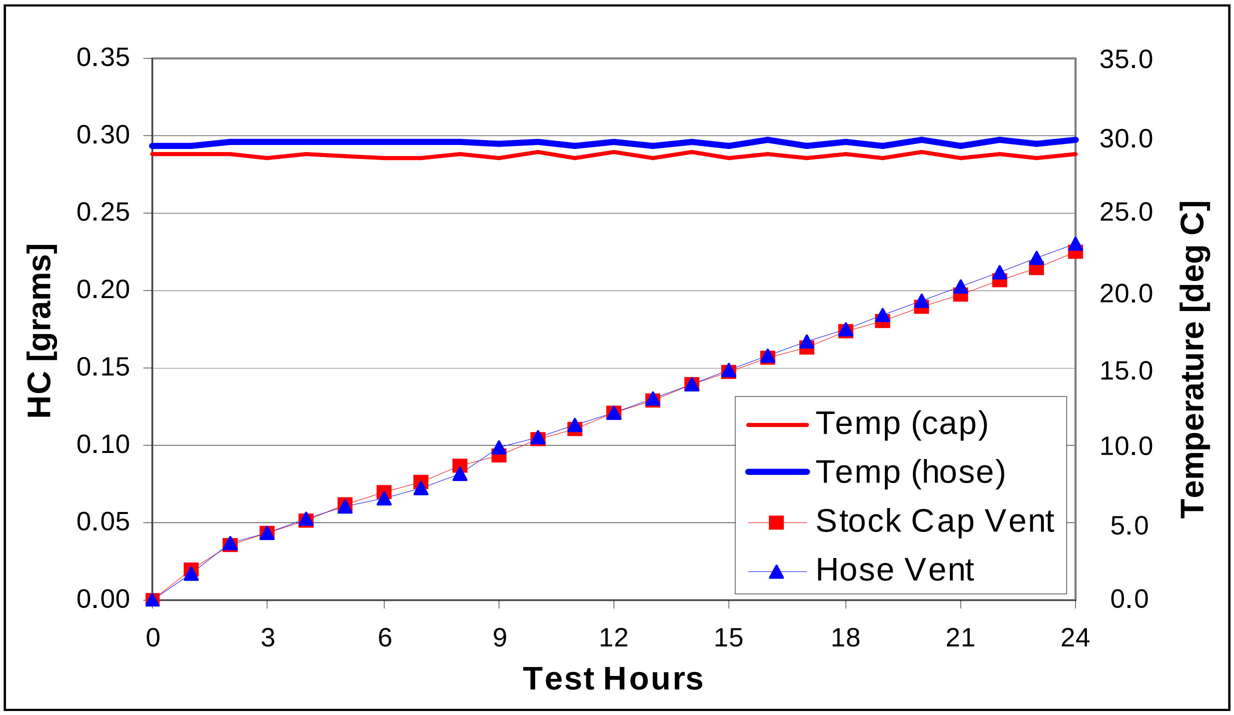
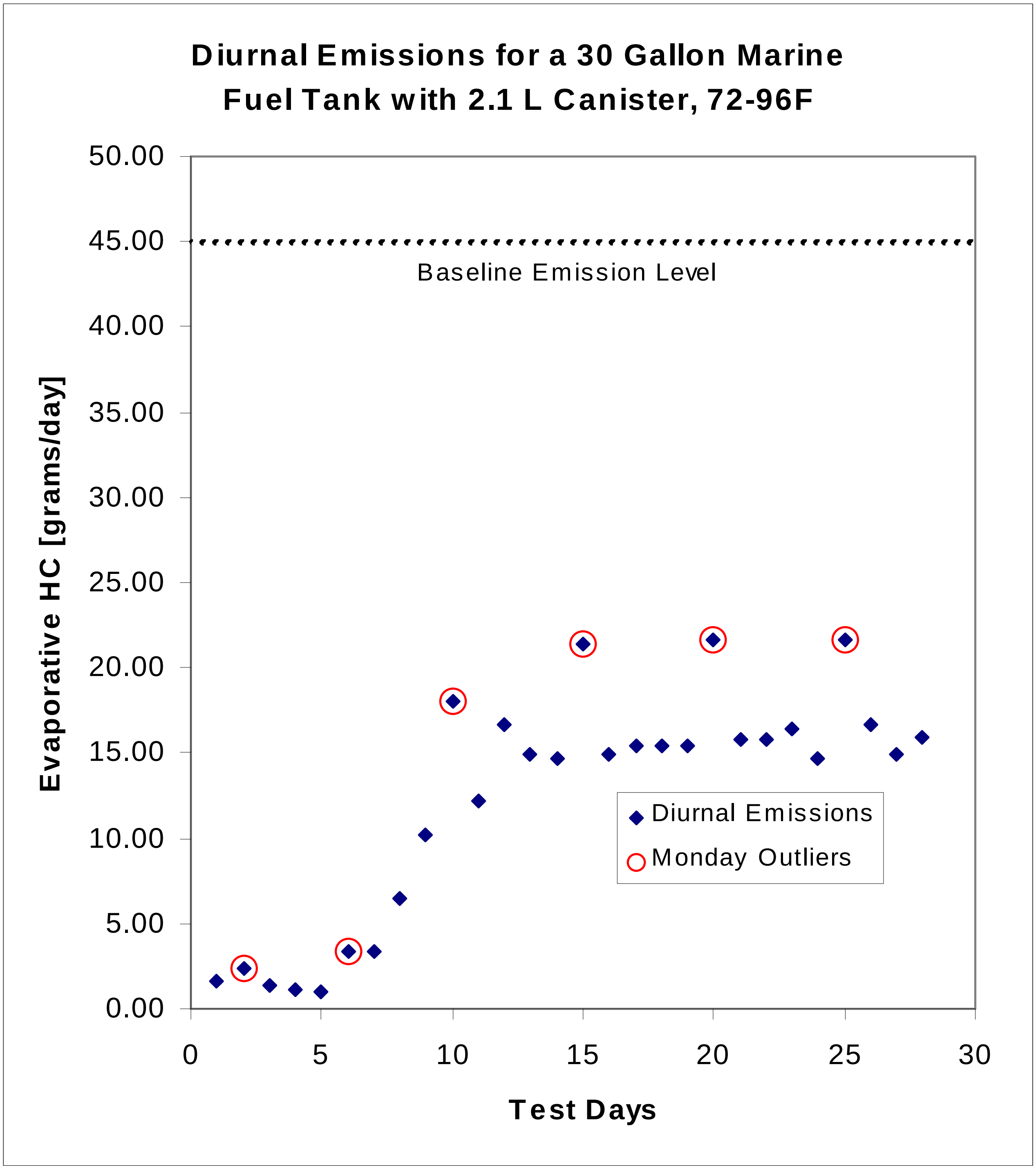


Figure 5B.2-4: Isothermal Diffusion Test Results for TP Plastic Fuel Tank



APPENDIX 5C: Diurnal Emission Results: Canister and Passive-Purge



APPENDIX 5D: Material Properties of Common Fuel System Materials

This appendix presents data on permeation rates for a wide range of materials that can be used in fuel tanks and hoses. The data also includes effects of temperature and fuel type on permeation. Because the data was collected from several sources, there is not complete data on each of the materials tested in terms of temperature and test fuel. Table D-1 gives an overview of the fuel systems materials included in the data set. Tables D-2 through D-3 present permeation rates using Fuel C, a 10 percent ethanol blend (CE10), and a 15 percent methanol blend (CE15) for the test temperatures of 23, 40, 50, and 60°C.

Table 5D-1: Fuel System Materials

Material Name	Composition
ACN NBR	acrylonitrile
Carilon	aliphatic poly-ketone thermoplastic
Celcon	acetal copolymer
CFM	fluoroelastomer
CO	epichlorohydrin homopolymer
CR	polychloroprene polymer
CSM	chlorosulfonated polyethylene
E14659	fluoropolymer film
E14944	fluoropolymer film
ECO	epichlorohydrin-ethylene oxide copolymer
ETER	epichlorohydrin-ethylene oxide terpolymer
ETFE	ethylenetetrafluoroethylene, fluoroplastic
EVOH	ethylene vinyl alcohol, thermoplastic
FEB	fluorothermoplastic
FEP	fluorothermoplastic
FKM	fluorocarbon elastomer
FPA	copolymer of tetrafluoroethylene and perfluoroalkoxy monomer
FVMQ	fluorovinyl methal silicone rubber (flourosilicone)
GFLT	fluoroelastomer
HDPE	high-density polyethylene
HDPE	high density polyethylene
HNBR	hydrogenated acrylonitrile-butadiene rubber
LDPE	low density polyethylene
NBR	acrylonitrile-butadiene rubber
Nylon 12	thermoplastic
PBT	polybutylene terephthalate, thermoplastic
PFA	fluorothermoplastic
Polyacetal	thermoplastic
PTFE	polytetrafluoroethylene, fluoroplastic
PVDF	polyvinylidene fluoride, fluorothermoplastic
THV	tetrafluoroethylene, hexafluoropropylene, vinyledene fluoride

Table 5D-2: Fuel System Material Permeation Rates at 23°C by Fuel Type [215,216,217,218,219,220]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
HDPE	35	–	35
Nylon 12, rigid	0.2	–	64
EVOH	–	–	10
Polyacetal	–	–	3.1
PBT	–	–	0.4
PVDF	–	–	0.2
NBR (33% ACN)	669	1028	1188
HNBR (44%ACN)	230	553	828
FVMQ	455	584	635
FKM Viton A200 (66%F)	0.80	7.5	36
FKM Viton B70 (66%F)	0.80	6.7	32
FKM Viton GLT (65%F)	2.60	14	60
FKM Viton B200 (68%F)	0.70	4.1	12
FKM Viton GF (70%F)	0.70	1.1	3.0
FKM Viton GFLT (67%F)	1.80	6.5	14
FKM - 2120	8	–	44
FKM - 5830	1.1	–	8
Teflon FEP 1000L	0.03	0.03	0.03
Teflon PTFE	–	–	0.05
Teflon PFA 1000LP	0.18	0.03	0.13
Tefzel ETFE 1000LZ	0.03	0.05	0.20
Nylon 12 (GM grade)	6.0	24	83
Nitrile	130	635	1150
Silicone Rubber	–	–	6500
Fluorosilicone	–	–	635
FKM	–	16	–
FE 5620Q (65.9% fluorine)	–	7	–
FE 5840Q (70.2% fluorine)	–	4	–
PTFE	0.05	–	0.08*
ETFE	0.02	–	0.04*
PFA	0.01	–	0.05*
THV 500	0.03	–	0.3

* tested on CM20.

Table 5D-3: Fuel System Material Permeation Rates at 40°C by Fuel Type [221,222]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
Carilon	0.06	1.5	13
EVOH - F101	<0.0001	0.013	3.5
EVOH - XEP380	<0.0001	–	5.3
HDPE	90	69	71
LDPE	420	350	330
Nylon 12 (L2101F)	2.0	28	250
Nylon 12 (L2140)	1.8	44	–
Celcon	0.38	2.7	–
Fortron PPS SKX-382	–	0.12	–
Celcon Acetal M90	–	0.35	–
Celanex PBT 3300 (30% GR)	–	3	–
Nylon 6	–	26	–
Dyneon E14659	0.25	–	2.1
Dyneon E14944	0.14	–	1.7
ETFE Aflon COP	0.24	0.67	1.8
m-ETFE	0.27	–	1.6
ETFE Aflon LM730 AP	0.41	0.79	2.6
FKM-70 16286	11	35	–
GFLT 19797	13	38	–
Nitrile	–	1540	3500
FKM	–	86	120
FE 5620Q (65.9% fluorine)	–	40	180
FE 5840Q (70.2% fluorine)	–	12	45
THV-310 X	–	–	5.0
THV-500	0.31	–	3.0
THV-610 X	–	–	2.1

Table 5D-4: Fuel System Material Permeation Rates at 50°C by Fuel Type [223]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
Carilon	0.2	3.6	–
HDPE	190	150	–
Nylon 12 (L2140)	4.9	83	–
Celcon	0.76	5.8	–
ETFE Afcon COP	–	1.7	–
FKM-70 16286	25	79	–
GFLT 19797	28	77	–

Table 5D-5: Fuel System Material Permeation Rates at 60°C by Fuel Type [224,225,226,227]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
Carilon	0.55	7.5	–
HDPE	310	230	–
Nylon 12 (L2140)	9.5	140	–
Celcon	1.7	11	–
ETFE Afcon COP	–	3.8	–
FKM-70 16286	56	170	–
GFLT 19797	60	130	–
polyeurethane (bladder)	285	460	–
THV-200	–	54	–
THV-310 X	–	–	38
THV-510 ESD	6.1	18	35
THV-500	–	11	20
THV-500 G	4.1	10	22
THV-610 X	2.4	5.4	9.0
ETFE 6235 G	1.1	3.0	6.5
THV-800	1.0	2.9	6.0
FEP	0.2	0.4	1.1

APPENDIX 5E: Diurnal Test Temperature Traces

Table 5E-1: Temperature vs. Time Sequence for Proposed Diurnal Testing

Test Time* [minutes]	Portable Fuel Tanks SHED Air Temperature		Installed Fuel Tanks Boat < 26 feet (7.9m) Fuel Temperature		Installed Fuel Tanks Boat ≥26 feet (7.9m) Fuel Temperature	
	Fahrenheit	Celsius	Fahrenheit	Celsius	Fahrenheit	Celsius
0	72.0	22.2	78.0	25.6	81.6	27.6
60	72.5	22.5	78.3	25.7	81.7	27.6
120	75.5	24.2	79.8	26.5	82.3	27.9
180	80.3	26.8	82.2	27.9	83.3	28.5
240	85.2	29.6	84.6	29.2	84.2	29.0
300	89.4	31.9	86.7	30.4	85.1	29.5
360	93.1	33.9	88.6	31.4	85.8	29.9
420	95.1	35.1	89.6	32.0	86.2	30.1
480	95.8	35.4	89.9	32.2	86.4	30.2
540	96.0	35.6	90.0	32.2	86.4	30.2
600	95.5	35.3	89.8	32.1	86.3	30.2
660	94.1	34.5	89.1	31.7	86.0	30.0
720	91.7	33.2	87.9	31.0	85.5	29.7
780	88.6	31.4	86.3	30.2	84.9	29.4
840	85.5	29.7	84.8	29.3	84.3	29.1
900	82.8	28.2	83.4	28.6	83.8	28.8
960	80.9	27.2	82.5	28.0	83.4	28.5
1020	79.0	26.1	81.5	27.5	83.0	28.3
1080	77.2	25.1	80.6	27.0	82.6	28.1
1140	75.8	24.3	79.9	26.6	82.4	28.0
1200	74.7	23.7	79.4	26.3	82.1	27.9
1260	73.9	23.3	79.0	26.1	82.0	27.8
1320	73.3	22.9	78.7	25.9	81.9	27.7
1380	72.6	22.6	78.3	25.7	81.7	27.6
1440	72.0	22.2	78.0	25.6	81.6	27.6

* Repeat as necessary

Chapter 5 References

1. Reddy, S., “Prediction of Fuel Vapor Generation From a Vehicle Fuel Tank as a Function of Fuel RVP and Temperature,” SAE Paper 892089, 1989, Docket Identification EPA-HQ-OAR-2004-0008-0169.

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CHAPTER 6: Costs of Control

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

6.1 Methodology

We developed the costs for individual technologies using estimates from ICF Incorporated[1], conversations with manufacturers, and other information as cited below. The technology characterization reflect our current best judgment based on EPA's technology demonstrations, engineering analysis, information from manufacturers, and the published literature.

Costs of control include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). Variable costs are marked up at a rate of 29 percent to account for the engine or equipment/vessel manufacturers' overhead and profit.[2] For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. Labor estimates are marked up by 100 percent to reflect fringe and overhead charges including management, supervision, general and administrative expenses, etc. All costs are in 2005 dollars.

The analysis presents an estimate of costs that will occur in the first year(s) of new emission standards and the corresponding long-term costs. Long-term costs decrease due to two principal factors. First, fixed costs are assessed for five years, after which they are fully amortized and are then no longer part of the cost calculation. Second, manufacturers are expected to learn over time to produce the engines with the new technologies or aftertreatment at a lower cost. Consistent with analyses from other programs, we reduce estimated variable costs by 20 percent beginning with the sixth year of production.[3] The small spark ignited engine industry and the marine industry have different reasons for the learning.

Learning for the Small SI industry is expected to occur in the catalyst muffler designs. It will likely occur for two reasons: 1) over time the number of different muffler catalyst designs may be reduced thereby decreasing substrate costs due to larger ordering volumes. 2) heat shield manufacturing may become automated and/or designs more uniform. Learning will not occur for other technologies such as electronic fuel injection systems for they currently exist on some Small SI equipment and motorized vehicles such as scooters .

In the marine industry, manufacturers are less likely to put in the extra R&D effort for low-cost manufacturing of engine families of relatively low sales volumes. Learning will occur in two basic ways. As manufacturers produce more units, they will make improvements in production methods to improve efficiency. The second way learning occurs is materials learning where manufacturers reduce scrap. Scrap includes units that are produced but rejected due to inadequate quality and material scrap left over from the manufacturing process. As production starts, assemblers and production engineers will then be expected to find significant improvements in fine-tuning the designs and production processes.

We believe it is appropriate to apply this learning factor here for the marine industries, given that they are facing new emission regulations, some for the first time, and it is reasonable to expect learning to occur with the experience of producing and improving emission-control technologies. Manufacturers do not have significant experience with most of the emissions controls that are anticipated for meeting the proposed standards.

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

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

6.2 Exhaust Emission Control Costs for Small SI Engines

This section presents our cost estimates for meeting the proposed exhaust emission standards for Small land-based spark-ignition (Small SI) engines.

In 1995, EPA finalized the first regulations for reducing emissions from small spark ignited (SI) engines <19kW. Small spark ignited engine designs include side valve and overhead valve engine configurations designated in two groups by engine displacement. Class I engines are <225cc and Class II engines are $\geq$225cc and less than 19kW. The Phase 2 regulations for these engines were set with the expectation that Class I side valve engines would be converted to overhead valve design. Certification data from 2005 shows that engine manufacturers have been able to achieve Phase 2 certification with the continued use of side valve engines in some cases. A summary of the 2005 technology market mix is presented in Table 6.2-1.

For the proposed Phase 3 standards, Class I engines are estimated to use catalysts and engine design improvements required to use catalysts safely. For Class II engines, different technologies were assigned depending on whether the engine was a one cylinder or a multiple cylinder engine. All one cylinder engines were estimated to use catalysts. For two or more cylinders, the largest engine family per engine manufacturer was assigned closed loop electronic fuel injection. The remainder were assigned catalysts with the appropriate muffler setup. The expected technology market mix is presented in Table 6.2-2.

Table 6.2-1: 2005 Technology Market Mix

	Class I	Class II
SV	65%	2%
OHV	35%	98%
w/ Catalyst	0.04%	0.2%
w/ Other (EFI and/or watercooled)	0	2%

Table 6.2-2: Technology Market Mix Expectations for Phase 3 Engines HC+NOx Emission Standards: 38% Reduction Class I, 34% Reduction Class II

Exhaust Standard Implementation Date	2012 Class I	2011 Class II
SV	65%	2%
OHV	35%	98%
w/ Catalyst	100%	72%
w/ Other (EFI and/or watercooled)	0	28%

The following sections describe the technologies and related variable and fixed costs followed by an analysis of aggregate costs. The costs are based on a report from ICF International entitled "Small SI engine Technologies and Costs."[4] Variable costs to the manufacturers vary with the engine size and the emission technologies considered. Manufacturers prices of all components were estimated from various sources including information from engine and catalyst manufacturers and previous work performed by ICF International on spark ignited engine technology. All hardware costs to the engine manufacturers are subject to a 29 percent mark-up. This includes manufacturer overhead, profit, dealer overhead and profit. A separate supplier markup of 29 percent is also applied to items typically purchased from a suppliers such as fuel injection and catalysts. A 5 percent warranty mark-up is added to hardware cost of specific technologies including electronics, to represent an overhead charge covering warranty claims associated with new parts.

Fixed costs to the manufacturer include the cost of researching, developing and testing a new technology. The cost of retooling the assembly line for the production of new parts as well as engine certification including durability testing are also fixed costs. Design and development fixed costs per month are listed in Table 6.2-3. Tooling and specific R&D costs are listed in the following sections. Fixed costs for certification are listed in Section 6.2.3.

Table 6.2-3: Design and Development Costs for use in Fixed Cost Estimates per Month [5]

	Hours	Rates	Costs
Design Costs Per Month			
Engineer	160	$64.41	$10,306
TOTAL Design Costs Per Month			$10,306
Development Costs Per Month			
Engineer	160	$64.41	$10,306
Technicians	320	$41.87	$13,398
Dynamometer Test Time	20 tests	$250 ea	$5,000
TOTAL Development Costs Per Month			$28,704

6.2.1 Class I

Class I engines currently emitting at or below the Phase 2 emission standard of 16.1 g/kWh will need to reduce their engine out HC+NOx emissions by 30-50 percent to comply with the proposed Phase 3 emission standard of 10 g/kWh with an appropriate margin. A number of Class I side valve (SV) engines have been redesigned for the Phase 1 and Phase 2 rulemakings, however SV and overhead valve (OHV) engines will need a different approach to meet these emission standards. One technology to reduce emissions to the Phase 3 levels is a three way catalyst with appropriate precious metal loading for minimal CO conversion. EPA work has shown that catalysts can function effectively through a dynamometer aging of 125 hours with a catalyst conversion of about the same amount at high hours as low hours[6]. The amount of conversion is only constrained by 1) the size of the catalyst to fit in the existing, or slightly larger, muffler, 2) residence time of the exhaust gas along with 3) muffler surface and exhaust gas temperature issues with respect to the amount of CO converted within a catalyst. EPA's work has been shown to convert HC+NOx within a range of 3.8-6.7 g/kW-h (median approx 5.7g/kW-h) on OHV engines and 3.8-10.3 g/kW-h on SV engines (median of 6.8 g/kW-h).

EPA's Phase 2 certification database lists OHV and SV engine HC+NOx emission levels at low hours, a deterioration factor (df) and resultant certification levels. Engine manufacturers with most regulated experience were considered for these df ranges. Engine families using credits to certify to the emission standard with ABT were not included.

Table 6.2-4: 2005 EPA Certification Database with Catalyst Assumptions[7]

Technology Type/UL	Engine Out "zero hours" (Min-Max)	DF (Min-Max)	Certification Level (Min-Max)	Catalyst conversion (median from EPA work)	Engine with Catalyst
SV/125	10-11	1-1.24	13-14	6.8	6.2-7.2
OHV/125	6-15	1-1.356	9-16	5.7	3.3-10.3
OHV/250	7-15	1-1.136	8-12	5.7	2.3-6.3
OHV/500	8-14	1-1.161	8-15	5.7	2.3-9.3

Table 6.2-4 is based on median HC+NOx catalyst conversion from EPA test work in the Safety Study.[8] The Safety Study also shows improvements in the cooling system design will provide cooling to the engine and/or catalyst muffler system for reduced muffler skin temperatures. Individual engine family applications will vary and engine improvements may be required for durable and effective catalyst operation.

6.2.1.1 Engine Improvements for Class I

Improvements in engine combustion efficiency and engine cooling will assure the engine systems support catalyst durability. Engine improvements for durable catalyst operation include changes that are fixed costs and variable costs. Improvements in engine systems resulting in fixed costs potentially include the following: 1) improved combustion chamber design for optimized combustion, 2) improved piston design for reduced crevice volumes and reduced HC emissions, 3) improved machining and casting tolerances for all combustion chamber components, 4) improved cylinder head fin design for improved cooling, and 5) improved carburetion for fuel delivery and system durability. Some engines would also benefit greatly from 6) improved flywheel design in order to provide additional cooling to the engine and muffler system. Clearly not all engines need these upgrades and many will implement few or none.

Fixed costs per engine family for engine improvements are estimated at four months of design work (one engineer) and six months of development work (one engineer, one technician and dynamometer test time) along with tooling costs for the cylinder head, piston, connecting rod, camshaft, carburetor, flywheel and setup changes. Tooling costs are estimated to be the same across engine useful life categories with the exception of Class I 125 hour SV engines which contains some engine families that are sold in much larger volumes and therefore would have more tools to be modified. These fixed costs are presented in Table 6.2-5.

Table 6.2-5: Fixed Costs for Engine Improvements for Class I[9]

Engine Class	Class I	
Useful life (hrs)	125	125,250,500
Valving	SV	OHV
R&D		
Design (4 months)	41,225	41,225
Development (6 months)	172,225	172,225
TOTAL R&D per Engine Line	213,450	213,450
TOOLING COSTS		
Cylinder Head	50,000	25,000
Piston	50,000	25,000
Connecting Rod	30,000	15,000
Camshaft	16,000	8,000
Carburetor	120,000	60,000
Flywheel	70,000	35,000
Setup Changes	150,000	75,000
TOTAL TOOLING per Engine Line	486,000	243,000
TOTAL FIXED	$699,450	$456,450

Variable cost items were identified from EPA field aging of engines from several engine manufacturers. EPA performed several lawnmower in-use test programs in 2003 to 2005. Several of the SV and OHV engines were equipped with catalysts. The process revealed that potentially several engine design characteristics needed improvement in some cases in order for catalysts to be successfully applied in-use. Items included: 1) fuel filter to screen out impurities (assure do not encounter a stuck float and thereby excessive fuel flowed through the engine coating the catalyst and rendering it inactive.), 2) incorporation of an intake gasket to assure leaks do not develop in the intake system thereby resulting in hot engine operation and a number of engine operational issues, 3) engine shroud screen over fan (avoid debris collecting in the engine fan), and 4) improved engine cooling system for SV engines to assure the engine's piston and combustion chamber walls stay in contact so oil does not seep past the rings and into the combustion chamber (see Chapter 4) thereby potentially poisoning the catalyst. Lastly, the incorporation of improved induction coils will reduce the opportunity for spark plug wire failures and misfire events. Table 6.2-6 lists the variable costs for engine improvements for Class I engines certified to various useful lives. Clearly not all engines need these upgrades to succeed and many will implement few or none.

Table 6.2-6: Variable Costs for Engine Improvements for Class I[10]

Engine Improvement	UL 125 SV	UL 125 OHV	UL 250	UL 500
Fuel Filter Screens (80% of engine sales) cost/engine: 0.02	0.02	0.02	0.02	--
Improved Intake Gaskets (75% of engine sales for Class I 125 hour useful life) cost/engine: 0.03	0.02	--	--	--
Screen over cooling fan (16% of 125 hr Class I) cost/engine: 0.45	0.07	0.07	--	--
Larger Induction Coils (all)	0.10	0.10	0.10	0.10
Engine Manufacturer Cost	0.21	0.19	0.12	0.10
TOTAL w/Markup 29% OEM	0.27	0.24	0.15	0.13
Learning Curve w/ 29% Markup (0.8*Total w/Markup)*1.29	0.22	0.19	0.12	0.10

6.2.1.2 Catalysts for Class I

The following paragraphs describe details on catalysts substrates, washcoat and precious metal, and muffler shielding for Class I engines. Although commonly in use today, spark arresters are discussed in the context of the overall design.

Based on catalyst/muffler development and emission testing by EPA (2004-2005), an engine which has an HC+NOx exhaust ratio of 60/40 is best suited for the use of a catalyst in Small SI engines for the catalyst can be designed for minimal CO oxidation and related heat generation. This ratio can be found on OHV engines for they have efficient combustion chambers. SV engines require slightly larger catalysts due to their less efficient combustion chambers and less than optimum HC/NOx ratios. In addition, SV engines are more likely to have oil seep past the piston rings due into the exhaust to cylinder distortion. A longer catalyst, or the use of a pipe catalyst prior to the brick catalyst, allows it to survive for the full useful life for the catalyst is poisoned from the front of the catalyst to the back. According to the EPA Phase 2 certification database, Class I SV engine families are certified to the 125 hour useful life and therefore the cost analysis includes two different catalyst costs for the 125 hour useful life.

The engines certified to the 250 and 500 useful life categories are all of OHV engine design. As with the 125 hour category, catalyst substrate sizes are calculated as a percentage of the engine displacement. The certification database was queried for this engine displacement data and the displacements are sales weighted, as seen in Table 6.2-7. Catalyst volumes range from 18 percent of the engine displacement for the 125 OHV useful life to 50 percent of the engine displacement for the 500 hour useful life. Larger catalysts are needed for longer useful life periods in order to provide the emission conversion durability. Specific costs for engines within each useful life category will differ.

The substrate cost is based on an average cost of metallic and ceramic substrates as presented in the ICF report[11] due to the variety of Small SI equipment types and variety of catalysts offered in the marketplace. This cost analysis estimatess equal weighting of the substrate types and therefore takes an average of the cost for both metallic and ceramic.

Due to the concern of oil sulfur poisoning in Class I engines, EPA envisions that a 5:1 ratio of Platinum/Rhodium precious metal would be used for these catalysts. The cost of precious metals was taken from a 3 year average in price from 2003-2005. Washcoat material is expected to be a 30%/70 percent mixture of cerium and alumina oxide, respectively.

The design of the catalyst/muffler forms the basis for the degree of cooling needed at the muffler and exhaust port. EPA's solution for muffler surface and exhaust gas cooling included three steps 1) forcing the cooling air from the engine fan/cylinder head region to the muffler can be achieved through a slight redesign of the engine's shroud, 2) a muffler shroud that is designed to guide the cooling air around the entire muffler and exits at a specified location, and lastly 3) and if when needed an ejector is added to the muffler at the exhaust gas outlet so the exhaust gas can be combined with ambient air before being accessible to the user.

EPA's observation of a number of lawnmower engine designs revealed that the majority of heat shields currently used on small engines need to be redesigned in order to allow the use of air flow from the engine's fan to flow optimally around the muffler for cooling. The portion of engines that do have such systems and will not incur this cost were removed from the cost analysis and ICF's estimates for this technology were adjusted. EPA utilized the 2005 certification database to estimate sales and to calculate a percentage of engines that will be estimated to redesign their muffler heat shield. Table 6.2-7 contains the variable costs for catalysts, heat shields and spark arresters.

Table 6.2-7: Variable Catalyst Costs for Class I[12] to Achieve Proposed Phase 3 Standards

Useful Life	UL 125 SV	UL 125 OHV	UL 250	UL 500
Engine Power (hp)	3.3	5.1	5.0	5.2
Engine Displacement (cc)	178	180	167	166
Catalyst Volume (cc)	45	32	55	83
Substrate Diameter (cm)	3.50	3.50	4.00	4.50
Substrate	$1.97	$1.53	$2.32	$3.22
Washcoat and Precious Metal	$1.83	$1.31	$2.81	$4.24
Labor	$1.40	$1.40	$1.40	$1.40
Labor Overhead 40%	$0.56	$0.56	$0.56	$0.56
Supplier Markup 29%	$1.67	$1.39	$2.06	$2.73
Catalyst Manufacturer Price	$7.43	$6.19	$9.15	$12.15
Heat Shield*	$0.50	$0.29	$0.18	$0.14
Spark Arrestors	$0.05	$0.05	$0.05	$0.05
Engine Manufacturer Cost	$7.98	$6.53	$9.38	$12.34
TOTAL w/Markup 29% OEM	$10.29	$8.42	$12.10	$15.92

* Based on EPA's work with small engine equipment from 2003-2005, it has been observed that some manufacturers have heat shielding that is sufficient or only needs slight modification. These sales volumes have been removed and the resultant price recalculated.

The fixed costs related to catalyst development for Class I engine applications include design (one engineer), of two months, and development (one engineer, one technician and dynamometer time), for five months, of the muffler and heat shield. The inside of the muffler is to be redesigned to house the catalyst, provide supplemental air when needed, and provide baffling for the exhaust flow in order to maximize heat dissipation from the exhaust flow. The muffler stamping will also need to be updated to account for the new design. A second critical component of the catalyst/muffler system is the heat shield. The heat shield must be designed to allow cooling air from the fan to flow around the muffler to maximize cooling of the muffler and then exit at an optimum point. The muffler/heat shield system must be located at a predetermined distance from the engine block in order to allow air to flow behind the muffler to cool the backside. Setup changes also are incurred with these modified stampings. The total tooling per engine line is estimated at $240,000 for Class I engines of 125 hour useful life and

$120,000 for Class I engines of other useful life periods. The difference is due to the additional tooling for high volume SV engine families. Table 6.2-8 presents the fixed costs associated with using catalysts on Class I engines.

Table 6.2-8: Fixed Costs for Catalysts for Class I Engines[13]

Engine Class	Class I	
Useful life (hrs)	125	125, 250, 500
Valving	SV	OHV
R&D		
Design (2 months)	20,612	20,612
Development (5 months)	143,521	143,521
TOTAL R&D per Engine Line	164,133	164,133
TOOLING COSTS		
Modified Muffler Stamping	100,000	50,000
Heat Shield Stamping	60,000	30,000
Engine Shroud Modification	30,000	15,000
Setup Changes	50,000	25,000
TOTAL TOOLING per Engine Line	240,000	120,000
TOTAL FIXED COSTS	$404,133	$284,133

A learning curve of 20 percent is applied to costs for catalyst technology starting in the sixth year after the standard is implemented. This somewhat conservative since the learning normally occurs at 20 percent with a doubling of production which would thus be in the third or fourth year. Optimized catalyst/muffler designs and manufacturing processes will likely be developed as the industry becomes experienced in using mufflers with catalysts on Small SI engines. The muffler washcoat will still be unique per engine family per engine manufacturer for engine out emissions will differ. Table 6.2-9 presents the estimated learning curve impacts on variable costs. The precious metal prices are determined in the marketplace and therefore would not be affected by the learning curve.

Table 6.2-9: Learning Curve Variable Catalyst Costs for Class I to Achieve Proposed Phase 3 Standards

Useful Life	UL 125 - SV	UL 125 - OHV	UL 250	UL 500
Engine Power (hp)	3.3	5.1	5.0	5.2
Engine Displacement (cc)	178	180	167	166
Catalyst Volume (cc)	45	32	55	83
Substrate Diameter (cm)	3.50	3.50	4.00	4.50
Substrate	$1.57	$1.22	$1.86	$2.58
Washcoat and Precious Metal	$1.83	$1.31	$2.81	$4.24
Labor	$1.40	$1.40	$1.40	$1.40
Labor Overhead	$0.56	$0.56	$0.56	$0.56
Supplier Markup 29%	$1.55	$1.30	$1.92	$2.55
Manufacture Price	$6.92	$5.80	$8.55	$11.32
Heat Shield (adjusted % for eng w/ sufficient heat shield)	$0.40	$0.23	$0.14	$0.11
Flame/Spark Arrester	$0.05	$0.05	$0.05	$0.05
Hardware Cost to Manufacturer	$7.37	$6.08	$8.74	$11.49
w/Markup 29% OEM	$9.50	$7.84	$11.28	$14.82

Table 6.2-10 contains the estimated total costs for Class I Phase 2 compliant engines to meet the Phase 3 emission standards. Near term costs are those costs for the first five years. Long term costs are those costs to which the learning curve has been applied.

Table 6.2-10: Class I Estimated Total Costs Per Engine (Variable) and Per Engine Family (Fixed) to Achieve Proposed Phase 3 Standards

Useful Life	UL 125 - SV	UL 125 - OHV	UL 250	UL 500
Engine Displacement (cc)	178	180	167	166
Catalyst Volume (cc)	45	32	55	83
Substrate Diameter (cm)	3.50	3.50	4.00	4.50
Variable Costs - Near Term				
Engine Improvements	$0.27	$0.24	$0.15	$0.13
Catalyst	$10.29	$8.36	$12.10	$15.92
Total Variable Cost (Near)	$10.56	$8.60	$12.25	$16.05
Variable Costs - Long Term (with Learning)				
Engine Improvements	$0.22	$0.19	$0.12	$0.10
Catalyst	$9.50	$7.84	$11.28	$14.82
Total Variable Cost (Long)	$9.72	$8.04	$11.39	$14.92
Fixed Costs				
Engine Improvements	$699,450	$456,450	$456,450	$456,450
Catalyst	$404,133	$284,133	$284,133	$284,133
Total Fixed Costs	$1,103,583	$740,583	$740,583	$740,583

6.2.2 Class II

The proposed Phase 3 HC+NOx emission standard for Class II is 8 g/k-Wh which is a 34 percent emission reduction from the Phase 2 standards of 12.1 g/k-Wh. This standard is to be met at the end of the regulatory useful life for each engine family. The EPA Phase 2 certification database shows that the majority of engines in this Class are of OHV design however, approximately 2 percent of the engines are still side valve engine technology.

Class II side valve engines are currently certified to the Phase 2 standards with credits from lower emitting OHV engines. The EPA 2005 certification database shows he majority of overhead valve engines currently certifying HC+NOx at a range of 7-11 g/kW-h and side valve engines certifying in the range of 13-20 g/kW-h. Lowering of the emission standard will reduce the number of emission credits available for side valves to certify and therefore, it is assumed that the remaining side valve engines will be phased out and replaced with currently produced overhead valve engines or continue to be certified using ABT credits from a limited number of lower emitting engine families.

Assuming a 2 g/kW-h compliance margin to 6 g/kW-h, emission reduction technologies will need to be designed to reduce emissions 15-45 percent. Table 6.2-11 illustrates potential engine out emissions with emission reduction technologies applied to Phase 2 engines. OHV engines are expected to potentially include some engine improvements and/or catalysts or electronic fuel injection.

Table 6.2-11: 2005 EPA Certification Database Summary With Catalyst Assumptions[14]

UL OHV	Engine Out "zero hours" (Min-Max)*	DF (Min-Max)**	Certification Level (Min-Max)*	Catalyst conversion (non-EFI engine)[15]	Engine with Catalyst (Based on Median values)
250	4.8-10.0 Median: 7.9	1-1.7 Median: 1.137	6.7-12.0 Median: 8.9	4.0	2.7-8.0
500	4.4-10.8 Median: 8.3	1-1.6 Median: 1.039	5.9-10.9 Median: 9.5	4.0	1.9-6.9
1000	6.0-11.2 Median: 8.4	1-1.4 Median: 1.03	6.9-11.2 Median: 8.9	4.0	2.9-7.2

* Values of engines that meet the standard. 500 hr UL has a liquid cooled engine with catalyst that meets a 2.6 g/kW-h HC+NOx and 1000 hr UL has the same that meets 1.8 g/kW-h HC+NOx.
**Some engines have catalysts and therefore claim a higher df

Class II contains several liquid cooled engines. These engines likely have the ability to be enleaned to more of a degree due to the additional cooling assistance and therefore may not need a catalyst to meet the Phase 3 proposed emission standards.

6.2.2.1 Engine Improvements for Class II

Engine improvements include improved engine design and larger induction coils as shown in Tables 6.2-12 and 6.2-13. Improvements in engine design will allow for more efficient combustion and a more favorable HC:NOx ratio for the use of a reducing catalyst. A larger induction coil will reduce the opportunity for spark plug wire failure and misfire events. It is estimated that 1000 hour engines currently have sufficient induction coils and will not need this improvement.

Table 6.2-12: Variable Costs for Engine Improvements for Class II per Engine[16]

	UL250	UL 500	UL 1000
Larger Induction Coils	0.09	0.09	--
TOTAL w/Markup 29% OEM	0.12	0.12	--
Learning w/29% OEM (0.8*Total)*1.29	0.10	0.10	--

Improved engine design includes machining and casting tolerances, improved combustion chamber configuration, reduced crevice volumes, better cooling (improved fin design on cylinder head and oil control), improved flywheel design and improved carburetion. Better carburetor performance is needed to assure floats do not stick and better cooling so engines operate at cooler temperatures. Fixed costs include design (one engineer at 4 months), development and tooling costs (one engineer, one technician and dynamometer time for 6 months) per engine family to achieve improved engine design. Projected fixed costs are presented in Table 6.2-13. The fixed cost is estimated to be the same per engine family and is estimated at $456,450.

Table 6.2-13: Fixed Costs for
Engine Improvements for Class II per Engine Family[17]

Engine Class	Class II
Useful life (hrs)	250,500,1000
Valving	OHV
R&D	
Design (4 months)	41,225
Development (6 months)	172,225
TOTAL R&D per Engine Line	213,450
TOOLING COSTS	
Cylinder Head	25,000
Piston	25,000
Connecting Rod	15,000
Camshaft	8,000
Carburetor	60,000
Flywheel	35,000
Setup Changes	75,000
TOTAL TOOLING per Engine Line	$243,000
TOTAL FIXED	$456,450

6.2.2.2 Catalysts for Class II

Further emission reduction can be achieved through the use of catalysts. The catalyst must be designed for durability throughout the engine's regulatory useful life. A catalyst efficiency of 25-45 percent is estimatedd for these engines. The catalyst technology that would be utilized would be similar to that used for Class I engines. The exceptions include 1) Class II engines would not use supplemental air because the HC and NOx ratios are more favorable in Class II OHV engines due to their more efficient combustion chamber and larger displacement and horsepower, and 2) the precious metals in the catalysts range from platinum/palladium/rhodium for 250 and 500 hour Class II engines to to palladium/rhodium (5:1) for 1000 hour regulatory useful life engines.

Class II engine designs include engines 1 to 4 cylinders. Engines with two or more cylinders have specific issues to be considered in terms of safety with regard to engine exhaust and catalyst use and this will be addressed towards the end of this section. The variable costs for catalysts of single cylinder engines are listed in Table 6.2-14. The catalyst substrate size is calculated based on the engine displacement size. To utilize one value per regulatory useful life category for this analysis, the engine horsepower and displacements were sales weighted with values from the 2005 EPA certification database information. Catalyst volumes range from 33 percent of the engine displacement for the 250 useful life to 50 percent of the engine displacement for the 1000 hour useful life. Larger catalysts are needed for longer useful life periods in order to provide the emission conversion durability.

Catalyst substrate and heat shield variable costs will be decreased in the sixth year with a learning curve of 20 percent. This somewhat conservative since the learning normally occurs at 20 percent with a doubling of production which would be in the third or fourth year. Optimized catalyst/muffler designs and heat shield manufacturing processes will likely be developed as the industry becomes experienced in application of the catalyst technology across their product line. The muffler washcoat will likely still be unique per engine family per engine manufacturer and therefore it is estimated there will likely not be a one size fits all catalyst/muffler design. The precious metal prices are determined in the marketplace and therefore are not discounted over time.

Table 6.2-14: Variable Catalyst Costs for Class II OHV Single Cylinder Engine HC+NOx Emission Reduction to Phase 3 Standards

	Near Term Estimates			Learning Curve Estimates		
Useful Life	250	500	1000	250	500	1000
Engine Power (hp)	11.3	11.1	9.5	11.3	11.1	9.5
Engine Displacement (cc)	406	338	329	406	338	329
Catalyst Volume (cc)	134	135	165	134	135	165
Substrate Diameter (cm)	5.25	6.00	7.00	5.25	6.00	7.00
Substrate*	$4.78	$4.81	$5.67	$3.82	$3.84	$4.53
Washcoat and Precious Metal	$4.03	$2.73	$4.10	$4.03	$2.73	$4.10
Labor	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Labor Overhead 40%	$0.56	$0.56	$0.56	$0.56	$0.56	$0.56
Supplier Markup 29%	$3.12	$2.75	$3.40	$2.84	$2.47	$3.07
Manufacture Price	$13.89	$12.25	$15.13	$12.65	$11.00	$13.66
Heat Shield	$4.23	$3.96	$4.05	$3.38	$3.17	$3.24
Spark Arrestor	$0.10	$0.05	$0.05	$0.10	$0.05	$0.05
Hardware Cost to Manufacturer	$18.22	$16.26	$19.23	$16.14	$14.23	$16.95
w/Markup 29% OEM	$23.50	$20.97	$24.80	$20.82	$18.35	$21.87

* 50/50- split of metallic vs ceramic substrates

Fixed costs involve modification to the existing heat shield and cooling system. If the muffler is in close proximity to the engine fan then cost for a heat shield can also be included because in some cases the heat shields will need to be improved in order to direct cooling air from the engine's flywheel over the muffler for muffler cooling. These fixed costs are presented in Table 6.2-15.

Table 6.2-15: Fixed Costs for Class II OHV Single Cylinder Engine

Engine Class	II
Useful life (hrs)	125, 250, 500
Valving	OHV
R&D	
Design (2 months)	20,612
Development (5 months)	143,521
TOTAL R&D per Engine Line	164,133
TOOLING COSTS	
Modified Muffler Stamping	50,000
Heat Shield Stamping	30,000
Engine Shroud Modification	15,000
Setup Changes	25,000
TOTAL TOOLING per Engine Line	120,000
TOTAL FIXED COSTS	$284,133

Carbureted V-Twins

Carbureted engines with more than one cylinder, ex: V-twins or more, have special concerns when considering the use of catalyst application. Multi-cylinder engines may continue to run if one cylinder misfires or does not fire at all. If this occurs, the results is raw unburned fuel and air from one cylinder and hot exhaust gases from the other cylinder combining in the muffler. In a catalyst muffler, this condition will likely result in continuous backfire which would create high temperatures within the muffler and potentially destroy the catalyst. One solution is to have separate catalyst mufflers for each cylinder. The two cylinders in the V-twins currently share one muffler. If two mufflers are used, then the individual mufflers would likely need to be slightly larger. Each individual muffler would need to be 25-30 percent larger than one half the volume of the original. Since the two cylinders in the V-twins currently share one muffler one option for consideration would be to package the two catalysts in separate chambers within one larger muffler.

Costs for this new muffler design are listed in Tables 6.2-16 and 6.2-17. V-twin engines from EPA's certification database were sales weighted for power and engine displacement per regulatory useful life. ICF provided the estimates for existing muffler costs and new muffler cost estimates.[18]

Table 6.2-16: Variable Costs for Change to Two Mufflers for V-Twins[19]

	250 OHV	500 OHV	1000 OHV
Engine Power (hp)	16.3	20.1	17.1
Engine Displacement - Total (cc)	605	632	627
Per Cylinder Displacement (cc)	393	411	408
Current Muffler Cost	($20.24)	($23.13)	($22.57)
New Muffler Cost (includes 2)	$26.31	$30.07	$29.34
Hardware Cost to Manufacturer	$6.07	$6.94	$6.77
OEM Markup @ 29%	$1.76	$2.01	$1.96
Total Component Costs	$7.83	$8.95	$8.73

Fixed costs include modified muffler stamping, exhaust pipe changes and setup changes. These costs are estimated at $100,000 per engine family. Special considerations were not accounted for in the case where OEM's obtain their own muffler and assemble the muffler onto the engine once the engine is received from the engine manufacturer. This analysis considers that in most cases equipment manufacturers would buy their catalyst mufflers from the engine manufacturer in order to avoid engine certification.

Table 6.2-17: Fixed Costs for Change to Two Mufflers for V-Twins[20]

	250 OHV	500 OHV	1000 OHV
Engine Power	16.3hp	20.1hp	17.1hp
Engine Displacement - Total (cc)	605	632	627
Per Cylinder Displacement	393	411	408
Modified Muffler Stamping	$50,000	$50,000	$50,000
Exhaust Pipe Changes	$25,000	$25,000	$25,000
Setup Changes	$25,000	$25,000	$25,000
Total Tooling per Engine Line	$100,000	$100,000	$100,000

In this analysis, catalyst sizes are related to the engine cylinder size and therefore since cylinders of V-twin engines are smaller than one cylinder Class II engines, costs are recalculated from Table 6.2-14. Note that one catalyst is used in each muffler for a total of two catalysts. Tables 6.2-18 and 6.2-19 present the projected variable and fixed catalyst costs for Class II OHV V-twin engines.

Table 6.2-18: Variable Catalyst Costs for Class II OHV V-Twin Engine, Near Term and Learning Curve Effect

	Near Term Costs			Learning Curve Effect		
Useful Life	250	500	1000	250	500	1000
Engine Power (hp)	16.3	21.0	17.1	16.3	21.0	17.1
Engine Displacement per Cylinder	303	316	314	303	316	314
Catalyst Volume (cc)	100	126	157	100	126	157
Substrate Diameter (cm)	5.00	5.00	5.50	5.00	5.00	5.50
Substrate*	$3.74	$4.55	$5.44	$2.99	$3.64	$4.35
Washcoat and Precious Metal	$3.00	$2.55	$3.91	$3.00	$2.55	$3.91
Labor	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Labor Overhead 40%	$0.56	$0.56	$0.56	$0.56	$0.56	$0.56
Supplier Markup 29%	$2.52	$2.63	$3.28	$2.31	$2.36	$2.96
Manufacture Price per Catalyst	$11.22	$11.68	$14.59	$10.26	$10.51	$13.19
Two Catalysts ($x2)	$22.45	$23.36	$29.18	$20.52	$21.02	$26.37
Heat Shield (2)	$8.53	$9.76	$10.50	$6.82	$7.81	$8.4
Spark Arrestor (2)	$0.20	$0.10	$0.10	$0.20	$O.10	$0.1
Hardware Cost to Manufacturer	$31.18	$33.22	$39.79	$27.54	$28.92	$34.87
Markup 29% OEM	$9.04	$9.63	$11.54	$7.99	$8.39	$10.11
New Muffler Differential	$7.83	$8.95	$8.73	$6.26	$7.16	$6.98
TOTAL COST	**$48.05**	**$51.80**	**$60.06**	**$41.97**	**$44.76**	**$51.97**

* 50/50- split of metallic vs ceramic substrates

Table 6.2-19: Fixed Costs for Class II OHV V-Twin Engine

Useful Lives	250, 500, 1000
R&D COSTS	
Design (2 months)	$20,612
Development (5 months)	$143,521
TOTAL R&D	$164,133
TOOLING COSTS	
Heat Shield Stamping	$50,000
Engine Shroud Modification	$25,000
Setup Changes	$25,000
New Muffler Design	$100,000
Total Tooling per Engine Line	$200,000
TOTAL FIXED COSTS	$364,133

Electronic Fuel Injection

Electronic fuel injection (EFI) is another solution for engines with two or more cylinders. EFI will allow more equal fuel delivery between or among the engine cylinders. In addition, it enables better atomization and more efficient fuel delivery during load pickup. If an engine family is somewhat close to the Phase 3 standard currently then EFI may allow the engine to meet the emission standards without a catalyst. If a small catalyst is needed, EFI allows the engine to be setup for cylinder monitoring and can be shut down if all cylinders are not operating properly. Due to the anticipated higher cost for EFI compared to catalyst, EPA estimates that each engine manufacturer will initially apply EFI to the engine family, of two or more cylinders, with the highest sales volume. Table 6.2-20 lists the estimated costs to apply electronic fuel injection. The cost tables include subtracting the existing carburetor.

Table 6.2-20: Variable Costs for Electronic Fuel Injection - Open and Closed Loop For Class II Engines and Applications with a Battery[21]

	Open Loop EFI	Closed Loop EFI
Injectors	8.00	8.00
Pressure Regulator	3.75	3.75
ECM/MAP Sensor	27.00	27.00
Throttle Body	2.75	2.75
Air Temperature Sensor	1.50	1.50
Fuel Pump	10.50	10.50
Oxygen Sensor	--	7.00
Wiring/Related Hardware	12.00	12.00
HARDWARE COST TO MANUFACTURE	66.75	73.75
OEM markup @ 29%	19.36	21.39
Warranty Markup @ 5%	2.85	3.69
Total Component Cost	88.96	98.83
Remove existing carburetor ($15) marked up 29%	-19.35	-19.35
EFI Technology Difference	$69.61	$79.48

Fixed costs for electronic fuel injection are listed in Table 6.2-21. Open loop fuel injection requires more research and development time due to the fact that it does not use an oxygen sensor to keep the air/fuel ratio in check. This analysis estimatess all engines using electronic fuel injection will be developed as closed loop fuel injection systems.

Table 6.2-21: Fixed Costs for Electronic Fuel Injection - Open and Closed Loop For Class II Engines and Applications with a Battery

	Open Loop	Closed Loop
Design	\$41,225	\$20,612
Development	\$229,633	\$57,408
Modified Exhaust Manifold for O_2 Sensor	---	\$25,000
Total Fixed Costs	\$270,858	\$103,020

6.2.2.3 Equipment Costs

The majority of Class I engines are sold as a unit and therefore the engine, fuel tank and muffler are provided by the engine manufacturer to the equipment manufacturer. As shown in EPA's Technical Study on the "Safety of Emission Controls for Nonroad Spark-Ignition Engines <50 Horsepower", catalysts can be applied to Class I engines such that muffler temperatures are equal to or less than those of the current Phase 2 product with minimal changes to the engine package. Some engines may require larger mufflers to house a catalyst depending on current muffler design. However the majority of equipment housing Class I engines are close coupled to the engine with open access for air cooling and therefore it no equipment redesign costs are applied to equipment manufacturers.

The majority of Class II engines are not sold as a unit. The current industry practice includes equipment manufacturers purchasing the muffler separate from the engine. Based on conversations with industry it is believed that for several reasons this practice will change to the dominant practice being the equipment manufacturer purchasing the muffler from the engine manufacturer. The offerings by the engine manufacturer will likely be influenced by the largest customers and smaller equipment manufacturers will have a few set models from which to choose. A limited amount of equipment redesign will be required on products.

EPA's work with catalysts in mufflers of two one-cylinder Class II lawn tractor engines has revealed that the current muffler on this equipment type has plenty of room to accommodate the catalyst and internal baffling to promote cooling of the exhaust gases. Smaller mufflers are used in other applications in which engine noise is not of concern. EPA did not work with these mufflers and therefore, it is uncertain if the catalyzed muffler will work in these mufflers. It is possible that a larger muffler can may be required to accommodate the catalyst.

Changes that will be required on Class II engines with catalysts includes a heat shield for the muffler (counted in catalyst costs), necessary sheet metal to direct cooling from the engine flywheel to the muffler and any equipment design changes to accommodate a different engine envelope.

Incorporating shrouding to direct the cooling air to and around the muffler is of most importance. The shrouding added includes extending and rerouting some of the engine sheet metal that is used to direct the air-flow out of the engine cylinder and blocking off the usual air exit into the engine compartment. The air is routed out the bottom of the chassis instead. In EPA's Class II one cylinder engine testing, the "touch-guard" was boxed in by closing off it's slots, closing off one end, and reducing the size of the opening on the opposite end. The exhaust exit was re-routed to a different location, and an ejector was added over the top of the exhaust. The amount of additional metal is fairly minimal and relatively thin-gage. The best examples are the Kohler CV490 on one of the Craftsman tractors and the Kohler SV590 on the Cub Cadet. Detailed photos of the SV590 installation can be found in EPA's Safety Study.[22]

For equipment that use engines with catalysts and require heat shield or equipment design changes, variable costs are estimated for the sheet metal and/or engine structure redesign at $1.30 per piece of equipment. Since a portion of engines are assigned to EFI, or will likely not require additional heat shield or equipment modifications due to current equipment design, it is estimated that 60 percent of equipment will utilize increased sheet metal and/or engine structure redesign. This yields a sales weighted average of $0.78 per equipment. Fixed costs for R&D for the added sheet metal design and/or engine restructure are estimated at $30,000 per equipment model and tooling changes are also estimated at $45,000 per model. These estimates are based on the estimates for developing and applying heat shields in the catalyst cost estimates for Class II and can be seen in Table 6.2-22.

Table 6.2-22: Average Equipment Costs Per Equipment Model

	Variable Costs	Fixed Costs
Heat Shield	-0- included in catalyst costs	-0- included in catalyst costs
Additional material for equipment redesign or air entrainment pathway	1.30 per equipment 0.78 avg over all for 60% of equipment	n/a
R&D	n/a	30,000
Tooling Changes	n/a	45,000

6.2.3 Compliance and Certification

The certification and compliance costs include engine dynamometer aging as well as emission testing pre- and post-aging. Certification and compliance costs are included in this analysis as fixed costs. After preliminary emission testing, engines are aged on the dynamometer to the regulatory useful life. The aged engines are then emission tested. The engine's emission levels must be below the proposed standards. If not, then the engine family cannot be certified unless the excesses are offset with other engine families within a manufacturers product line and the manufacturer must be involved in the averaging, banking and trading program. Engine families will need to certify to the new emission standards using the updated test procedure found in Chapter 4.

The Phase 2 certification database was used as the basis for the number of engine families to be certified to these proposed standards. The 2005 Certification database contains a number of engine manufacturers that have certified to the Phase 1 emission standards (1997) as well as a large number of additional engine manufacturers that have certified to the Phase 2 standards (2002).

6.2.3.1 Measurement Protocol 1065 Compliance Costs

New to the small engine industry are the 1065 protocols for gaseous emission measurement. These protocols are found in 40 CFR Part 1065. Depending on the analyzing equipment used by the industry, the certification analyzers may have to be upgraded to the estimated cost of $250,000. It is possible that less costly upgrades on some analyzers will be available. A CVS system can be assembled for $50,000 given manufacturer ingenuity.

6.2.3.2 Certification Costs

Certification costs include emission testing after a short engine break-in period and aging on a dynamometer to the full useful life and then repeat emission testing. Costs for dynamometer aging of each Class and corresponding useful life are found in ICF's report "Small SI Engine Technologies and Costs."[23] The costs per dynamometer aged engines are estimated in Table 6.2-3. are based on test setup, data analysis, engine aging operation, dyno costs, scheduled maintenance, prototype engine cost and fuel.

Table 6.2-23: Dynamometer Aging Certification Costs Per Class and Useful Life

CLASS I		CLASS II	
125	$9,532	250	$18,413
250	$17,462	500	$34,658
500	$33,353	1,000	$70,069

The costs for the emission compliance tests are found in Tables 6.2-24 and 6.2-25 and they are the same for each engine regardless of useful life category. A total of two emission tests after break-in and two at end of useful life are accounted for in this cost analysis. The emission test costs are estimated at $2,012 each and are based on the costs for a private test laboratory in 2005.[24]

Table 6.2-24: Emission Testing Costs Per Class

CLASS I		CLASS II	
all useful lives	$8,048	all useful lives	$8,048

Table 6.2-25: Per Engine Family Emission Testing and Dynamometer Aging Costs Per Class and Useful Life

CLASS I		CLASS II	
125	$17,580	250	$26,461
250	$25,510	500	$42,706
500	$41,401	1,000	$78,117

6.2.4 LPG/CNG Engine Costs

Engine manufacturers and equipment manufacturers certify engines to run on LPG. The number of engine families are obtained from EPA's 2005 Certification Database. Certification costs found in Section 6.2.3.2 apply to these engines. Part 1065 compliance costs are not applied since the engine manufacturers are the same as listed in the gasoline section (costs already applied) and it is estimated that equipment manufacturers contract with a test lab due to the high cost of maintaining an individual test lab.

For engine certification, all engine families will be required to be tested for baseline emissions, see Table 6.2-26. Small volume engine manufacturers with a production of 10,000 engines or less can utilize an assigned deterioration factor and do not have to undergo dynamometer aging or end of life emission testing. Those listed under dynamometer aging in Table 6.2-26 will need to age the engines and perform end of life emission testing. Several families were also removed from 250 useful life Class II for they sufficiently met the proposed Class II standard. Table 6.2-26 lists 3 engine families in Class I and 37 engine families in Class II for certification.

Table 6.2-26: Number of Engine Families Per Class and Useful Life Designation for Fixed Cost Analysis

CLASS I				CLASS II			
UL	BaselineEmission Testing	Dynamo-meter Aging + End of Life Emission Testing	Catalyst Dev	UL	Baseline Emission Testing	Dynamo-meter Aging + End of Life Emission Testing	Catalyst Dev
125	1	1	1	250	11	11	7*
250	2	2	1	500	19	6**	17***
500	--	--	--	1000	7	7	7

* Two engine families were sufficiently below the Phase 3 standard

** For Phase 3, companies with small volume production (<10,000) can use an assigned df.

***Eight engine families had catalysts however only one sufficiently met the Phase 3 standard and therefore the remaining seven engine families will need new catalyst designs to reduce HC+NOx.

Table 6.2-27 lists the certification costs as incurred.

Table 6.2-27: Certification Costs As Incurred - LPG

	Class I	Class II
Year	2012	2011
Baseline Emission Testing	$12,072	$148,888
Dynamometer Aging	$26,994	$900,974
End of Life Emission Test	$8,048	$96,576
Total	$47,114	$1,146,438

As mentioned above, the technology to reduce emissions to the Phase 3 levels is catalysts. Catalysts are currently being utilized on LPG engines as shown in EPA's 2005 Certification Database. Basic engine improvement design changes, accounted for in the gasoline engine families, were not accounted for in these engines for they were already made in the base engine before they were converted to run on LPG/CNG. Costs that will be applied to these engines are R&D for catalyst formulation and variable parts costs which will need to be formulated for the exhaust makeup from these engines. The majority of these engines are two cylinder engines, however the concerns of the application of catalysts to these engine designs are relieved in that eight of the V-twin LPG engines are already certified with catalysts. Costs for catalyst system redesign for seven of the eight engine families are included in order for these families to meet the Phase 3 standards. Table 6.2-28 lists the R&D and Tooling costs for catalysts for LPG. Table 6.2-29 contains the totals for fixed cost for each class given the total number of engine families listed in Table 6.2-26 (3 in Class I and 37 in Class II).

Table 6.2-28: Fixed Costs for Class II OHV Single Cylinder Engine - LPG

Engine Class	II
Useful life (hrs)	125, 250, 500
Valving	OHV
R&D	
Design	$20,612
Development (5 months)	$143,521
TOTAL R&D per Engine Line	$164,133
TOOLING COSTS	
TOTAL TOOLING per Engine Line	0*
TOTAL FIXED COSTS	$164,133

*LPG engines are modified from gasoline version engines. Tooling costs are not included for it is estimated that catalyst volume for these engines will be determined based on a percentage of engine displacement, as the gasoline version, and therefore the catalysts will fit into the same muffler space.

Table 6.2-29: Total Fixed Costs for LPG Engine Families, as Incurred, 2005$

	Class I	Class II
	2012	2011
Catalyst R&D	$492,399	$6,072,921
Certification Cost	$47,114	$1,146,438
TOTAL	$539,413	$7,219,359

Certification data on gaseous fueled engines show that the HC:NOx ratio is higher in NOx than in HC which is opposite from gasoline engines. Platinum will be used in the precious metal mixture in order for the oxygen reduced from the NOx to be utilized to convert CO due to the lack of HC. For Class I engines, the cost estimate presented in Table 6.2-7 is applicable because it is calculated with a platinum/palladium/rhodium ratio of 5/0/1. For Class II engines, the 500 and 1000 hour catalyst cost estimates will be modified in order to include more platinum and all useful life periods will have resized catalysts based on the sales weighted engine displacement in the certification listing of LPG engines. Table 6.2-30 lists the variable catalyst costs for Class II OHV Engines, 250 and 500 hour useful life engines (no 1000 hour UL engines are listed in the LPG certification). Two to three cylinder engines have higher displacement and therefore costs are recalculated for those engine designs.

Table 6.2-30: Variable Catalyst Costs for Class II OHV Engines - LPG HC+NOx Emission Reduction to Phase 3 Standards

	1 cylinder			2 cylinders		
Useful Life	250	500	1000**	250	500	1000
Engine Power (hp)	13.8	17.8	-	18.2	19.2	23
Engine Displacement (cc)	415	389	-	597	743	751
Engine/Catalyst	33%	40%	-	33%	40%	50%
Catalyst Volume (cc)*** (per cylinder)	137	156	-	197	297	376
Substrate Diameter	5.25	6.00	-	5.00	5.00	5.50
Substrate* (per cylinder)	5.55	8.91	-	3.70	5.20	6.34
Washcoat and Precious Metal	4.24	4.82	-	2.96	4.46	8.86
Labor	$1.40	$1.40	-	$1.40	$1.40	$1.40
Labor Overhead 40%	$0.56	$0.56	-	$0.56	$0.56	$0.56
Supplier Markup 29%	$3.41	$4.55	-	$2.50	$3.37	$4.97
Manufacture Price (per catalyst)	$15.16	$20.24	-	$11.12	$14.99	$22.14
Total Catalyst Cost	$15.16	$20.24		$22.24	$30.00	$44.24
Heat Shield (2 for v-twin)	$4.23	$4.26	-	$5.90	$6.92	$7.32
Spark Arrestor (2 for v-twin)	$0.10	$0.05	-	$0.20	$0.10	$0.10
Hardware Cost to Manufacturer	$19.49	$24.55	-	$28.34	$37.00	$51.69
w/Markup 29% OEM	$25.14	$31.67	-	$8.22	$10.73	$14.99
Add’l Muffler for V-twin	-	-	-	$7.83	$8.95	$8.73
Total Catalyst Cost for LPG engines	$24.14	$31.67	-	$44.40	$56.68	$75.41
Total Catalyst Cost for Gasoline Engines	$23.50	$20.97	-	$48.05	$51.80	$60.06
Cost Difference	$1.64	$10.70	-	-$3.66	$4.87	$15.37

* 50/50- split of metallic vs ceramic substrates

** No one cylinder LPG engines are certified to the 1000 hour useful life

*** these catalyst volumes were calculated from the engine disp in EPA’s certification data for 2005

Calculations for the rulemaking have been completed using gasoline assumptions. To account for the increase in costs due to some of the gasoline engines being used as LPG engines, an increase in the total cost is added to the current gasoline engine variable cost total.
Table 6.2.-31 is an example of costs for 2012 in 2005$.

Table 6.2-31: Change in Variable Cost in 2012, 2005$

	Total Engine Sales Estimate per Useful Life 2012	% of LPG/CNG Engines in Useful Life per Class	# of Cyl	Number of Engines with change in Cost Estimate	Variable Cost Change in 2012	Total Change in costs in 2012 2005$
Class I						
125 OHV	2,953,419	0%	1	200	0*	0
250	905,005	1.34%	1	4,500	0	0
500	623,431	0.95%	1	5,398	0	0
Class II						
250	3,334,488	0.67%	1	14,500	$1.64	$23,780
			2	10,469	-$3.65	-$38,306
500	724,231	12.07%	1	12,918	$10.70	$138,172
			2	90,630	$4.90	$ 441,661
1000	821,463	1.92%	2	18,700	$15.37	$ 287,377
					2012 Total Increase	$852,673

* Using same cost as Class I gasoline engine.

Table 6.2-31 contains the catalyst cost estimates for LPG engines including a learning curve discount. This cost estimate is used in year six of the cost estimates.

Table 6.2-32: Variable Catalyst Costs with Learning Curve for Class II OHV Engines - LPG; HC+NOx Emission Reduction to Phase 3 Standards

	1 cylinder			2 cylinders		
Useful Life	250	500	1000**	250	500	1000
Engine Power (hp)	13.8	17.8	-	18.2	19.2	23
Engine Displacement (cc)	415	389	-	597	743	751
Engine/Catalyst	33%	40%	-	33%	40%	50%
Catalyst Volume (cc)*** (per cylinder)	137	156	-	197	297	376
Substrate Diameter	5.25	6.00	-	5.00	5.00	5.50
Substrate* (per cylinder)	4.44	7.13	-	2.96	4.16	5.07
Washcoat and Precious Metal	4.24	4.82	-	2.96	4.46	8.86
Labor	$1.40	$1.40	-	$1.40	$1.40	$1.40
Labor Overhead 40%	$0.56	$0.56	-	$0.56	$0.56	$0.56
Supplier Markup 29%	$3.09	$4.03	-	$2.29	$3.07	$4.61
Manufacture Price (per catalyst)	$13.73	$17.94	-	$10.17	$13.65	$20.50
Total Catalyst Cost	$15.90	$24.88		$20.33	$27.30	$41.00
Heat Shield (2 for v-twin)	$3.38	$3.41	-	$4.72	$5.54	$5.86
Spark Arrestor (2 for v-twin)	$0.10	$0.05	-	$0.20	$0.10	$0.10
Hardware Cost to Manufacturer	$17.21	$21.40	-	$25.25	$32.93	$46.96
w/Markup 29% OEM	$22.20	$27.61	-	$7.32	$9.55	$13.62
Add'l Muffler for V-twin	-	-	-	$6.26	$7.16	$6.98
Total Catalyst Cost for LPG engines	$22.20	$27.61	-	$38.84	$49.64	$67.56
Total Catalyst Cost for Gasoline Engines	$20.82	$18.35	-	$41.79	$44.47	$51.97
Cost Difference	$1.38	$9.25	-	-$2.95	$5.17	$15.59

* 50/50- split of metallic vs ceramic substrates

** No one cylinder LPG engines are certified to the 1000 hour useful life

*** these catalyst volumes were calculated from the engine disp in EPA's certification data for 2005

6.2.5 Small SI Aggregate Costs

Costs presented in the previous sections are combined here to present streams of costs. The first, Section 6.2.5.1, presents variable costs (recurring costs) for meeting the Phase 3 exhaust standards. Section 6.2.5.2 presents a stream of fixed costs for meeting the Phase 3 exhaust standards. Costs are based on assuming all engines are gasoline engines. Additional costs for LPG engines are included at the end of this section.

6.2.5.1 Variable Costs for Meeting Exhaust Standards

Variable costs for Class I are summarized in Table 6.2-10 for engine improvements and catalysts in near term and long term (with learning) costs. Every engine in Class I is estimated to have both technologies applied and therefore the costs are added according to useful life period and then multiplied by the number of engines sold per useful life category, as will be discussed later. The resultant variable costs per engine is presented in Table 6.2-33. Long term costs are 6 years after the near term costs and include a 20 percent learning curve reduction for engine improvement components, catalyst substrate and heat shield costs.

Variable costs for Class II are a combination of engine improvements and catalyst or engine improvements and electronic fuel injection (EFI), see Section 6.2.2. Information on engine designs and related certification emission results in the 2005 EPA Certification Database were utilized to determine the percentage of technologies per useful life. A portion of the engines, one large multi-cylinder engine family per engine manufacturer, are assigned the use of electronic fuel injection and the remainder catalysts. Some engines would not to require any costs. Long term costs (learning) are 6 years after the near term costs and include a 20 percent learning curve reduction for engine improvement components, catalyst substrate and heat shield costs.

Table 6.2-32: Percentage Technologies Per Useful Life per Class II

Useful Life	No changes	EFI - Class II V-twin	V-twin catalyst	Catalyst-Single Cylinder
250	0.40%	13.50%	4.50%	81.70%
500	1.90%	7.80%	0.20%	90.10%
1000	8.10%	44.50%	30.70%	16.70%

Table 6.2-33: Variable Costs Per Engine for Meeting Proposed Exhaust Standards, Per Engine (2005$)

Useful Life (hrs)	Class I		Class II	
	Near Term (2012)	Long Term (2017)*	Near Term (2011)	Long Term (2016)*
125- SV	10.56	9.72	--	--
125 - OHV	8.67	8.04	--	--
250	12.24	11.39	32.21	27.05
500	16.05	14.92	25.32	21.38
1000	--	--	57.94	46.18

*Long term includes learning reduction

The total Small SI engine costs for the first 30 years (2008-2037) were estimated using sales and growth estimates from the US EPA's NONROAD model. The percentage sales per useful life category (Class I: 125, 250, 500, Class II: 250, 500, 1000) were calculated from the manufacturer prescribed useful life period and yearly estimated sales per engine family in the EPA 2005 Phase 2 certification database (confidential information). The percentages in Table 6.2-34 were applied to US EPA's NONROAD model sales estimates and the results are presented in Table 6.2-35 Note that snowblowers are not included for they only have to comply with the evaporative standards since they are exempted from the exhaust emission standards**.**

Table 6.2-34: Small SI Engines Sale Percentages per Useful Life

Useful Life	Class I	Class II
125- SV	55%	---
125 - OHV	30%	---
250	9%	68%
500	6%	15%
1000	---	17%

Table 6.2-35: Class I and Class II Projected Sales per Useful Life Category (snowblowers excluded)

	CLASS I				CLASS II		
	125	125	250	500	250	500	1000
	SV	OHV	OHV	OHV	OHV	OHV	OHV
2008	5,127,510	2,753,967	843,888	581,329	3,107,434	674,916	765,527
2009	5,219,801	2,803,536	859,077	591,793	3,163,391	687,070	779,312
2010	5,311,789	2,852,943	874,217	602,222	3,219,633	699,285	793,168
2011	5,407,460	2,904,327	889,962	613,068	3,278,156	711,996	807,585
2012	5,498,863	2,953,419	905,005	623,431	3,334,488	724,231	821,463
2013	5,594,305	3,004,681	920,714	634,252	3,393,240	736,992	835,937
2014	5,687,801	3,054,897	936,101	644,852	3,450,280	749,380	849,989
2015	5,780,726	3,104,807	951,395	655,387	3,506,937	761,686	863,946
2016	5,872,307	3,153,994	966,467	665,770	3,563,590	773,991	877,903
2017	5,966,857	3,204,777	982,028	676,490	3,621,088	786,479	892,068
2018	6,060,404	3,255,021	997,424	687,096	3,678,416	798,930	906,191
2019	6,155,080	3,305,871	1,013,006	697,830	3,736,330	811,509	920,458
2020	6,249,153	3,356,397	1,028,489	708,495	3,793,793	823,989	934,614
2021	6,342,877	3,406,736	1,043,914	719,121	3,851,245	836,468	948,768
2022	6,435,905	3,456,701	1,059,224	729,668	3,908,253	848,850	962,812
2023	6,529,799	3,507,131	1,074,677	740,313	3,965,663	861,319	976,955
2024	6,623,557	3,557,488	1,090,108	750,943	4,023,108	873,795	991,107
2025	6,717,690	3,608,047	1,105,601	761,615	4,080,946	886,357	1,005,355
2026	6,812,592	3,659,018	1,121,220	772,375	4,138,843	898,932	1,019,618
2027	6,907,322	3,709,897	1,136,810	783,115	4,196,572	911,471	1,033,840
2028	7,001,813	3,760,648	1,152,362	793,828	4,254,228	923,993	1,048,044
2029	7,096,586	3,811,550	1,167,960	804,572	4,312,046	936,551	1,062,288
2030	7,191,371	3,862,459	1,183,559	815,319	4,369,880	949,112	1,076,535
2031	7,286,256	3,913,421	1,199,176	826,076	4,427,794	961,691	1,090,802
2032	7,381,095	3,964,359	1,214,784	836,829	4,485,625	974,251	1,105,049
2033	7,475,836	4,015,244	1,230,377	847,570	4,543,399	986,799	1,119,282
2034	7,570,510	4,066,093	1,245,958	858,303	4,601,154	999,343	1,133,510
2035	7,665,267	4,116,987	1,261,553	869,046	4,658,962	1,011,899	1,147,751
2036	7,760,044	4,167,891	1,277,152	879,792	4,716,772	1,024,455	1,161,993
2037	7,854,864	4,218,818	1,292,757	890,542	4,774,603	1,037,016	1,176,240

The Total Variable Costs were calculated using the sales information found in Table 6.2-35 and applying the corresponding variable cost from Table 6.2-33. Results are presented in Table 6.2-36. Engines used in snowblowers and handheld equipment will require only evaporative control measures and these are presented in Section 6.5.

Table 6.2-36: Variable Costs for Meeting Phase 3 Exhaust Emission Standards, 2005$

Year	Class I			Class II: Engine & Equipment		
	125	250	500	250	500	1,000
2008	-	-	-	-	-	-
2009	-	-	-	-	-	-
2010	-	-	-	-	-	-
2011	-	-	-	105,600,269	18,028,276	46,793,243
2012	83,668,785	11,079,868	10,008,033	107,414,910	18,338,075	47,597,340
2013	85,121,010	11,272,180	10,181,740	109,307,519	18,661,185	48,435,987
2014	86,543,605	11,460,567	10,351,904	111,144,960	18,974,876	49,250,188
2015	87,957,519	11,647,805	10,521,029	112,970,045	19,286,458	50,058,913
2016	89,350,983	11,832,335	10,687,708	96,391,317	16,547,001	40,539,821
2017	83,764,367	11,189,968	10,092,486	97,946,590	16,813,987	41,193,931
2018	85,077,605	11,365,401	10,250,714	99,497,254	17,080,182	41,846,102
2019	86,406,692	11,542,952	10,410,851	101,063,746	17,349,093	42,504,930
2020	87,727,306	11,719,371	10,569,967	102,618,074	17,615,917	43,158,642
2021	89,043,033	11,895,137	10,728,495	104,172,095	17,882,688	43,812,225
2022	90,348,981	12,069,597	10,885,844	105,714,100	18,147,395	44,460,754
2023	91,667,093	12,245,682	11,044,659	107,266,966	18,413,968	45,113,852
2024	92,983,300	12,421,512	11,203,244	108,820,807	18,680,708	45,767,359
2025	94,304,760	12,598,044	11,362,463	110,385,260	18,949,270	46,425,330
2026	95,637,018	12,776,019	11,522,982	111,951,301	19,218,104	47,083,968
2027	96,966,870	12,953,672	11,683,211	113,512,803	19,486,159	47,740,698
2028	98,293,351	13,130,875	11,843,035	115,072,341	19,753,877	48,396,601
2029	99,623,807	13,308,609	12,003,337	116,636,271	20,022,348	49,054,352
2030	100,954,421	13,486,363	12,163,658	118,200,597	20,290,888	49,712,269
2031	102,286,451	13,664,307	12,324,150	119,767,112	20,559,804	50,371,106
2032	103,617,823	13,842,164	12,484,562	121,331,392	20,828,336	51,029,004
2033	104,947,825	14,019,837	12,644,810	122,894,111	21,096,600	51,686,246
2034	106,276,880	14,197,383	12,804,943	124,456,311	21,364,775	52,343,268
2035	107,607,109	14,375,087	12,965,218	126,019,956	21,633,197	53,000,899
2036	108,937,613	14,552,827	13,125,526	127,583,669	21,901,632	53,658,558
2037	110,268,714	14,730,647	13,285,906	129,147,933	22,170,161	54,316,449

6.2.5.2 Fixed Costs

The stream of fixed costs for meeting the proposed exhaust emission standards are presented per useful life category per Class in Table 6.2-37. The total cost per engine family is determined by multiplying the costs for engine design changes (R&D, Tooling), certification, equipment modifications, by the number of engine families in each class per related useful life which is presented in Table 6.2-38.

EPA does not know the test cell makeup within the facilities of each manufacturer and therefore estimates that at least two upgraded analyzers will be purchased for a total of $600,000 per engine manufacturer. The certification database lists 16 different engine manufacturers of nonhandheld engines and 15 engine manufacturers of handheld engines. The 2005 certification database for nonhandheld and handheld engines also lists a number of new offshore manufacturers. These companies typically certify through independent test laboratories within the United States and therefore only encounter costs for these upgrades through increased service fees. This analysis estimates the cost for two manufacturer upgrades. A total of 17 different nonhandheld engine manufacturers test facilities at 600,000 per test facility yields a total estimated cost of $10,200,000. This cost is spread evenly across all products for a total of 1,700,000 for each category. These costs are fixed costs in this rulemaking. It is estimated that engine manufacturers will incur this cost two years prior to implementation of the standard for each class - 2010 for Class I and 2009 for Class II. Handheld engines must also be certified using the latest test procedures for small engines. The costs for upgrade of equipment totals $9,600,000 and is estimated to be incorporated into new certification for the 2010 model year. Recovered over 5 years yields $2,680,612 per year.

Table 6.2-37: Fixed Costs for Compliance with 1065, 2005$ (thousands), As Incurred

	CLASS I			CLASS II			HANDHELD
	125	250	500	250	500	1000	
2008							9,600
2009				1,700	1,700	1,700	
2010	1,700	1,700	1,700				
2011							

The number of engine families per Class and per useful life category were taken from EPA’s 2005 Certification Database. For Class I, the 2005 database lists 48 engine families from traditional companies and 38 newer engine families, accounting for 10 percent of engine sales, from companies which have been new to the marketplace since the time of the Phase 2 rulemaking promulgation. Engine families still certified to Phase 1 (either through credits, small engine family flexibilities or averaging) were not included. For Class II, there are a number of small volume engine families which have not yet been certified to Phase 2 due to flexibilities in that rulemaking. Due to the low volume sales, these engine families were estimated to be certified to the 250 hour useful life. For Class I-A, engine families are being moved to the <80cc category where they already meet the handheld emission standard. Class I-B engines are traditionally low volume sales engine families; we believe that they will likely be incorporated into the engine manufacturers ABT programs and certification of these low volume sales engine families will be covered without engine improvement. Costs for certifiers of LPG engines are covered in Section 6.2.4. The estimates in Table 6.2-38 represent the number of engine families per useful life designation used in this cost analysis to calculate fixed costs.

Table 6.2-38: Number of Engine Families Per Class and Useful Life Designation for Certification

CLASS I		CLASS II	
125	39	250	58
250	17	500	20
500	18	1000	58

Certification costs include 1065 compliance and engine aging and emission testing for engine family certification compliance. The costs for 1065 compliance are determined as shown in Table 6.2-37. This analysis estimates test cells are upgraded two years prior to standard implementation. The total engine certification costs are calculated by taking the number of engine families from Table 6.2-38 and multiply them by the emission test and dynamometer aging costs from Table 6.2-23. This analysis estimates that engine certification costs are incurred one year prior to standard implementation as shown in Table 6.2-39. Total certification costs as recovered are presented in Table 6.2-40.

Table 6.2-39: Engine Certification Costs As Incurred, (thousands)

	CLASS I			CLASS II			Handheld
	125	250	500	250	500	1000	
2008							9,600
2009				$1,700	$1,700	$1,700	
2010	$1,700	$1,700	$1,700	$1,535	$854	$4,531	
2011	$686	$434	$745				
2012							

Table 6.2-40: Stream of Costs for Engine Certification by Year As Recovered, (thousands)

	CLASS I			CLASS II			
	125	250	500	250	500	1000	Handheld
2010							2,681
2011				875	698	1,657	2,681
2012	654	588	669	875	698	1,657	2,681
2013	654	588	669	875	698	1,657	2,681
2014	654	588	669	875	698	1,657	2,681
2015	654	588	669	875	698	1,657	
2016	654	588	669				

Fixed costs to meet exhaust emission standards are presented throughout sections 6.2.1 Class I and 6.2.2. Class II. The fixed costs include engine improvements, catalyst development, and EFI development and application. All Class I engine families are assigned engine improvements and catalyst development costs. The number of engine families are taken from the 2005 EPA Certification Database. Table 6.2-41 presents the number of engine families estimated per technology package. Information on the number of cylinders per engine family and the number of manufacturers per Class was obtained from EPA's 2005 Certification Database.

Table 6.2-41: Estimates of the Number of Engine Families per Technology Package

Technology/Useful Life	250	500	1000
- One Cylinder Engine Improvements With Catalyst	45	13	28
- Two or More Cylinders per Engine for Catalyst	11	4	24
- Electronic Fuel Injection on Two or More Cylinder Engines	2	3	6
Total Number of Engine Families	58	20	58

Table 6.2-42: Total Fixed Costs as Incurred (thousands)
for Engines to Meet Phase 3 Exhaust Emission Standards

	CLASS I				CLASS II		
	125	125	250	500	250	500	1000
	SV	OHV	OHV	OHV	OHV	OHV	OHV
R&D	1,888	12,838	6,419	6,796	21,301	6,653	20,102
TOOLING	3,630	12,342	6,171	6,534	21,258	6,566	20,946
TOTAL	5,518	25,180	12,590	13,330	42,559	13,219	41,048

Table 6.2-43: Total Fixed Costs as Recovered (thousands)
for Engines to Meet Phase 3 Exhaust Emission Standards

	CLASS I				CLASS II		
	125	125	250	500	250	500	1000
	SV	OHV	OHV	OHV	OHV	OHV	OHV
2011	--	--	--	--	11,504	3,574	11,088
2012	1,475	6,811	3,405	3,606	11,504	3,574	11,088
2013	1,475	6,811	3,405	3,606	11,504	3,574	11,088
2014	1,475	6,811	3,405	3,606	11,504	3,574	11,088
2015	1,475	6,811	3,405	3,606	11,504	3,574	11,088
2016	1,475	6,811	3,405	3,606	--	--	–

Total fixed costs for Small SI exhaust emissions are shown in Table 6.2-44.

Table 6.2-44: Certification and Technology Fixed Costs for Engines to Meet Proposed Exhaust Standards, As Recovered

	Class I			Class II			Handheld
	125	250	500	250	500	1000	
2010							2,681
2011				12,380	4,272	12,745	2,681
2012	8,940	3,993	4,275	12,380	4,272	12,745	2,681
2013	8,940	3,993	4,275	12,380	4,272	12,745	2,681
2014	8,940	3,993	4,275	12,380	4,272	12,745	2,681
2015	8,940	3,993	4,275	12,380	4,272	12,745	
2016	8,940	3,993	4,275				
TOTAL	44,699	19,967	21,375	61,898	21,358	63,725	10,722

Equipment companies using Class II engines are also estimated to incur fixed costs in redesigning equipment models to incorporate Phase 3 Class II engines. The PSR database shows there are 413 businesses using Class II engines.[25] Assuming each business on average produces three unique models requiring clearly different redesign yields a number of 1239 redesigns. Table 6.2-22 contains equipment costs per equipment model and Table 6.2-45 contains the total equipment costs as incurred and recovered.

Table 6.2-45: Total Class II Equipment Cost

	Incurred	As Recovered
2010	92,925,000	
2011		25,987,098
2012		25,987,098
2013		25,987,098
2014		25,987,098
2015		25,987,098
TOTAL		129,935,492

6.2.5.3 Operating Cost Savings

The application of electronic fuel injection to an estimated additional 17.7 percent of the Class II engines is expected to result in fuel savings. Fuel savings from the use of fuel injection on Class II engines is estimated at 10 percent. Kohler has been offering a fuel injected Class II engine for nearly 10 years and two articles (1996 OEM Off-Highway and 1998 Diesel Progress)[26,27] claim 15-20 percent fuel savings over carbureted engines. We elected to conservatively use a figure of ten percent. In calculating the fuel savings, we use a gasoline price of $1.81 per gallon without taxes.[28] Table 6.2-46 presents estimated fuel savings for Class II engines with electronic fuel injection. The improvements and catalyst application to Class I engines are estimated to result in no operating or fuel savings. Fuel savings that are obtained from evaporative reduction technologies are presented later in the evaporative portion of this proposal. In calculating the fuel savings, we use a gasoline price of $1.81 per gallon without taxes.[29]

Table 6.2-46: Fuel Savings from the Increased Use of Electronic Fuel Injection on Class II Engines

Year	Gallons	Fuel Savings $
2009	0	0
2010	0	0
2011	10,173,297	$18,454,361
2012	18,376,598	$33,335,150
2013	26,158,818	$47,452,096
2014	31,081,817	$56,382,417
2015	35,936,184	$65,188,238
2016	39,616,047	$71,863,509
2017	42,132,893	$76,429,068
2018	44,068,991	$79,941,150
2019	45,654,106	$82,816,549
2020	47,024,456	$85,302,363
2021	48,137,286	$87,321,037
2022	49,132,949	$89,127,169
2023	50,046,687	$90,784,690
2024	50,928,776	$92,384,800
2025	51,781,644	$93,931,901
2026	52,622,410	$95,457,051
2027	53,452,741	$96,963,273
2028	54,275,859	$98,456,408
2029	55,091,652	$99,936,257
2030	55,900,128	$101,402,832
2031	56,703,268	$102,859,728
2032	57,503,764	$104,311,828
2033	58,301,990	$105,759,810
2034	59,098,563	$107,204,794
2035	59,893,659	$108,647,097
2036	60,685,412	$110,083,337
2037	61,473,943	$111,513,733

6.2.5.4 Total Aggregate Costs

The aggregate costs for meeting the exhaust emission standards are presented in Table 6.2-47. Aggregate costs include variable costs and fixed costs for engine manufacturers (technology, certification, 1065 compliance), equipment manufacturers and LPG engine families and converters. An average cost per engine is presented in Table 6.2-48 and the aggregate costs with fuel savings is presented in Table 6.2-49.

Table 6.2-47: Total Aggregate for 30 year Cost Analysis for Exhaust Emission Standard Compliance without Fuel Savings, 2005$

Year	Exhaust Only		1065 Compliance
	Class I	Class II	Handheld
2010	0	0	2,680,612
2011	0	231,735,198	2,680,612
2012	122,084,986	234,740,187	2,680,612
2013	123,903,229	237,874,288	2,680,612
2014	125,684,375	240,917,033	2,680,612
2015	120,443,340	243,939,317	
2016	122,188,014	158,329,126	
2017	105,046,821	160,883,764	
2018	106,693,720	163,430,833	
2019	108,360,496	166,003,899	
2020	110,016,644	168,556,986	
2021	111,666,665	171,109,568	
2022	113,304,422	173,642,413	
2023	114,957,434	176,193,100	
2024	116,608,057	178,745,385	
2025	118,265,267	181,315,103	
2026	119,936,019	183,887,430	
2027	121,603,753	186,452,300	
2028	123,267,260	189,013,944	
2029	124,935,752	191,582,803	
2030	126,604,442	194,152,312	
2031	128,274,908	196,725,417	
2032	129,944,548	199,294,850	
2033	131,612,472	201,861,721	
2034	133,279,206	204,427,738	
2035	134,947,414	206,996,128	
2036	136,615,966	209,564,630	
2037	138,285,267	212,134,037	

Table 6.2-48: Sales Weighted Average Per-Equipment Cost Estimates (Without Fuel Savings), 2005$

Short Term Costs (years 1-5) per Class per Useful Life	Class I			Class II			Handheld
	125	250	500	250	500	1000	
Variable	9.90	12.24	16.05	32.99	26.10	58.72	--
Fixed	1.10	4.41	6.86	6.42	18.17	26.51	0.30
Total	11.00	16.66	22.91	39.41	44.27	85.23	0.30
Long Term	9.13	11.39	14.92	27.84	22.16	47.22	0.00

* Long term is without fixed costs and with learning, if applicable

Table 6.2-49: Total Aggregate for 30 year Cost Analysis for Exhaust Emission Standard Compliance with Fuel Savings, 2005$

Year	Exhaust Only		1065 Compliance
	Class I	Class II	Handheld
2010	$0	0	2,680,612
2011	$0	$213,280,837	2,680,612
2012	$0	$201,405,037	2,680,612
2013	$0	$190,422,192	2,680,612
2014	$0	$184,534,617	2,680,612
2015	$134,647,294	$178,751,079	
2016	$136,508,481	$86,465,617	
2017	$112,806,498	$84,454,696	
2018	$114,575,051	$83,489,683	
2019	$116,364,950	$83,187,350	
2020	$118,143,436	$83,254,623	
2021	$119,915,342	$83,788,531	
2022	$121,674,078	$84,515,244	
2023	$123,449,196	$85,408,410	
2024	$125,221,748	$86,360,585	
2025	$127,001,374	$87,383,202	
2026	$128,795,542	$88,430,379	
2027	$130,586,470	$89,489,027	
2028	$132,372,859	$90,557,536	
2029	$134,164,600	$91,646,546	
2030	$135,956,554	$92,749,480	
2031	$137,750,415	$93,865,690	
2032	$139,543,389	$94,983,022	
2033	$141,334,520	$96,101,911	
2034	$143,124,374	$97,222,944	
2035	$144,915,811	$98,349,031	
2036	$146,707,616	$99,481,294	
2037	$148,500,226	$100,620,305	

At a 7 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for Small SI exhaust emission control, without fuel savings, is $265 million. The corresponding estimated annualized fuel savings due to the use of electronic fuel injection on Class II engines is $63 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for Small SI exhaust emission control, without fuel savings, is $273 million. The corresponding estimated annualized fuel savings due to the use of electronic fuel injection on Class II engines is $71 million.

6.3 Exhaust Emission Control Costs for Outboard and Personal Watercraft Marine Engines

This section presents our cost estimates for meeting the proposed exhaust emission standards for outboard and personal watercraft marine engines.

Less than a decade ago, outboard and personal watercraft (OB/PWC) engines were primarily two-stroke carbureted engines. There were no emission control requirements. Since then, manufacturers have used two primary strategies to meet exhaust emission standards. The first is two-stroke direct injection. By injecting the fuel directly into the combustion chamber after the exhaust port closes, the short-circuiting fuel losses with traditional two-strokes can be largely eliminated. The second approach is to convert to using four-stroke engines, either carbureted or fuel-injected. One other approach that has been used by one PWC manufacturer has been the use of a two-way catalyst in the exhaust of a two-stroke engine. Today, engine sales are a mix of old and new technology. We anticipate that the proposed standards will largely be met by phasing out the old-technology engines and using technology already available in the marketplace.

Since California ARB has adopted standards similar to those we are proposing, manufacturers have already started with design and testing efforts to meet our proposed standards. To reflect this in the cost analysis, we include no estimated costs for R&D to introduce the various emission-control technologies. This reflects the expectation that manufacturers will not need to conduct additional R&D for EPA’s requirements, since they are introducing those technologies for sale in California. As noted below, we are including estimated R&D expenditures as part a compliance cost, since EPA’s proposed NTE standards represent an incremental requirement beyond what California ARB has adopted.

For the purpose of this analysis, we divide outboards into five power categories and PWC into three power categories. We present cost estimates of various emission-control technologies for each of these power categories. Additional detail on the per-engine costs presented in this section is available in the docket.[30] Table 6.3-1 presents these power categories and the engine size we use to represent each category.

Table 6.3-1: Engine Sizes Used for Cost Analysis

	Power Range	Engine Power	Displacement	Cylinders
Outboard Engines	0-25 hp	9.9 hp	0.25 L	2
	25-50 hp	40 hp	0.76 L	3
	50-100 hp	75 hp	1.60 L	3
	100-175 hp	125 hp	1.80 L	4
	>175 hp	225 hp	3.00 L	6
Personal Watercraft Engines	50-100 hp	85 hp	1.65 L	2
	100-175 hp	130 hp	1.85 L	3
	>175 hp	175 hp	2.50 L	4

6.3.1 Two-Stroke Direct Injection

Traditional outboards use carbureted two-stroke engine designs where the fuel and air are mixed in the carburetor then pumped into the combustion chamber through the crankcase. The piston itself acts to open and close the intake and exhaust ports. As a result, fuel may be lost out the exhaust port. Better control of the fuel can be achieved using indirect injection in place of the carburetor; however, this does not prevent short-circuiting losses. Indirect injection is primarily used on the largest two-stroke engines. Direct-injection has been used by manufacturers to reduce emissions from two-stroke outboards. By injecting the fuel directly into the cylinder after the exhaust port is closed, short-circuiting losses can be minimized.
Table 6.3-2 and 6.3-3 present incremental costs of applying direct injection to outboards and PWC, respectively. For the largest power category, costs are presented incremental to indirect injection. For the remaining categories, costs are presented incremental to carbureted engines. For 135 hp PWC engine, incremental costs are presented for both IDI and carbureted engines because baseline engines in this power category use both approaches.

Table 6.3-2: Outboard—Projected Incremental Costs for 2-Stroke Direct Injection

	9.9 hp carb.	40 hp carb.	75 hp carb.	125 hp carb.	225 hp IDI
Hardware Cost to Manufacturer					
carburetor(s)	($28)	($114)	($135)	($165)	--
fuel metering solenoids	$36	$60	$66	$96	$156
IDI injectors	--	--	--	--	($102)
fuel distributer	--	--	--	--	($25)
pressure regulator	--	--	--	--	($35)
air compressor	$80	$100	$120	$140	$165
air regulator	$15	$15	$17	$20	$22
throttle body position sensor	$30	$35	$35	$40	$10
intake manifold	$5	$5	$9	$10	($5)
fuel pump	$3	$0	($5)	($6)	($35)
electronic control module	$85	$90	$95	$100	$0
air intake temperature sensor	$5	$5	$5	$5	$0
manifold air pressure sensor	$10	$10	$11	$11	$0
injection timing sensor/timing wheel	$5	$8	$9	$10	$0
wiring/related hardware	$20	$30	$30	$50	$0
Total Incremental Hardware Cost	$266	$244	$257	$311	$151
Engine Manufacturer Markup					
labor at $28/hour	$13	$15	$19	$22	$14
labor overhead at 40%	$5	$6	$8	$9	$6
markup at 29%	$82	$77	$82	$99	$49
warranty markup at 5%	$13	$12	$13	$16	$8
Total Incremental Component Cost	$380	$354	$379	$456	$228

Table 6.3-3: PWC—Projected Incremental Costs for 2-Stroke Direct Injection

	85 hp carb.	130 hp carb.	130 hp IDI	175 hp IDI
Hardware Cost to Manufacturer				
carburetor(s)	($114)	($165)	--	--
fuel metering solenoids	$44	$72	$72	$104
IDI injectors	--	--	($51)	($68)
fuel distributer	--	--	($20)	($25)
pressure regulator	--	--	($30)	($35)
air compressor	$120	$140	$140	$165
air regulator	$17	$20	$20	$22
throttle body position sensor	$35	$40	$0	$0
intake manifold	$9	$10	($10)	($5)
fuel pump	($5)	($6)	($30)	($35)
electronic control module	$95	$100	$0	$0
air intake temperature sensor	$5	$5	$0	$0
manifold air pressure sensor	$11	$11	$0	$0
injection timing sensor/timing wheel	$9	$10	$0	$0
wiring/related hardware	$20	$30	$0	$0
Total Incremental Hardware Cost	$246	$267	$91	$123
Engine Manufacturer Markup				
labor at $28/hour	$19	$22	$12	$12
labor overhead at 40%	$8	$9	$5	$5
markup at 29%	$79	$86	$31	$41
warranty markup at 5%	$12	$13	$5	$6
Total Incremental Component Cost	$364	$398	$144	$186

6.3.2 Migration from Two-Stroke to Four-Stroke Engines

The primary technology that manufacturers are using to meet exhaust emissions standards has been to convert their product offering more to four-stroke engines. Because four-stroke engines are common in the market today, we do not include costs for research and development or warranty. Rather, we anticipate that manufacturers will sell more of the four-stroke engines and phase out the carbureted two-stroke designs as a result of the proposed standards. Tables 6.3-4 and 6.3-5 below present a comparison between costs for two-stroke and four-stroke outboard and PWC engines, respectively. These costs are based on prices for current product offerings.

Table 6.3-4: Outboard—Projected Incremental Costs for 4-Stroke

	9.9 hp	40 hp	75 hp	125 hp	225 hp
2-stroke baseline technology	carb	carb	carb	carb	DFI
4-stroke control technology	carb	carb	carb	EFI	EFI
2-stroke cost	$900	$2,101	$3,076	$4,195	$6,339
4-stroke cost	$1,124	$2,633	$3,861	$5,504	$7,761
Markup at 29%	$65	$154	$228	$380	$412
Total Incremental Cost	$289	$686	$1,013	$1,689	$1,834

Table 6.3-5: PWC—Projected Incremental Costs for 4-Stroke

	85 hp	130 hp	175 hp
2-stroke baseline technology	carb	DFI	DFI
4-stroke control technology	EFI	EFI	EFI
2-stroke cost	$3,319	$4,578	$5,862
4-stroke cost	$4,350	$5,587	$7,207
Markup at 29%	$299	$293	$390
Total Incremental Cost	$1,330	$1,302	$1,735

6.3.3 Four-Stroke Electronic Fuel Injection

Manufacturers can gain better control of their fuel and air management through the use of electronic fuel injection. This is often used in larger OB/PWC engines today. For this analysis, we consider the use of a port fuel-injection system, which refers to individual injectors located at each intake port in the engine. In addition to the injectors, this system includes a fuel rail, pressure regulator, electronic control module, manifold air pressure and temperature sensors, a high pressure fuel pump, a throttle assembly, a throttle position sensor, and a magnetic crankshaft pickup for engine speed. Tables 6.3-6 and 6.3-7 present the incremental costs of a port fuel-injection system compared to a carburetor-based fuel system for outboards and personal watercraft, respectively.

Table 6.3-6: Outboard—Projected Incremental Costs for 4-Stroke EFI

	9.9 hp	40 hp	75 hp	125 hp	225 hp
Hardware Costs					
carburetor(s)	($28)	($114)	($135)	($165)	($240)
injectors	$34	$51	$51	$68	$102
fuel rail	$40	$55	$65	$70	$80
pressure regulator	$15	$15	$20	$30	$35
intake manifold	$5	$5	$6	$10	$15
throttle body position sensor	$30	$35	$35	$40	$50
fuel pump	$13	$10	$10	$14	$17
electronic control module	$95	$100	$105	$110	$115
air intake temperature sensor	$5	$5	$5	$5	$5
manifold air pressure sensor	$10	$10	$11	$11	$11
injection timing sensor	$5	$8	$9	$10	$10
wiring/related hardware	$20	$30	$30	$40	$60
Hardware Cost to Manufacturer	$244	$210	$212	$243	$260
Engine Manufacturer Markup					
labor at $28/hour	$3	$4	$4	$4	$4
labor overhead at 40%	$1	$2	$2	$2	$2
markup at 29%	$72	$63	$63	$72	$77
warranty markup at 5%	$12	$11	$11	$12	$13
Total Incremental Component Cost	$332	$289	$291	$333	$356

Table 6.3-7: PWC—Projected Incremental Costs for 4-Stroke EFI

	85 hp	130 hp	175 hp
Hardware Costs			
carburetor(s)	($135)	($165)	($240)
injectors	$34	$51	$68
fuel rail	$65	$70	$80
pressure regulator	$20	$30	$35
intake manifold	$6	$10	$15
throttle body position sensor	$35	$40	$50
fuel pump	$10	$14	$17
electronic control module	$105	$110	$115
air intake temperature sensor	$5	$5	$5
manifold air pressure sensor	$11	$11	$11
injection timing sensor	$9	$10	$10
wiring/related hardware	$20	$30	$40
Hardware Cost to Manufacturer	$185	$216	$206
Engine Manufacturer Markup			
labor at $28/hour	$4	$4	$4
labor overhead at 40%	$2	$2	$2
markup at 29%	$55	$64	$61
warranty markup at 5%	$9	$11	$10
Total Incremental Component Cost	$255	$297	$283

6.3.4 Catalysts

We believe the proposed OB/PWC exhaust emission standards can be achieved without the use of catalysts. At this time, three-way catalysts have not been demonstrated on OB/PWC engines. However, one manufacturer has been using a two-way catalyst on PWCs with 2-stroke engines for several years. We include research and development costs for this technology because it is not currently used in the marine industry, but is an alternative we assess in Chapter 11. Catalyst sizes and formulations are based on the analysis discussed below for SD/I engines. Tables 6.3-8 and 6.3-9 present the incremental cost of adding catalysts to four-stroke, electronic fuel-injection OB and PWC engines, respectively.

Table 6.3-8: Outboard—Projected Incremental Costs for Catalytic Control

	9.9 hp	40 hp	75 hp	125 hp	225 hp
Catalyst Unit Price					
catalyst volume (L)	0.09	0.27	0.56	0.63	1.05
substrate diameter (cm)	4.5	6.0	8.5	9.0	10.0
substrate	$2	$4	$5	$6	$8
ceria/alumina	$1	$3	$6	$7	$12
Pt/Pd/Rd	$2	$7	$16	$18	$29
can (18 gauge SS)	$0.4	$0.8	$1	$1	$2
Total Material Cost	$6	$15	$29	$32	$52
Labor	$14	$14	$14	$14	$14
labor overhead at 40%	$6	$6	$6	$6	$6
supplier markup at 29%	$8	$10	$14	$15	$21
Manufacturer Price per Unit	$33	$45	$62	$67	$92
Hardware Cost to Manufacturer					
catalyst	$33	$45	$62	$67	$92
exhaust manifold modifications	$15	$17	$20	$25	$30
oxygen sensor	$25	$25	$25	$25	$25
Total Incremental Hardware Cost	$73	$87	$107	$117	$147
Engine Manufacturer Markup					
labor at $28/hour	$1	$1	$1	$1	$1
labor overhead at 40%	$1	$1	$1	$1	$1
markup at 29%	$22	$26	$32	$34	$43
warranty markup at 5%	$2	$2	$2	$3	$3
Total Incremental Component Cost	$99	$116	$143	$156	$195
Fixed Cost to Manufacturer					
research & development	$342,788	$352,938	$362,068	$372,980	$388,643
tooling	$75,000	$75,000	$75,000	$75,000	$75,000
units/year	5,000	5,600	6,400	5,900	4,700
years to recover	5	5	5	5	5
Fixed Cost/Unit	$23	$21	$19	$21	$27
Total Incremental Cost	$122	$137	$162	$177	$222

Table 6.3-9: PWC—Projected Incremental Costs for Catalytic Control

	85 hp	130 hp	175 hp
Catalyst Unit Price			
catalyst volume (L)	0.58	0.65	0.88
substrate diameter (cm)	9.0	9.0	9.0
substrate	$5	$6	$7
ceria/alumina	$7	$7	$10
Pt/Pd/Rd	$16	$18	$25
can (18 gauge SS)	$1	$1	$2
Total Material Cost	$30	$33	$44
Labor	$14	$14	$14
labor overhead at 40%	$6	$6	$6
supplier markup at 29%	$14	$15	$18
Manufacturer Price per Unit	$63	$68	$82
Hardware Cost to Manufacturer			
catalyst	$63	$68	$82
exhaust manifold modifications	$35	$40	$45
oxygen sensor	$25	$25	$25
Total Incremental Hardware Cost	$123	$133	$152
Engine Manufacturer Markup			
labor at $28/hour	$1	$1	$1
labor overhead at 40%	$1	$1	$1
markup at 29%	$36	$39	$45
warranty markup at 5%	$3	$3	$4
Total Incremental Component Cost	$165	$177	$202
Fixed Cost to Manufacturer			
research & development	$363,502	$371,332	$381,016
tooling	$75,000	$75,000	$75,000
units/year	1,700	5,300	1,000
years to recover	5	5	5
Fixed Cost/Unit	$71	$23	$126
Total Incremental Cost	$236	$200	$328

6.3.5 Certification and Compliance

Outboard and PWC engines must already be certified to meet the current EPA HC+NOx exhaust emission standards. We therefore do not anticipate any increase in clerical work associated with these proposed standards. In addition, manufacturers are likely to meet the proposed standards by selling more of their lower-emission engines, which are certified today. However, manufacturers may need to adjust engine calibrations to meet the proposed standard and collect further data to demonstrate compliance with the proposed not-to-exceed zone. We therefore allow on average two months of R&D for each engine family as part of the certification process. Considering two engineers and three technicians and the corresponding testing costs for the two-month period, we estimate a total cost of $130,000 per engine family. Unless engine designs were significantly changed, manufacturers could recertify engine families each year using carryover of this original test data. This cost is therefore amortized over five years of engine sales with an average volume of 5,500 engines per family for outboards and 4,200 engines per family for PWC. The resulting cost is $5 per engine for outboards and $6 for PWC.

6.3.6 Operating Cost Savings

We anticipate that the proposed standards will largely be met on average by phasing out old, high-emitting technologies, such as carbureted two-stroke engines and replacing them with currently available clean technologies such as four-stroke engines and direct-injection two-stroke engines. In addition to having lower emissions, these newer-technology engines have significantly lower fuel consumption. Over the life of an engine, these fuel savings result in significant operating cost savings. In calculating the fuel savings, we use a gasoline price of $1.81 per gallon without taxes.[31]

The largest portion of the fuel savings would come from phasing out carbureted crankcase-scavenged two-stroke engines. As discussed in Chapter 4, scavenging losses from these engines can result in more than 25 percent of the fuel passing through the engine unburned. In addition, we model incremental fuel-consumption benefits between fuel-injected two-stroke engines, carbureted four-stroke engines, and fuel-injected four strokes. These fuel consumption rates and their derivation are described in more detail in the docket.[32]

Table 6.3-10: Projected Fuel Savings for OB/PWC Engines

	Outboard	PWC
Annual Per-Engine Gallons Consumed	72	225
Average Life (years)	19	9.9
Anticipated Reduction in Fuel Consumption	5.2%	4.7%
Lifetime Gallons Saved	72	103
Lifetime Cost Savings	$130	$187
Discounted Cost Savings (7%)	$77	$142

6.3.7 Total OB/PWC Engine Costs

As discussed above, we anticipate that manufacturers would meet the proposed standards largely by changing their technology mix from older to newer technologies. For this reason, our estimated per-engine costs for the average OB/PWC engine reflect a mix of technology changes. Table 6.3-11 presents the baseline technology mix by power class. This technology mix is based on an analysis of sales projections submitted to EPA by OB/PWC manufacturers at time of certification. These sales projections are confidential, but a general description of this analysis is available in the docket.[33]

Table 6.3-11: Baseline Technology Mix for OB/PWC Engines

	2-Stroke Carbureted	2-Stroke Indirect Injection	2-Stroke Direct Injection	4-Stroke Carbureted	4-Stroke Fuel Injection
Outboards					
9.9 hp	24%	0%	0%	76%	0%
40 hp	32%	0%	2%	35%	32%
75 hp	20%	0%	10%	0%	70%
125 hp	20%	0%	30%	0%	50%
225 hp	0%	25%	60%	0%	15%
PWC					
85 hp	30%	60%	10%	0%	0%
130 hp	5%	0%	5%	0%	90%
175 hp	0%	70%	30%	0%	0%

To develop the control technology mix, we made three adjustments to the baseline technology mix. First, we considered that all the 2-stroke carbureted and indirect injection engines would be replaced by either 2-stroke direct injection or 4-stroke engines. Second, we included calibration costs for the for the 2-stroke direct injection and 4-stroke engines for better emission performance. These engines are well below the existing HC+NOx standards; however, there is currently wide variability in certified emission levels. We believe the proposed standards would require engine manufacturers to pay closer attention to emissions calibrations for their higher-emitting new technology engines. Third, we included the conversion of a small number of 2-stroke direct injection engines to 4-stroke based on product plans conveyed to us in private conversations with manufacturers. While there is no way of knowing exactly what the actual technology mix will be, we believe our analysis represents a reasonable scenario. Table 6.3-12 presents the projected technology mix for this control scenario.

Table 6.3-12: Projected Control Technology Mix for OB/PWC Engines

	2-Stroke Carbureted	2-Stroke Indirect Injection	2-Stroke Direct Injection	4-Stroke Carbureted	4-Stroke Fuel Injection
Outboards					
9.9 hp	0%	0%	0%	100%	0%
40 hp	0%	0%	2%	66%	32%
75 hp	0%	0%	10%	20%	70%
125 hp	0%	0%	30%	0%	70%
225 hp	0%	0%	50%	0%	50%
PWC					
85 hp	0%	0%	0%	100%	0%
130 hp	0%	0%	5%	0%	95%
175 hp	0%	0%	30%	0%	70%

We developed the per-engine costs based on the technology mix and technology cost tables presented above. As discussed above, our cost estimates include both variable and fixed, and we distinguish between near-term and long-term costs. Because our analysis amortizes fixed costs over 5 years, the long-term costs are made up of variable costs only. Variable costs are lower in the long term due to the learning effect discussed above. Table 6.3-13 presents these average per-engine cost estimates.

Table 6.3-13: OB/PWC Per-Engine Cost Estimates (Without Fuel Savings)

	Short Term (years 1-5)			Long Term (years 6-10)
	Fixed	Variable	Total	
OB aggregate	<u>$11</u>	<u>$273</u>	<u>$284</u>	<u>$219</u>
9.9 hp	$5	$69	$74	$55
40 hp	$5	$216	$222	$173
75 hp	$8	$203	$210	$162
125 hp	$15	$338	$353	$270
225 hp	$27	$690	$717	$552
PWC aggregate	<u>$19</u>	<u>$340</u>	<u>$359</u>	<u>$272</u>
85 hp	$29	$870	$899	$696
130 hp	$14	$85	$98	$68
175 hp	$45	$1,290	$1,336	$1,032

6.3.8 OB/PWC Aggregate Costs

Aggregate costs are calculated by multiplying the per-engine cost estimates described above by projected engine sales. Engine sales are based on estimates supplied by the National

Marine Manufacturers Association (www.nmma.org) and projections for future years are based on the growth rates in the NONROAD model. Fuel-consumption reductions are calculated using the NONROAD based on population estimates. These population estimates in the NONROAD model are similar to those estimated by NMMA. A description of the sales and population data and our analysis of the data are available in the docket.[34] Table 6.3-14 presents the projected costs of meeting the proposed exhaust emission standards over a 30-year time period, with and without the fuel savings. Fuel savings from the proposed evaporative emission standards are not included in this table, but they are presented separately below.

The population and sales data reported by NMMA, suggest that the NONROAD model may somewhat underestimate the useful life of outboard and personal watercraft marine engines. If useful life were back-calculated—dividing NMMA population by sales and adjusted for growth—we would get a longer average life estimate. As a result, the per-engine fuel savings described above may be understated. Because the current approach gives us a conservative benefits estimate, and because we do not have new data on average lives for marine engines to update the estimates in the NONROAD model, we are not proposing to update the model at this time. For this reason, the 30-year stream may give a better view of the impact of the fuel savings than the per-engine analysis.

At a 7 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for OB/PWC exhaust emission control is $108 million. The corresponding estimated annualized fuel savings due to more efficient engines is $57 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for OB/PWC exhaust emission control is $103 million. The corresponding estimated annualized fuel savings due to more efficient engines is $64 million.

Table 6.3-14: Projected 30-Year Aggregate Cost Stream for OB/PWC Engines

Year	Without Fuel Savings		With Fuel Savings	
	OB	PWC	OB	PWC
2009	$84,242,873	$28,070,735	$80,280,824	$25,794,193
2010	$84,850,618	$28,273,243	$76,945,029	$23,741,117
2011	$85,473,947	$28,480,943	$73,647,593	$21,688,747
2012	$86,097,276	$28,688,644	$70,386,332	$19,661,793
2013	$86,720,605	$28,896,344	$67,153,841	$17,666,970
2014	$67,170,271	$22,049,479	$43,776,465	$8,674,759
2015	$67,649,631	$22,206,835	$40,438,909	$6,733,884
2016	$68,122,998	$22,362,224	$37,127,048	$4,863,926
2017	$68,596,366	$22,517,613	$33,855,111	$3,087,340
2018	$69,069,734	$22,673,001	$30,639,110	$1,449,882
2019	$69,543,101	$22,828,390	$27,488,204	$588,957
2020	$70,016,469	$22,983,779	$24,419,419	$(4,321)
2021	$70,489,837	$23,139,168	$21,461,639	$(464,863)
2022	$70,963,204	$23,294,557	$18,701,687	$(835,954)
2023	$71,436,572	$23,449,946	$16,563,074	$(1,140,064)
2024	$71,909,940	$23,605,334	$14,854,769	$(1,376,955)
2025	$72,383,307	$23,760,723	$13,335,677	$(1,557,763)
2026	$72,859,671	$23,917,096	$11,975,643	$(1,693,743)
2027	$73,336,035	$24,073,468	$10,861,355	$(1,784,708)
2028	$73,812,398	$24,229,840	$9,875,510	$(1,830,521)
2029	$74,288,762	$24,386,213	$9,063,546	$(1,842,333)
2030	$74,765,126	$24,542,585	$8,383,095	$(1,854,144)
2031	$75,241,489	$24,698,957	$7,792,111	$(1,865,948)
2032	$75,717,853	$24,855,329	$7,318,336	$(1,877,773)
2033	$76,194,217	$25,011,702	$6,919,063	$(1,889,590)
2034	$76,670,580	$25,168,074	$6,603,636	$(1,901,401)
2035	$77,146,944	$25,324,446	$6,371,857	$(1,913,212)
2036	$77,623,308	$25,480,819	$6,192,965	$(1,925,031)
2037	$78,099,671	$25,637,191	$6,049,717	$(1,936,841)
2038	$78,576,035	$25,793,563	$5,935,965	$(1,948,650)

6.4 Exhaust Emission Control Costs for Sterndrive/Inboard Marine Engines

This section presents our cost estimates for meeting the proposed exhaust emission standards for sterndrive and inboard marine engines.

Sterndrive and inboard (SD/I) marine engines are typically “marinized” using automotive engine blocks. There are a few exceptions where unique engine blocks are used, but these applications represent a very small portion of the sales volume. Typical automotive blocks are 3.0 liter in-line 4-cylinder engines, 4.3 liter V-6 engines, and V-8 engines ranging from 5.0 to 8.2 liters total displacement. For purposes of this analysis, we present costs for an in-line 4 cylinder engine, a V-6 engine, and three V-8 engine configurations. In addition, this analysis considers costs to the original engine manufacturer and to the engine “marinizer.” Additional detail on the projected costs may be found in the docket.[35]

Because California ARB has adopted standards similar to those we are proposing, manufacturers have already started with design and testing efforts to meet our proposed standards. To reflect this in the cost analysis, we include no estimated costs for R&D to introduce the various emission-control technologies. This reflects the expectation that manufacturers will not need to conduct additional R&D for EPA’s requirements, since they are introducing those technologies for sale in California. As noted below, we are including estimated R&D expenditures as part a compliance cost, because EPA’s proposed NTE standards represent an incremental requirement beyond what California ARB has adopted.

6.4.1 Fuel Injection

Current SD/I engines are sold with carburetors or with fuel-injection systems. The smaller 3.0 L I4 engines are typically carbureted while the larger 8.1 and 8.2 L V8 engines are typically fuel injected. Our estimate is that about 25-30 percent of V6 engines and 70-80 percent of the 5.0 - 6.2L V8 engines are currently sold with fuel injection. For the purpose of this analysis we anticipate that all SD/I engines will need to be fuel injected to meet the proposed emission standards. Fuel injection allows better control of the air-to-fuel ratio in the engine and exhaust for better emission design control and catalyst efficiency.

We consider the use of a port fuel-injection system for this analysis, which refers to individual injectors located at each intake port in the engine. In addition to the injectors, this system includes a fuel rail, pressure regulator, electronic control module, manifold air pressure and temperature sensors, a high pressure fuel pump, a throttle assembly, a throttle position sensor, and a magnetic crankshaft pickup for engine speed. We also consider a cool fuel system to prevent the occurrence of vapor lock in the fuel lines. Table 6.4-1 presents the incremental costs of a port fuel-injection system compared to a carburetor-based fuel system. Because this technology is widely used today, we include fixed costs for final calibrations as part of the cost of certification and compliance in Section 6.4.4.

Table 6.4-1: Projected Incremental Hardware Costs for Controlled Port Fuel Injection

	3.0L I4	4.3L V6	5.0L V8	5.7L V8	8.1L V8
Hardware Cost to Manufacturer					
carburetor	($140)	($145)	($145)	($145)	($145)
injectors	$68	$102	$136	$136	$160
pressure regulator	$15	$15	$15	$15	$15
fuel filter	$1	$1	$1	$1	$1
intake manifold	$14	$25	$25	$30	$40
fuel rail	$80	$80	$80	$80	$80
throttle assembly (w/ position sensor)	$150	$150	$150	$150	$60
cool fuel system (w/ pump)	$115	$120	$120	$120	$120
electronic control module	$70	$65	$65	$65	$60
air intake temperature sensor	$5	$5	$5	$5	$5
manifold air pressure sensor	$14	$14	$14	$14	$14
crank position sensor	$16	$16	$16	$16	$16
wiring/related hardware	$80	$80	$80	$80	$80
Total Incremental Hardware Cost	$488	$528	$562	$567	$506
Engine Manufacturer Markup					
labor at $28/hr	$3	$4	$4	$4	$4
labor overhead at 40%	$1	$2	$2	$2	$2
markup at 29%	$143	$155	$165	$166	$148
warranty markup at 5%	$24	$26	$28	$28	$25
Total Incremental Component Cost	$659	$715	$760	$767	$685

6.4.2 Exhaust Gas Recirculation

We do not anticipate that manufacturers will use exhaust gas recirculation (EGR) to meet the proposed exhaust emission standards. However, in developing this proposal, we considered the option of a standard based on emission reductions possible through the use of EGR. This analysis is reflected in our alternatives discussion in Chapter 11. For this analysis, we consider an EGR system with a valve, plumbing, and modification to the intake manifold. Table 6.4-2 presents incremental variable costs of a controlled engine with EGR compared to an uncontrolled engine with port fuel injection and no EGR.

Table 6.4-2: Projected Incremental Hardware Costs for Exhaust Gas Recirculation

	3.0L I4	4.3L V6	5.0L V8	5.7L V8	8.1L V8
Hardware Cost to Manufacturer					
intake manifold	$5	$5	$10	$10	$10
exhaust gas recirculation	$25	$25	$25	$25	$25
exhaust manifold	$2	$5	$5	$5	$5
oxygen sensors	$17	$34	$34	$34	$34
Total Incremental Hardware Cost	$49	$69	$74	$74	$74
Engine Manufacturer Markup					
labor at $28/hr	$1	$1	$1	$1	$1
labor overhead at 40%	$0	$0	$0	$0	$0
markup at 29%	$15	$20	$22	$22	$22
warranty markup at 5%	$2	$3	$4	$4	$4
Total Incremental Component Cost	$67	$94	$101	$101	$101

6.4.3 Catalysts

We anticipate that manufacturers will use small three-way catalysts to meet the proposed SD/I exhaust emission standards. A catalyst will likely be placed in the riser of each exhaust manifold upstream of where the water and exhaust gases mix. Catalyst sizes and configurations are based on the developmental catalyst efforts on SD/I engines discussed in Chapter 4. Costs are included to modify the exhaust manifolds for packaging of the catalyst. We believe these catalysts will be used in conjunction with port fuel injection and closed-loop electronic control. Therefore, we include the cost of an oxygen sensor upstream of each catalyst. The costs in Table 6.4-3 are presented incremental to an open-loop port fuel injection.

Table 6.4-3: Projected Incremental Hardware Costs for Catalytic Control

	3.0L I4	4.3L V6	5.0L V8	5.7L V8	8.1L V8
Catalyst Unit Price					
catalyst volume (L) (each)	1.00	0.75	0.88	1.00	1.40
number of catalysts	1	2	2	2	2
substrate diameter (cm)	9.5	8.3	9.0	9.5	11.0
substrate	$8	$7	$7	$8	$10
ceria/alumina	$11	$9	$10	$11	$16
Pt/Pd/Rd	$28	$21	$25	$28	$39
can (18 gauge SS)	$3	$3	$3	$3	$4
Total Material Cost	$51	$39	$45	$51	$69
labor at $28/hr	$5	$5	$5	$5	$5
labor overhead at 40%	$2	$2	$2	$2	$2
supplier markup at 29%	$17	$13	$15	$17	$22
Manufacturer Price per Unit	$74	$59	$66	$74	$98
Hardware Cost to Manufacturer					
catalysts	$74	$119	$132	$148	$195
oxygen sensors	$17	$34	$34	$34	$34
exhaust manifold	$10	$20	$20	$25	$30
Total Incremental Hardware Cost	$101	$173	$186	$207	$259
Engine Manufacturer Markup					
labor at $28/hr	$2	$1	$1	$1	$1
labor overhead at 40%	$1	$0	$0	$0	$0
markup at 29%	$30	$50	$54	$60	$76
warranty markup at 5%	$5	$9	$9	$10	$13
Total Incremental Component Cost	$139	$233	$251	$279	$349

As discussed above, we do not include research and development costs in our fixed costs for SD/I engines. However, we do include tooling costs that would be associated with ramping up production of California engines for the entire United States. These tooling costs are presented in Table 6.4-4.

Table 6.4-4: Projected Incremental Tooling Costs for Catalytic Control

	3.0L I4	4.3L V6	5.0L V8	5.7L V8	8.1L V8
Fixed Costs to Engine Manufacturer					
tooling	$30,000	$35,000	$40,000	$40,000	$45,000
units/year	15,000	15,000	15,000	15,000	15,000
years to recover	5	5	5	5	5
fixed costs/unit	$1	$1	$1	$1	$1
Fixed Costs to Engine Marinizer					
tooling	$35,000	$45,000	$50,000	$55,000	$55,000
units/year	2,000	2,000	2,000	2,000	1,000
years to recover	5	5	5	5	5
fixed costs/unit	$5	$6	$7	$7	$14
Total Incremental Fixed Costs	$5	$6	$7	$8	$15

6.4.4 Certification and Compliance

We estimate that certification costs for SD/I engines would come to about $130,000 per engine family. We expect that manufacturers would combine similar engines into the same family. The above certification cost estimate allows for two months of R&D for each engine family as part of the certification process. This would include two engineers and three technicians and the corresponding testing costs for the two-month period. Unless engine designs were significantly changed, engine families could be recertified each year using carryover of this original test data. This cost is therefore amortized over five years of engine sales with an average volume of 2,000 engines per family. The resulting cost is $13 per engine.

6.4.5 Operating Cost Savings

We anticipate that manufacturers will convert their remaining carbureted engines to fuel injection to meet the proposed standards. We believe this will result in fuel savings because of the better fuel control offered by fuel injection compared to carburetion. The fuel consumption rates we use for carbureted and fuel injected SD/I engines and their derivation are described in more detail in the docket.[36] We use the price of gasoline discussed earlier in this chapter.

Table 6.4-5: Projected Fuel Savings for SD/I Engines

Annual Per-Engine Gallons Consumed	228
Average Life (years)	19.7
Anticipated Reduction in Fuel Consumption	2.3%
Lifetime Gallons Saved	103
Lifetime Cost Savings	$186
Discounted Cost Savings (7%)	$106

6.4.6 Total SD/I Engine Costs

We expect that SD/I engine manufacturers would use catalytic convertors and electronic fuel injection to meet the proposed standards. In 2003, about 60 percent of SD/I engines were sold with electronic fuel injection. This estimate is based on confidential sales information submitted to the California Air Resources Board by SD/I manufacturers certifying to the 2003 California exhaust emission standards. The manufacturers who certified in California represent more than 90 percent of U.S. sales of SD/I engines. Manufacturers have indicated to us that they are moving in the direction of selling more fuel-injected engines and using carburetors only on their low-cost “introductory” engines. For this cost analysis, we use the projected technology mix for 2009 from the NONROAD model which projects that about 85 percent of SD/I engines sold will be fuel-injected. Table 6.4-6 presents our estimates of the sales mix between carbureted and fuel-injected SD/I engines.

Table 6.4-6: Baseline Technology Mix for SD/I Engines

	2003 MY California Certification		Projected 2009 Baseline	
	Carbureted	Fuel Injection	Carbureted	Fuel Injection
3.0L I-4	100%	0%	50%	50%
4.3L V-6	75%	25%	20%	80%
5.0L V-8	40%	60%	5%	95%
5.7L V-8	10%	90%	0%	100%
8.1L V-8	100%	0%	0%	100%
high performance	--	--	50%	50%

We developed the per-engine costs by assigning costs for catalysts to all SD/I engines and costs for electronic fuel injection for engine models that are projected to be carbureted in 2009. As discussed above, our cost estimates include both variable and fixed costs, and we distinguish between near-term and long-term costs. Because our analysis amortizes fixed costs over 5 years, the long-term costs are made up of variable costs only. These variable costs are lower in the long term due to the learning effect discussed above. Table 6.4-7 presents these average per-engine cost estimates. To develop high-performance engine cost we considered that larger catalysts would be needed, even than the 8.1L engine, due to higher exhaust flow rates. Therefore, the variable costs were increased by 37 percent to account for this increase. Fixed costs were based on an engine family size of 50 engines, compared to 2,000 engines for traditional SD/I engines.

Table 6.4-7: SD/I Per-Engine Cost Estimates (Without Fuel Savings)

	Short Term (years 1-5)			Long Term (years 6-10)
	Fixed	Variable	Total	
SD/I Aggregate	$20	$342	$362	$274
3.0L	$18	$465	$483	$372
4.3L	$19	$377	$396	$301
5.0L	$20	$297	$317	$238
5.7L	$21	$279	$300	$223
8.1L	$28	$349	$377	$279
high performance	$95	$825	$920	$672

6.4.7 SD/I Aggregate Costs

Aggregate costs are calculated by multiplying the per-engine cost estimates described above by projected engine sales. Engine sales are based on estimates supplied by the National Marine Manufacturers Association (www.nmma.org) and projections for future years are based on the growth rates in the NONROAD model. Fuel consumption reductions are calculated using the NONROAD based on population estimates. These population estimates in the NONROAD model are similar to those estimated by NMMA. A description of the sales and population data and our analysis of the data is available in the docket.[37] Table 6.4-8 presents the projected costs of the proposed rule over a 30-year time period with and without the fuel savings that would be expected from meeting the exhaust emission standards. Fuel savings from the proposed evaporative emission standards are not included in this table, but they are presented separately below.

At a 7 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for SD/I exhaust emission control is $33 million. The corresponding estimated annualized fuel savings due to more efficient engine controls is $10 million. At a 3 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for SD/I exhaust emission control is $31 million. The corresponding estimated annualized fuel savings due to more efficient engine controls is $11 million.

Table 6.4-8: Projected 30-Year Aggregate Cost Stream for SD/I Engines

Year	Without Fuel Savings	With Fuel Savings
2009	$34,371,313	$33,494,477
2010	$34,619,275	$32,867,058
2011	$34,873,594	$32,183,227
2012	$35,127,914	$31,506,139
2013	$35,382,234	$30,816,636
2014	$26,919,578	$21,417,165
2015	$27,111,689	$20,680,689
2016	$27,301,399	$19,951,604
2017	$27,491,109	$19,238,380
2018	$27,680,818	$18,545,390
2019	$27,870,528	$17,864,335
2020	$28,060,238	$17,188,875
2021	$28,249,948	$16,506,937
2022	$28,439,658	$15,839,760
2023	$28,629,367	$15,182,967
2024	$28,819,077	$14,541,220
2025	$29,008,787	$13,918,790
2026	$29,199,697	$13,321,013
2027	$29,390,608	$12,751,094
2028	$29,581,518	$12,230,592
2029	$29,772,429	$11,947,322
2030	$29,963,339	$11,732,535
2031	$30,154,250	$11,567,788
2032	$30,345,160	$11,435,606
2033	$30,536,071	$11,325,500
2034	$30,726,981	$11,233,060
2035	$30,917,892	$11,157,682
2036	$31,108,802	$11,094,904
2037	$31,299,713	$11,044,775
2038	$31,490,623	$11,006,958

6.5 Evaporative Emission Control Costs for Small SI Equipment

This section presents our cost estimates for meeting the proposed evaporative emission standards for land-based equipment using small spark-ignition engines.

In our analysis of the costs of the proposed evaporative emission standards for Small SI equipment, we consider the approximately 250 equipment types used in the NONROAD model to determine emission inventories. These equipment types are then aggregated into the five engine classes, with each class divided by general equipment types and between residential and commercial applications. For each of these aggregate categories, we determine weighted average hose lengths and tank sizes which we use as inputs to our cost calculations. These inputs are presented in more detail in the evaporative emission inventory discussion in Chapter 3. This discussion presents our cost estimates as a function of hose length and tank size. In addition, we present examples of costs for four typical Small SI equipment configurations which include a handheld (HH) configuration, a walk-behind mower (WBM), and two other nonhandheld (NHH) configurations. These configurations, which are presented in Table 6.5-1, are based on average tank sizes and hose lengths used in our inventory model (see Chapter 3). Although these typical configurations do not, by any means, represent all of the equipment types included in our cost calculations, they should give a good indication of how we performed our analysis.

Table 6.5-1: Typical Small SI Equipment Configurations

	HH	WBM	NHH #1	NHH #2
Fuel Tank Capacity (gallons)	0.25	0.5	2	5
Fuel Tank Material*	HDPE	HDPE	HDPE	XLPE
Fuel Tank Molding Process	IM/BM	IM/BM	IM/BM	RM
Fuel Tank Weight (lbs.)	0.6	0.8	1.8	5.9
Fuel Hose Length (in.)	4	8	24	36
Fuel Hose Inner Diameter (in.)	0.125	0.25	0.25	0.25

* HDPE = high-density polyethylene, XLPE = cross-link polyethylene
* IM = injection-molded, BM = blow-molded, RM = rotational-molded

The fuel tank weights are based on measurements made in our lab on many of the fuel tanks that were included in our evaporative emission test programs. The higher weight to capacity ratio of the smaller fuel tank is due to the smaller surface to volume ratio and due to extra structural components often molded as part of the fuel tanks. We use the fuel tank weight to determine costs of material changes. The method used to mold the fuel tank and material used affect the permeation control strategies that may be used. This effect is discussed below.

Note that some handheld equipment has structurally-integrated constructions where the fuel tank is part of the structure of the equipment. These fuel tanks are typically made out of nylon 6 with up to 30 percent fiberglass reinforcement. Data in Chapter 5 suggest that these fuel tanks would be able to meet the proposed tank permeation standards without changing the fuel tank material.

6.5.1 Hose Permeation

Barrier fuel hose incremental costs estimates are based on costs shared confidentially by component manufacturers. These costs are supported by the costs of existing products used in other nonroad and automotive applications.[38,39,40] For baseline hose, we consider nitrile rubber hose such as that used to meet SAE J30 R7 recommendations. For handheld equipment, we consider the baseline hose to be injected-molded rubber hose for structurally-integrated constructions and clear elastomeric tubing for other equipment

For this analysis, we considered three primary approaches to reducing permeation from fuel hoses. The first was the use of thermoplastic fuel lines such as those used in automotive applications. The incremental cost of these fuel lines is about $0-0.10/ft compared to typical hose used on Small SI equipment. However, there have been concerns expressed in the past by manufacturers that this fuel line is not flexible or durable enough for small nonroad applications.

Two other approaches are using thermoplastic or thermoelastomer barrier materials in the fuel hose construction. Our estimate is that thermoplastic fuel lines, such as Teflon or THV800, would result in an incremental cost to the manufacturer of about $0.75-0.85 per foot. Manufacturers have expressed in the past that they would have to upgrade their fuel clamps for the use of thermoplastic barrier hose. Therefore, we include an incremental cost for the two clamps totaling $0.10. Manufacturers have recently shared with us that they believe the proposed standards can be met through the use of a lower cost approach. In this approach, the barrier layer is made of a thermoelastomer such as FKM. Our estimate of the incremental cost for this approach is $0.20-0.30 per foot. Although the high flexibility of thermoelastomers such as FKM may allow manufacturers to use existing hose clamps, we also include the hose clamp cost due to the uncertainty of how manufacturers will construct their equipment with the new hose.

In some handheld applications, the fuel lines are molded in intricate custom shapes rather than extruded like traditional hoses. In these designs, a section of the fuel line is inside the fuel tank while the remainder is external to the fuel tank. In addition, a vent line may be molded into the same part. Because the tanks are typically sealed with a one way valve on the vent, the vent lines are exposed to saturated vapor. The fuel lines may be formed from molded cured rubber such as NBR or injection-molded out of a rubberized plastic such as Alcryn. A low permeation approach would be to mold the fuel lines out of FKM which is a thermoelastomer used in other fuel line applications. Based on a sample of six fuel lines (two of which included vent lines) we got an average weight of 11 grams (0.025 lbs.). Based on cost estimates of $1.00/lb. for NBR and $10-15/lb. for FKM, we get a cost estimate of $0.25 to $0.35 per fuel line. Manufacturers have raised the concern that if a new material is used, that they may need to modify their hose connectors to make sure that the hose does not pull off the barbs. To account for this, we include a $0.10 cost for the addition of clamps or hose connector modifications.

Table 6.5-2 presents the estimated incremental costs of low permeation hose for four typical equipment configurations. These costs include the markup discussed above for overhead and profit. Because these hose constructions are established technology, we consider the short and long-term costs to be the same. We believe the proposed standards can be achieved using a thermoelastic barrier and therefore use these costs in our analysis.

Table 6.5-2: Fuel Line Permeation Cost Estimates for Typical Small SI Equipment

	HH 4", 1/8" ID	**WBM** 8", 1/4" ID	**NHH #1** 2 ft, 1/4" I.D.	**NHH #2** 3 ft, 1/4" I.D.
thermoplastic barrier hose	$0.54	$0.86	$2.32	$3.42
thermoelastic barrier hose	$0.28	$0.34	$0.77	$1.10
thermoelastic molded fuel line	$0.48	NA	NA	NA

6.5.2 Tank Permeation

As discussed in earlier chapters, plastic fuel tanks for Small SI equipment are constructed in one of three primary molding processes: blow-molding, injection-molding, and rotational molding. Blow-molded tanks are primarily made of high-density polyethylene (HDPE), injection-molded tanks are primarily HDPE or nylon, and rotational molded tanks are primarily cross-link polyethylene (XLPE). Because the molding process can affect the permeation control approaches available, we discuss the technologies for each approach individually.

6.5.2.1 All HDPE fuel tanks

Surface treatments can be used to reduce permeation from HDPE fuel tanks, whether they are blow-molded, injection-molded, or rotational-molded. Our surface treatment cost estimates are based on price quotes from a companies that specialize in fluorination[41] and sulfonation.[42] In the fluorination process, costs are based on the number of fuel tanks that will fit into the fluorination treatment chamber. Therefore, costs are higher for larger fuel tanks, because less tanks will fit in the chamber. The price sheet referenced for our fluorination prices assumes rectangular shaped containers. These fuel tanks would stack easily in the fluorination treatment chamber with little wasted space. However, tor irregular shaped fuel tanks, less fuel tanks would fit in the treatment chamber due to dead space between the tanks when they are placed in the support baskets in the chamber. To account for this inefficiency with typical shaped fuel tanks, we consider a void space equal to about 25 percent of the volume of the fuel tank. For handheld equipment, we consider a void space of 100 percent because of the structurally-integrated nature of many tanks.

For sulfonation, the shape of the fuel tanks is less of an issue because the treatment process is limited only by the spacing on the production line which is roughly the same for the range of fuel tank sizes used in Small SI equipment. These prices do not include the cost of transporting the tanks; we estimated that shipping, handling and overhead costs would be an additional $0.03 to $0.76 per fuel tank depending on tank size (using the same void space estimates as above).[43]

Manufacturers, with high enough production volumes, could reduce the costs of sulfonating fuel tanks by constructing an in-house treatment facility. The cost of a sulfonation production line facility that could treat 150-500 thousand fuel tanks per year (depending on tank size) would be approximately $800,000.[44] This facility, which is designed to last at least 10 years, is made up of a SO_3 generator, a scrubber to clean up used gas, a conveyor belt, and injection systems for the SO_3 gas and for the neutralizing agent (ammonia solution). The manufacturer of this equipment estimates that the operating costs, which includes electricity and chemicals, would be about 3 cents per tank. We based our costs on a production capacity of 300,000 units per year for handheld tanks and 150,000 units per year for non-handheld tanks. In the long term, the costs would be based on the full life of the equipment which we estimate to be 10 years for this analysis. Finally, we use a labor rate of $28/hr with a 40 percent markup for overhead which is consistent with our engine costs above and apply one full time employee to operation of the sulfonation machine. A manufacturer that sulfonates its fuel tanks in-house would not need to pay shipping costs. In the long run, we calculate that this approach will be less expensive than shipping tanks to an outside facility.

6.5.2.2 Blow-molded fuel tanks

Manufacturers may reduce permeation from blow-molded fuel tanks by blending in a low permeation material such as ethylene vinyl alcohol (EVOH) with the HDPE. This is typically known by its trade name, Selar. The EVOH in the plastic forms non-continuous barrier platelets in the tank during blow-molding that make it harder for fuel to permeation through the walls of the tank. Using this approach, no changes should be necessary in the blow-molding equipment, so the costs are based on increased material costs. We used 10 percent EVOH which costs about \$3-4 per pound and 90 percent HDPE which costs about \$0.65-0.75 per pound.[45] This equates to a price increase of about \$0.35 per pound. We then applied the material weights shown in Table 6.5-1 to estimate costs per tank for this technology.

For higher production volumes, manufacturers may consider blow molding multi-layer fuel tanks with continuous barriers. Practically, a new blow-molding machine would be required because four or five additional injection screws would be necessary for the barrier layer, two adhesion layers, an additional HDPE layer, and potentially a regrind layer. A machine that could blow-mold multi-layer tanks would approximately double the price of the blow-molding machine. For this analysis, we use a mono-layer machine cost of \$1,000,000 and a multi-layer machine cost of \$3,000,000[46], resulting in an increase in machine cost of \$2,000,000. In addition, tooling costs for each new tank design would be about \$50,000. For this analysis we considered a fuel tank with a material composition of 3 percent EVOH at \$3.50/lb, 4 percent adhesive layer at \$1/lb, 45 percent regrind, and the remainder HDPE. Our analysis uses a total annual production of 80,000-160,000 blow-molded tanks per year, depending on tank size (smaller sizes would allow more tanks per mold), with 5 different molds. Capital costs are amortized over 5 years in the short term and 10 years in the long-term (reflecting a 10 year life of the machine).

6.5.2.3 Injection-molded fuel tanks

The technologies discussed above for blow-molded fuel tanks do not appear to be feasible for injection-molded fuel tanks. The non-continuous barrier platelet approach does not work well in this process because of the high shear stresses associated with injection molding. Multi-layer rotomolded tanks would have to be formed by making separate molds, then fusing the layers when the tank sides are welded together. While this may be possible, it would be cumbersome. Barrier treatments would work for fuel tanks injected out of HDPE, but many handheld tanks are injection molded out of nylon for better thermal resistance. At this time, it appears that fluorination and sulfonation would not work effectively on nylon tanks. However, nylon has low permeation on gasoline, and some nylon formulations are capable of meeting the proposed standards which are based on test fuel with 10 percent ethanol.

The advantages of injection molding are that it has lower tooling costs than blow-molding and it is a faster molding process than rotational-molding. Although injection-molding does not lend itself well to multi-layer construction, there is another process with similar costs and production rates called thermoforming which does. Thermoforming entails using sheets of plastic that are heated and pulled into a mold using vacuum suction. As with injection molding, two halves are then joined together. In thermoforming, however, the sides are combined while the plastic is still molten rather than by welding as is used in injection-molding. By using sheets of extruded multi-layer plastic, thermoforming can be used to produce low-permeation, multi-layer fuel tanks.

Because the thermoforming process requires extruded sheets, this process requires the addition of an extruder. A small extruder, which would support several thermoforming machines considered in this analysis would cost $2-3 million. The thermoforming machine itself would cost about two-thirds that of an injection molding machine because it has less moving parts (such as the injection screw). However, we estimate that two thermoforming machines would be necessary to maintain the cycle time possible with an injection molding machine. At the same time, hot plate welding machines would not be necessary because the tanks halves are assembled in the thermoforming machine. We use an incremental cost savings of $100,000 for the molding machine. Mold costs are somewhat lower for thermoforming as well because they are made of aluminum rather than hardened steel. We estimate that a four-cavity injection mold would cost about $60-80,000 while a four-cavity thermoforming mold would cost $20-30,000. For this analysis we use a production of 300,000 tanks per year using 5 different molds. In the short term, we amortize the fixed costs over 5 years, while in the long term we use 10 years to represent the full life of the machines. Incremental material costs are based on 3 percent EVOH and 4 percent adhesion material to create the barrier layer.

Another option would be to mold the entire fuel tank of a low permeation material such as an acetal copolymer, or a thermoplastic polyester. These materials have list prices in the range of about $1- 2 per pound which is about double the material cost of HDPE, but comparable to the cost of nylon.[47] In addition, these fuel tanks could be made out of metal, which does not permeate. For larger marine fuel tanks, metal tanks are available that cost about 25-30 percent more than plastic fuel tanks (made under low volume construction). Private conversations with Small SI equipment manufacturers suggest that making small fuel tanks out of metal could increase the cost of the tanks for Small SI equipment by 200-300 percent and would limit the possibility of constructing complex designs.

6.5.2.4 Rotational-molded fuel tanks

Many larger fuel tanks are rotationally molded. This process is more cost-effective for smaller production volumes than blow-molding or injection-molding because of the lower tooling costs for new tank designs. However, this process is slower which limits its usefulness for large production volumes. Typically, rotational-molded fuel tanks manufactured for Small SI equipment are made of cross-link polyethylene (XLPE). Although XLPE is more expensive than HDPE which may also be used in the rotational-molding process, it is considered to be more impact resistant than HDPE. This is important because the rotational molded fuel tanks are often larger fuel tanks mounted on the outside of the equipment where it could be exposed to impacts such as stepping, thrown rocks, branches, etc.

As discussed in Chapter 5, neither sulfonation or fluorination has been demonstrated to be successful in creating a barrier on XLPE that would meet the proposed standards. Therefore, we look to multi-layer approaches for our cost estimates. In the rotational-molding process, fuel tanks may be formed with two layers. The traditional method is to add the first material to the mold prior to entering the oven, and once that shell forms to add a second material through the use of a drop box in the mold. Depending on the complexity and size of a drop box, it can add from $1,000 to nearly $9,000 to the cost of the mold.[48,49,50] One manufacturer is currently making multi-layer rotational-molded fuel tanks for use Small SI equipment without the use of a drop box. Their approach is proprietary, but the material manufacturer is making efforts to develop an alternative to using a drop box as well.[51] For this analysis, we include a $5,000 cost for a drop box in the short term, but not in the long term. In addition, we do not project that this process will have an increase on the cycle processing time because the increased heating time is offset by decreased cooling time. The inner layer could be molded out of an acetal copolymer, nylon, or even HDPE which could then be surface treated. Typical acetal copolymers cost about the same as XLPE, although the rotational-molding grade may cost a little more.[52] We use a cost of $1.50/lb. for this acetal copolymer compared to XLPE which is approximately $1.20/lb. Nylon, which can range in cost from $2 to $6 depending on the grade may also be used in conjunction with XLPE to provide a permeation barrier. The advantage of nylon is that it bonds to XLPE better than acetal copolymers. For this analysis, we consider the use of nylon at $4.00/lb in a fuel tank with a 1 mm barrier and 4-5mm average total wall thickness. We amortize the fixed cost of the drop boxes over 5 years of production of 1000 tanks per year for each mold.

Another material is also available for molding an inner layer in rotomolded XLPE fuel tanks. This material is poly butylene terephthalate cyclic oligimor and is known by the trade name CBT®. With this material, no drop box is necessary. The CBT is added in the mold with the XLPE resin. During the molding process, the XLPE shell forms in the mold. Due to differences in viscosity and temperature properties, the CBT goes to the inside of the fuel tank. It then polymerizes to form an inner liner. We use a cost of $5/lb. for CBT in this analysis and use the same barrier thickness as discussed above.

Another technology that has been demonstrated for reducing permeation from XLPE fuel tanks is a low permeation epoxy barrier. To apply this barrier, an adhesion treatment must first be performed to increase the fuel tank surface energy so that the epoxy will adhere to the XLPE. This can be done through a low level fluorination treatment. For this analysis we use the cost of level 1 fluorination.[53] We use the same void space and shipping costs discussed above for our fluorination cost analysis. The epoxy could be applied by dipping the fuel tank or spraying it on like paint and then must be cured using UV light. We include a fixed cost of $10,000 for a volume of 100,000 fuel tanks per year to account for coating and curing equipment. In addition, we apply the cost of one full time employee to apply the coating and use a labor rate of $28/hr with a 40 percent markup for overhead which is consistent with our engine costs above. For traditional epoxies, we estimate that the cost would be $6-7/lb. Manufacturers have commented that UV-curable epoxy, which could be processed much faster, would cost $12-15/lb.[54,55] We use a cost of $12/lb. for this analysis. Because only a thin coating needed (we use 0.125 mm), the epoxy layer makes up only about 3 percent of the material of the fuel tank. Because there are benefits to the epoxy coating such as allowing the fuel tank to be painted, there may be an incentive to use this technology even on HDPE fuel tanks. For that reason, we estimated the cost for smaller HDPE tanks as well using the same general assumptions except for a larger production volume of 150,000 tanks per year due to their smaller size.

6.5.2.5 Summary of Fuel Tank Costs per Equipment

Table 6.5-3 summarizes the incremental costs of the fuel tank permeation emission-control strategies discussed above. For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. Both long-term and short-term costs are presented. The long-term costs account for the stabilization of the capital investments and the learning curve effect discussed above. We use the same material and shipping costs for our short-term and long-term estimates because these cost components are well established with a wide range of applications. As discussed above, for the multilayer fuel tank constructions, we consider an EVOH barrier for hand-held and Class I equipment and nylon barrier for Class II equipment.

Table 6.5-3: Tank Permeation Control Cost Estimates for Typical Small SI Equipment

	HH 0.25 gallons IM/BM	**WBM** 0.5 gallons IM/BM	**NHH #1** 2 gallons IM/BM	**NHH #2** 5 gallons RM
fluorination[a,b]: short term	$0.62	$0.77	$3.10	NA
long term	$0.50	$0.63	$2.52	
sulfonation[a,b]: short term	$0.64	$1.25	$1.40	NA
long term	$0.52	$1.01	$1.16	
non-continuous platelets[a]	$0.17	$0.22	$0.51	NA
multi-layer[a]: short term	$4.13	$4.08	$3.80	NA
EVOH long term	$2.01	$1.98	$1.75	
multi-layer[c]: short term	NA	NA	NA	$5.54
PA11 long term				$3.40
multi-layer[c]: CBT	NA	NA	NA	$5.77
thermo-forming[b]: short term	$0.36	$0.53	$1.50	NA
long term	$0.20	$0.29	$0.82	
acetal-copolymer[a,b,c]	$0.62	$0.79	$1.82	$2.28
metal construction[a,b,c]	$1.94	$3.87	$5.16	$9.68
epoxy coating[a,b,c]: short term	$1.26	$1.32	$2.56	$5.69
long term	$1.01	$1.06	$2.08	$4.64

[a] incremental to traditional blow-molding
[b] incremental to traditional injection-molding
[c] incremental to traditional rotational-molding

6.5.3 Venting Losses

Venting losses are made up of diurnal breathing losses and running losses which are similar to diurnal emissions except that the heating event is caused by the engine. We are proposing that equipment manufacturers install systems to capture their running losses by sealing the fuel tank and venting vapor to the engine intake. For the purpose of our cost analysis, we consider a system with a purge hose running from the fuel tank to the engine intake (with 2 hose clamps) that is the same length of the fuel hose. We use a cost of $0.25/ft for the hose and $0.10 each for the two hose clamps. This is consistent with the above cost analysis for low permeation hose. We also consider a fuel cap redesign to meet the proposed sealing requirements with a one way valve to prevent a vacuum from occurring in the fuel tank as fuel is drawn out to the engine. We use a cost of $1 for the valve and cap redesign. Also, we include a cost of $0.10 to account for a limiting flow orifice in the purge line. Finally, using the labor costs discussed above, we calculate an incremental assembly labor cost of about $0.20 per engine.

Diurnal emissions could be captured through the use of a carbon canister. The carbon then could be purged by air drawn into the fuel tank as the fuel cools. This is known as passive purge. This system would be similar to the running loss control system except that venting would occur through a canister and the valving would be modified to provide liquid/vapor separation. This valve would prevent fuel from entering the canister if the equipment were tipped over. We estimate the cost of a canister to vary based on size ranging from about $2 for a 1 quart tank to about $4 for a five gallon tank. The majority of these canister costs for small fuel tanks are for the canister, connections, and mounting hardware. As the fuel tank size increases, the carbon becomes a more significant fraction of the cost. For this analysis, we add the cost of the canister to the cost of running loss control and include another $0.20 for assembly costs.

Diurnal emissions could be controlled further through an active purge canister system. In an active purge system, the canister would also be purged by the engine during operation. The added components of this system compared to the passive purge system would include a line to the air filter (or separate air filter for the canister breathing line) and a purge valve. This amounts to an additional cost of $0.15/ft for the air line, $0.20 for two clamps, $1 for the purge valve, and another $0.20 for assembly.

Table 6.5-4: Venting Control Cost Estimates for Typical Small SI Equipment

		WBM 0.5 gallons 8", 1/4" ID	**NHH #1** 2 gallons 2 ft, 1/4" ID	**NHH #1** 5 gallons 3 ft, 1/4" I.D.
running loss:	short term	$2.06	$2.32	$2.51
	long term	$1.65	$1.85	$2.01
passive purge canister*:	short term	$3.07	$3.82	$4.38
	long term	$2.45	$3.06	$3.51
active purge canister**:	short term	$1.93	$2.19	$2.38
	long term	$1.54	$1.75	$1.91

* incremental to running loss control
** incremental to passive purge canister

6.5.4 Certification and Compliance

The proposed running loss standards call for manufacturers to certify their running loss systems based on design rather than requiring emission testing. However, they will still need to integrate the emission-control technology into their designs and there will be some engineering and clerical effort need to submit the required information for certification. We expect that in the early years, plastic fuel tank manufacturers will perform durability and permeation testing on their fuel tanks for certification. They will be able to carry over this data in future years and will be able to carry across this data to other fuel tanks made of similar materials and using the same permeation control strategy regardless of tank size or shape. Typical certification costs may be spread between the tank manufacturer, hose manufacturer, and equipment manufacturer. For the sake of this analysis, we combine the tank, hose, and boat certification costs to calculate the total certification of an average fuel system. We estimate that 90 percent of fuel tank sales in Small SI equipment are plastic and the remainder are metal.

For the first year we estimate fuel tank durability and certification testing to cost about $15,000 per tank manufacturer on the assumption that the manufacturer will use the same materials and permeation control strategy for all of their fuel tanks to reduce costs. Low permeation fuel lines are largely an established technology. However, we include a cost of $1,000 to perform certification testing on fuel lines. In addition, we estimate about $10,000 for engineering and clerical work for the equipment manufacturers.

For handheld equipment manufacturers, we spread these costs over sales of 500,000 units per year. For handheld and Class I equipment manufacturers, which are integrated manufacturers, we base the costs on average annual sales per manufacturer. We estimate the average annual sales to be about 500,000 units for handheld equipment and 100,000 units for Class I equipment. Generally for Class II equipment, a large number equipment manufacturers purchase their engines from a smaller number of engine manufacturers. We estimate average annual sales per year to be 50,000 units for Class II.

As with other fixed costs, we amortized the cost over 5 years of sales to calculate per unit certification costs. Combining these costs, we get average fuel system integration and compliance costs of about $0.01 for handheld equipment, $0.05 for Class I equipment, and $0.10 for Class II equipment.

6.5.5 Operating Cost Savings

Evaporative emissions are essentially fuel that is lost to the atmosphere. Over the lifetime of a piece of Small SI equipment, this can result in a significant loss of fuel. The proposed reduction in evaporative emissions would therefore result in meaningful fuel savings which can be directly related to operating cost savings based on an average density of 6 lbs/gallon for gasoline (based on lighter hydrocarbons which evaporate first) and the price of gasoline described above. Table 6.5-5 presents the estimated fuel savings for Small SI equipment associated with the proposed evaporative emission standards.

Table 6.5-5: Projected Evaporative Fuel Savings for Small SI Equipment

	Handheld	Class I	Class II
Evaporative HC Reduced [lbs/life]	1.4	4.9	28.6
Lifetime Gallons Saved	0.2	0.8	4.7
Lifetime Cost Savings	$0.41	$1.46	$8.57
Average Equipment Life [years]	4.2	5.3	5.9
Discounted Cost Savings (7%)	$0.40	$1.32	$5.98

6.5.6 Total Small SI Equipment Costs

We expect that Small SI manufacturers will use a variety of technologies to meet the proposed fuel tank permeation standards. As discussed above, many options are available so the technologies chosen will depend on the baseline fuel tank construction, the equipment application, and the manufacturers' particular design philosophies. Hose permeation standards will likely be met through the use of barrier hose constructions.

For the purpose of this analysis, we divided Small SI equipment into 23 categories to better quantify differences in costs that may be associated with different equipment applications. Earlier in this chapter, engine costs are presented as a function of design life. However, we believe evaporative emission costs are more a function of the application than the design life due to the differences in hose lengths and tank sizes and constructions. Manufacturers would not likely design a less robust fuel system for equipment used with lower hour engines. Table 6.5-6 presents our assessment of the mix of the fuel system constructions used today. This assessment is based on the NONROAD 2005 model and on confidential information supplied by Small SI equipment manufacturers.

Table 6.5-6: Baseline Technology Mix for Small SI Equipment

Equipment Class	Fuel Line Description		Fuel Tank Construction	
	Length ft*	construction	gallons	material/process**
Handheld Equipment				
Class III commercial	0.25	rubber hose	0.9	HDPE
Class III residential	0.25	rubber hose	0.3	HDPE
Class IV commercial	0.33	6% molded line	0.4	6% Nylon/94% HDPE
Class IV residential	0.33	24% molded line	0.3	24% Nylon/76% HDPE
Class V	0.50	52% molded line	0.5	52% Nylon/48% HDPE
Class I Equipment				
ag/const/gen ind/mat hand	0.72	rubber hose	1.6	100% IM
commercial mowers	0.72	rubber hose	0.8	90% IM/10% BM
residential mowers	0.62	rubber hose	0.4	100% IM
com. other L&G	0.72	rubber hose	1.1	90% IM/10% BM
res. other L&G	0.62	rubber hose	0.6	100% IM
pumps/comp/press. wash	0.72	rubber hose	0.8	100% IM
snow equipment	0.63	rubber hose	0.3	100% IM
utility/rec. vehicles	0.72	rubber hose	3.6	100% IM
welders/generators	0.72	rubber hose	0.8	100% IM
Class II Equipment				
ag/const/gen ind/mat hand	3.6	rubber hose	5.4	60% IM/40% RM
commercial mowers	6.5	rubber hose	4.7	60% IM/40% RM
residential mowers	3.2	rubber hose	2.6	70/18/12% IM/BM/RM
com. other L&G	1.5	rubber hose	1.2	60% IM/40% RM
res. other L&G	1.1	rubber hose	5.0	70/18/12% IM/BM/RM
pumps/comp/press. wash	2.6	rubber hose	4.7	60% IM/40% RM
snow equipment	1.2	rubber hose	0.7	60% IM/40% RM
utility/rec. vehicles	2.7	rubber hose	3.9	60% IM/40% RM
welders/generators	3.8	rubber hose	6.0	60% IM/40% RM

* we use 1/8" I.D. for handheld and 1/4" I.D. for non-handheld hose
** IM = injection molded HDPE, BM = blow-molded HDPE, RM = rotational-molded XLPE

We base our fuel tank costs on several technologies. In our cost analysis for handheld engines, we model costs based on fluorination for HDPE tanks, but we do not apply costs to tanks that are molded out of nylon as these tanks would likely meet the proposed standards today. For non-handheld equipment, we split the costs of permeation control of injected molded HDPE fuel tanks 50/50 between fluorination and converting to multi-layer thermoformed constructions with an EVOH barrier. For blow-molded fuel tanks, we base our costs on using a multi-layer blowmolded construction with an EVOH barrier. For rotational-molded XLPE fuel tanks, we base our costs on rotational-molding a nylon layer in the tank.

For fuel line permeation, we distinguish between the costs for traditional hose versus molded fuel lines. Fuel hose costs are based on using a fluoroelastomer barrier within the traditional construction. For molded fuel lines, we base the costs on molding the parts completely out of a high-grade fluoroelastomer. We do not apply costs to fuel lines used in cold-weather equipment.

In the case where current equipment designs are such that the fuel in the tank does not heat up substantially during operation, equipment manufacturers would not need to add additional hardware for running loss control. However, we are not able to quantify what fraction of the equipment population this represents at this time. Therefore, we are applying the cost of the running loss system described above for all non-handheld equipment in our analysis. This cost approach presents a somewhat conservatively high cost of control for running loss. This running loss control system would also control diffusion from Small SI equipment. In some cases, manufacturers may choose to move the fuel tank further away from heat sources such as the engine or hydraulic system to meet the proposed running loss requirement (or insulate the tank). Presumably, manufacturers would not choose this option unless it were less expensive than the running loss control system described above. Therefore, we are not attempting to estimate the range of approaches that manufacturers may take to meet the proposed running loss requirements.

As discussed above, our cost estimates include both variable and fixed costs, and we distinguish between near-term and long-term costs. Because our analysis amortizes fixed costs over 5 years, the long-term costs are generally made up of variable costs only. The exception to this is fuel tank permeation control strategies where more expensive molding equipment is used. We assume an equipment life of 10 years, so in the long term, the amortized additional cost of the molding equipment is half, on average, of the short-term amortized cost over 5 years (5 years of amortized payments/10 years of equipment life = ½). In addition, variable costs are lower in the long term due to the learning effect discussed in Section 6.1. Table 6.5-7 presents these average per-engine cost estimates.

Table 6.5-7: Small SI per Equipment Cost Estimates (Without Fuel Savings)

	Short Term (years 1-5)			Long Term (years 6-10)		
	Fixed	Variable	Total	Fixed	Variable	Total
Handheld aggregate	$0.01	$0.81	$0.82	$0	$0.69	$0.69
tank permeation	$0.01	$0.62	$0.63	$0	$0.50	$0.50
hose permeation	$0	$0.19	$0.19	$0	$0.19	$0.19
Class I aggregate	$0.47	$2.71	$3.16	$0.19	$2.10	$2.29
tank permeation	$0.45	$0.32	$0.75	$0.19	$0.26	$0.45
hose permeation	$0.02	$0.33	$0.35	$0	$0.20	$0.20
running loss	$0	$2.05	$2.05	$0	$1.64	$1.64
Class II aggregate	$1.25	$5.68	$6.90	$0.68	$4.62	$5.30
tank permeation	$1.20	$2.08	$3.26	$0.68	$1.66	$2.34
hose permeation	$0.04	$1.09	$1.13	$0	$0.96	$0.96
running loss	$0	$2.51	$2.51	$0	$2.00	$2.00

6.5.7 Small SI Equipment Aggregate Costs

Aggregate costs are calculated by multiplying the per-engine cost estimates described above by projected equipment sales. Fuel savings are calculated directly from the projected HC reductions due to the proposed evaporative emission standards. Table 6.5-8 presents the projected costs of the proposed rule over a 30-year time period with and without the fuel savings associated with reducing evaporative emissions.

At a 7 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for Small SI evaporative emission control is $67 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from Small SI equipment is $52 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for Small SI evaporative emission control is $70 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from Small SI equipment is $58 million.

Table 6.5-8: Projected 30-Year Aggregate Cost Stream for Small SI Evap

Year	Without Fuel Savings			With Fuel Savings		
	Handheld	Class I	Class II	Handheld	Class I	Class II
2008	$-	$3,869,095	$6,281,721	$-	$2,982,585	$4,213,867
2009	$5,714,115	$3,938,646	$6,394,682	$5,480,395	$2,097,799	$1,977,749
2010	$5,909,315	$4,008,024	$6,508,249	$5,230,762	$1,225,996	$(258,757)
2011	$6,017,988	$4,080,278	$39,786,661	$4,942,678	$415,185	$25,506,408
2012	$7,848,826	$34,157,324	$40,469,354	$6,193,002	$25,627,296	$19,923,826
2013	$7,981,700	$32,774,886	$39,835,064	$5,806,851	$20,174,259	$14,024,588
2014	$6,909,877	$33,321,924	$40,503,217	$4,336,640	$17,817,514	$10,833,852
2015	$6,922,632	$33,866,041	$41,167,585	$4,075,983	$16,541,314	$8,032,827
2016	$7,034,855	$34,402,748	$33,342,748	$3,968,662	$15,570,529	$(2,641,523)
2017	$7,147,090	$26,950,398	$33,879,410	$3,967,964	$6,863,628	$(4,071,321)
2018	$7,259,067	$27,372,435	$34,414,535	$3,997,894	$6,516,375	$(5,142,350)
2019	$7,371,143	$27,799,282	$34,954,723	$4,043,702	$6,346,214	$(5,931,671)
2020	$7,483,470	$28,223,637	$35,491,162	$4,098,612	$6,262,715	$(6,542,467)
2021	$7,595,660	$28,646,477	$36,027,436	$4,158,860	$6,230,543	$(6,972,441)
2022	$7,707,763	$29,066,350	$36,559,874	$4,219,200	$6,236,111	$(7,317,102)
2023	$7,819,853	$29,489,883	$37,095,737	$4,279,643	$6,281,352	$(7,598,592)
2024	$7,931,999	$29,912,857	$37,631,938	$4,340,208	$6,346,064	$(7,856,488)
2025	$8,044,212	$30,337,439	$38,171,542	$4,400,839	$6,412,326	$(8,091,169)
2026	$8,156,448	$30,765,267	$38,711,628	$4,461,480	$6,478,674	$(8,313,604)
2027	$8,268,656	$31,192,359	$39,250,255	$4,522,093	$6,544,241	$(8,526,931)
2028	$8,380,840	$31,618,433	$39,788,258	$4,582,681	$6,608,795	$(8,733,177)
2029	$8,493,060	$32,045,711	$40,327,667	$4,643,307	$6,674,550	$(8,932,174)
2030	$8,605,303	$32,473,046	$40,867,213	$4,703,955	$6,740,348	$(9,125,631)
2031	$8,717,528	$32,900,804	$41,407,443	$4,764,584	$6,806,591	$(9,314,633)
2032	$8,829,741	$33,328,357	$41,946,957	$4,825,202	$6,872,622	$(9,502,186)
2033	$8,941,949	$33,755,498	$42,485,978	$4,885,815	$6,938,242	$(9,687,202)
2034	$9,054,168	$34,182,354	$43,024,838	$4,946,439	$7,003,562	$(9,869,734)
2035	$9,166,396	$34,609,570	$43,564,162	$5,007,071	$7,069,255	$(10,050,377)
2036	$9,278,617	$35,036,864	$44,103,498	$5,067,698	$7,135,021	$(10,228,844)
2037	$9,390,834	$35,464,338	$44,643,012	$5,128,319	$7,200,976	$(10,405,188)
2038	$9,503,051	$35,891,721	$45,182,425	$5,188,941	$7,266,812	$(10,580,702)

6.6 Costs of Evaporative Emission Controls for Marine Vessels

This section presents our cost estimates for meeting the proposed evaporative emission standards for marine vessels.

To determine the cost impacts of the proposed evaporative emission standards on marine fuel systems, we considered three primary marine applications. The first is a porTable fuel tank with a detachable fuel line and a primer bulb. The second is a personal watercraft vessel. The third is a larger vessel with an installed fuel tank and fuel lines meeting SAE J1527 specifications. In our cost analysis, we consider a wide range of vessel sizes for each of these categories. However, to simplify this discussion we only present our cost estimates for the three typical applications shown in Table 6.6-1. For this illustration, costs are based on vessels with one fuel tank and one engine. Although these typical configurations do not, by any means, represent all of the vessel types included in our cost calculations, they should give a good indication of how we performed our analysis.

Table 6.6-1: Typical Marine Vessel Fuel System Configurations

	PorTable Tank	PWC	Installed Tank
Fuel Tank Capacity (gallons)	6	17	57
Fuel Tank Material*	HDPE	HDPE	XLPE
Fuel Tank Molding Process	blow-molded	blow-molded	rotational-molded
Fuel Tank Weight (lbs.)	4.4	12	55
Fuel Hose: Length (ft.)	6, primer bulb	5.7	9.9
Inner Diameter (in.)	1/4	1/4	3/8
Vent Hose: Length (ft.)	–	2	8.0
Inner Diameter (in.)	–	1/4	5/8
Fill Neck: Length (ft.)	–	1.9	10.1
Inner Diameter (in.)	–	1.5	1.5

* HDPE = high-density polyethylene, XLPE = cross-link polyethylene

Fuel tank weights are based on measurements of fuel tanks used in our permeation testing and are used to determine material costs. XLPE fuel tanks are typically thicker walled; thus they typically weigh more per gallon of capacity. Fuel hose lengths are based on conversations with (and confidential business information from) boat builders and fuel system suppliers. This data is within the range of hose lengths included in the written comments made by one boat builder on our earlier proposal.[56]

6.6.1 Hose Permeation

There are several grades of fuel system hose used in marine applications. For sterndrive and inboard (SD/I) applications, Title 33 of the Code of Federal Regulations, Part 183 defines fuel system requirements. These requirements reference SAE J1527 for fuel hose specifications. For personal watercraft (PWC), fuel line specifications are defined in SAE J2046. For outboards, no fuel hose specifications exist. Typically, larger vessels, with installed fuel tanks use SAE J1527 Class I hose for lines filled with fuel and Class II hose for lines containing fuel vapor. Inner diameters (ID) of these fuel system lines are typically 3/8" for fuel lines, 5/8" for vent lines, and 1.5" for fill necks. PWC typically have fuel supply/return hose with a 1/4" ID. PorTable marine fuel tanks for outboards typically have fuel lines with a 1/4" ID and a primer bulb. Fill neck hose is made by wrapping several layers of materials over a mandrill and vulcanizing the rubber in an oven. The remaining fuel lines are typically extruded. Fuel hose meeting the CFR requirements typically has several layers for durability and flame resistance.

Barrier fuel hose incremental costs estimates are based on costs of existing products used in marine and automotive applications.[57,58,59,60,61] Because the manufacturing process is not fundamentally changed in adding a barrier layer, this cost is mostly the result of more expensive materials. For 1/4" hose such as used in some small outboards and personal watercraft, we estimate a cost increase of $0.25/ft for a thermoelastic barrier and $0.85/ft for a thermoplastic barrier. These costs are consistent with the costs described above for Small SI equipment.

SD/I vessels are required to use marine fuel hose meeting Coast Guard requirements specified in 33 CFR part 183. This hose is recommended by the American Boat and Yacht Council for outboard boats not using porTable fuel tanks as well. Marine hose with a nylon barrier is available today that meets these requirements. The cost differential of traditional versus marine barrier hose for fuel and vent lines in the market today varies from no cost at all to more than $1 per foot. One hose distributer stated that they sell both non-barrier and barrier hose at the same price. They stated that the fuel resistance provided by the barrier layer allows the hose construction to use a thinner wall and therefore use less rubber. Another hose distributor, lists about a $1 cost markup for A1 barrier hose compared to their B1 marine hose. Note that B1 hose does not meet the Coast Guard fire requirements for fuel lines and this may be part of the reason for the cost differential. For this analysis, we use a cost increase of $0.50/ft for fuel hose and $1.00 for vent hose for vessels with installed fuel tanks. We use a higher incremental cost for vent hose because this hose typically has a larger diameter, requiring more material.

For 1½" fill neck hose, we estimate a cost increase of $2.00/ft. This cost increase is based on our estimates of material and labor costs. The fill neck hose would be constructed in the same manner as today except that a thin barrier layer would be included in the multi-layer construction. One hose distributer advertises barrier fill-neck hose with a price markup of $9 per foot. However, this cost markup likely represents the high costs typical of special orders where setup costs must be spread over low hose production. Currently, little or none of this hose is purchased by boat builders. Our price estimate is more consistent with differences in cost for barrier versus non-barrier chemical hose manufactured in the same manner.

We do not expect the addition of a barrier layer to affect the flexibility of the hose because marine hose is already fairly stiff and because the barrier layer is very thin and flexible. In fact, the barrier hose samples we tested appeared a little more flexible than the baseline hose because less wall thickness was needed for permeation control. Therefore, we believe special hose clamps or fittings will typically be required.

Primer bulbs are typically formed from molded cured rubber such as NBR or injection-molded out of a rubberized plastic such as Alcryn. Primer bulbs could also be molded from FKM which is a fluoroelastomer used in fuel line applications. Primer bulbs typically weigh between 0.1 and 0.2 lbs, nitrile costs about $1.00/lb and FKM costs about $10-15/lb depending on the level of fluorine in the material. If the whole primer bulb was molded out of FKM, it would increase the material cost by about $1.50-2.00 per primer bulb. Alternatively, manufacturers could save on material costs by injection molding an inner layer of Alcryn and curing a coating of FKM over this shell. Using a higher grade of FKM ($15/lb) could help minimize the amount of the fluoroelastomer needed. For the multi-layer design, we assume about 30-50 percent of the material would be FKM which results in a material cost increase of about $0.90 per primer bulb.

Table 6.6-2 presents our estimates of incremental costs for low permeation marine fuel system hose. Primer bulb costs are presented both for 100 percent FKM and multi-layer constructions. The incremental cost for the 1/4" fuel lines are presented for the thermoelastic barrier and the costs for the heavier fuel hose are based on costs of existing nylon barrier marine hose. These costs include a markup, and no long-term cost savings are applied to these costs because they are primarily material costs.

Table 6.6-2: Hose Permeation Control Cost Estimates for Typical Marine Vessels

	PorTable Tank 6', 1/4" ID fuel hose primer bulb	**PWC** 5.7', 1/4" ID fuel hose 1.9', 1.5" ID fill neck 2.0', 1/4" ID vent hose	**Installed Tank** 9.9', 3/8" ID fuel hose 10.1', 1.5" ID fill neck 8.0', 5/8" ID vent hose
primer bulb			
100% FKM	$2.13	–	–
multi-layer	$1.16	–	–
fuel supply/return	$1.94	$1.84	$6.58
fill neck	–	$5.16	$26.12
vent hose	–	$0.65	$10.29

6.6.2 Tank Permeation

PorTable fuel tanks and fuel tanks used in personal watercraft are typically blow-molded out of HDPE and have a capacity ranging from 4 to18 gallons. Because of the manufacturing process and material used, some permeation control technologies are available that are different from what would be feasible for larger rotational-molded fuel tanks. Larger, low-production volume marine fuel tanks are typically rotational-molded out of XLPE. Rotational-molding is used for smaller production runs because of the much lower relative tooling costs compared to blow-molding. For fuel tanks in vessels that are subject to the 33 CFR 183 fuel system requirements, manufacturers have found that fuel tanks molded out of HDPE will not pass the fire test, while XLPE fuel tanks will. Therefore, XLPE is used in rotational-molded marine fuel tanks.

6.6.2.1 Blow-Molded Fuel Tanks

Our surface treatment cost estimates are based on price quotes from companies that specialize in this fluorination[62] and sulfonation.[63] The fluorination costs are a function of the geometry of the fuel tanks because they are based on how many fuel tanks can be fit in a treatment chamber. The price sheet referenced for fluorination assumes rectangular shaped containers. For irregular shaped fuel tanks, the costs would be higher because they could not efficiently utilize the chamber volume. There would be significant void space. We consider a void space equal to about 25 percent of the volume of the fuel tank. For sulfonation, the shape of the fuel tanks is less of an issue because the treatment process is limited only by the spacing on the production line which is roughly the same for the range of fuel tank sizes used for porTable and personal watercraft fuel tanks. These prices do not include the cost of transporting the tanks; we estimated that shipping, handling and overhead costs would be an additional $0.40-$1.40 per fuel tank, for tanks ranging from 4-18 gallons.[64]

As discussed above for Small SI fuel tanks, manufacturers, with high enough production volumes, could reduce the costs of sulfonating fuel tanks by constructing an in-house treatment facility. We base our costs for marine fuel tanks on 150,000 tanks per year and use this approach for our long-term cost determination for sulfonation.

Our estimate of the cost for non-continuous barrier platelets (generally known as Selar) is based on increased material costs. No changes should be necessary to the blow-molding equipment. We used 10 percent ethylene vinyl alcohol (EVOH) which is about $3-4 per pound and 90 percent HDPE which is about $0.65-0.75 per pound.[65] This equates to a price increase of about $0.35 per pound. We then applied the material weights shown in Table 6.5-1 to estimate costs per tank for this technology.

For higher production volumes, manufacturers may consider blow molding multi-layer fuel tanks with continuous barriers. Practically, a new blow-molding machine would be required because four or five additional injection screws would be necessary for the barrier layer, two adhesion layers, an additional HDPE layer, and potentially a regrind layer. A machine that could blow-mold multi-layer tanks would approximately double the price of the blow-molding machine For this analysis, we use a mono-layer machine cost of $1,000,000 and a multi-layer machine cost of $3,000,000 for smaller tanks and $4,000,000 for larger tanks (>6 gallons)[66], resulting in an increase in machine cost of $2,000,000-$3,000,000. In addition, tooling costs for each new tank design would be about $50,000. For this analysis we considered a fuel tank with a material composition of 3 percent EVOH at $3.50/lb, 4 percent adhesive layer at $1/lb, 45 percent regrind, and the remainder HDPE. Our analysis uses a total annual production of 60,000-80,000 blow-molded tanks per year, depending on tank size, with 5 different molds. Capital costs are amortized over 5 years in the short term and 10 years in the long-term (reflecting a 10 year life of the machine).

6.6.2.2 Rotational-Molded Fuel Tanks

Most installed fuel tanks are rotational-molded out of XLPE for the reasons discussed above. As discussed above, barrier treatments have not been demonstrated to provide effective permeation control for XLPE. In addition, Selar and traditional multi-layer blow-molding approaches do not work for rotational-molded cross-link polyethylene fuel tanks.

Two approaches were discussed above in the Small SI section for rotational-molded XLPE fuel tanks: 1) dual-layer molding with a barrier layer and 2) epoxy coating of fuel tanks. These approaches could also be applied to marine fuel tanks. For the dual layer approach, marine fuel tank manufacturers have expressed concern that the acetal copolymer will not adhere well to the XLPE. For large fuel tanks, this could be an issue because the layers could pull apart and cause leaks at the fittings. As an alternative, one company has developed an approach using a high grade, non-hygroscopic nylon known a polyamide 11 as a barrier layer. This material costs about \$5-7/lb compared to XLPE which costs about \$1.20/lb. The barrier layer would likely be about 20 percent of the total material. Using a nylon cost of \$6/lb. and a barrier fraction of 30 percent, we get an average material cost of \$2.64/lb. For the short term, we add a \$5,000 cost to the mold or a drop box which we amortize over 100 tanks per year for 5 years. Consistent with the analysis for Small SI equipment, we do not include the cost of a drop box in the long term because of the ongoing development of a process that does not require a drop box.[67] In fact, one manufacture is already using a proprietary process to mold multi-layer rotational-molded fuel tanks without a drop box.

Another material is also available for molding an inner layer in rotomolded XLPE fuel tanks. This material is poly butylene terephthalate cyclic oligimor and is known by the trade name CBT®. With this material, no drop box is necessary. The CBT is added in the mold with the XLPE resin. During the molding process, the XLPE shell forms in the mold. Due to differences in viscosity and temperature properties, the CBT goes to the inside of the fuel tank. It then polymerizes to form an inner liner. We use a cost of \$5/lb. for CBT in this analysis and use the same barrier thickness as discussed above.

Another technology that has been demonstrated for reducing permeation from XLPE fuel tanks is a low permeation epoxy barrier. To apply this barrier, an adhesion treatment must first be performed to increase the fuel tank surface energy so that the epoxy will adhere to the XLPE. This can be done through a low level fluorination treatment. For this analysis we use the cost of level 1 fluorination.[68] We use the same void space and shipping costs discussed above for our fluorination cost analysis. Shipping costs are estimated to range from \$4-\$10 per tank for 20-130 gallon tanks. The epoxy could be applied by dipping the fuel tank or spraying it on like paint and then the epoxy must be allowed to cure. We include a fixed cost of \$10,000 for a volume of 15,000 fuel tanks per year to account for coating and curing equipment. In addition, we apply the cost of part of one employee's time (using a labor standard of 15,000 tanks annually per employee) time to apply the coating and use a labor rate of \$28/hr with a 40 percent markup for overhead which is consistent with our engine costs above. We estimate that the epoxy cost would be \$6-7/lb. Manufacturers have commented that UV-curable epoxy, which could be processed much faster, would cost \$12-15/lb.[69,70] We use a cost of \$12/lb. for this analysis. However with only a thin coating needed (we use 0.125 mm), the epoxy layer makes up only about 2.0-2.5 percent of the material of the fuel tank. Because there are benefits to the epoxy coating such as allowing the fuel tank to be painted, there may be an incentive to use this technology even on HDPE fuel tanks. For that reason, we estimated the cost for porTable fuel tanks as well using the same general assumptions except for a larger production volume of 100,000 tanks per year with a increased labor standard due to the smaller tank sizes.

6.6.2.3 Other Marine Fuel Tank Constructions

We do not anticipate that the permeation standard would affect the cost of metal fuel tanks. Although some permeation can occur at rubber seals (such as for the sending unit), this would be small due to the small exposed surface area of the seals.

Another type of fuel tank construction that is used in some applications, such as offshore racing boats, is fiberglass fuel tanks. This fiberglass is commonly made of vinyl ester or epoxy which have high permeation rates. One manufacturer has developed a fiberglass composite that uses treated volcanic ash in a carrier matrix to create a non-continuous permeation barrier. This composite is known as an unsaturated polyester nanocomposite (UPE). In addition to being a low permeation technology for fiberglass tanks, this construction could also be used as an alternative for metal or plastic fuel tanks. These low permeation fiberglass constructions can be fabricated or molded. We estimate that fabricated fiberglass composite fuel tanks would cost at least as much as metal fuel tanks because of the labor involved in hand constructing the tanks. However, these fuel tanks may also be molded with an average mold cost of $2,500.[71] For the purposes of this analysis we use a cost increase of 20 percent when comparing this technology to rotational-molded fuel tanks which is a somewhat lower than the cost of a metal fuel tank.

6.6.2.4 Summary of Fuel Tank Costs per Vessel

Table 6.6-3 summarizes the incremental costs of the fuel tank permeation emission-control strategies discussed above. For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. Both long-term and short-term costs are presented. The long-term costs account for the stabilization of the capital investments and the learning curve effect discussed above. We use the same material, shipping, and fluorination costs for our short-term and long-term estimates because these cost components are well established with a wide range of applications. As discussed above, for the multilayer fuel tank constructions, we consider an EVOH barrier for porTable and PWC fuel tanks and a polyamide 11 barrier for rotational-molded fuel tanks. UPE fiberglass nanocomposite costs presented here are incremental to rotational-molded XLPE tanks.

Table 6.6-3: Tank Permeation Control Cost Estimates for Typical Marine Vessels

		PorTable Tank 6 gallons	**PWC** 17 gallons	**Installed Tank** 57 gallons
fluorination:	short term long term	$9.30 $7.44	$26 $21	NA
sulfonation:	short term long term	$1.67 $1.26	$3.27 $1.29	NA
non-continuous platelets		$1.27	$3.37	NA
multi-layer: EVOH	short term long term	$7.74 $4.22	$15 $8.58	$81 $68
multi-layer: PA11	short term long term	NA	NA	$81 $68
multi-layer:	CBT	NA	NA	$54
UPE fiberglass nanocomposite	short term long term	NA	NA	$48 $39
epoxy coating:	short term long term	$5.47 $4.85	$12 $11	$43 $39

6.6.3 Venting Losses

For porTable fuel tanks, the proposed standards would require the fuel cap to be modified to remove the user-controlled screw and add a one-way valve. We estimate that the cost of a vacuum relief valve would be about $0.50 more than the manual valve used on porTable fuel tanks today. We double this cost to account for upgrading the valve for marine applications. For personal watercraft, we are not claiming any costs or benefits because these vessels already seal their fuel tanks with a pressure relief valve.[72]

Larger fuel tanks are currently vented to atmosphere. One emission-control technology that could be used to meet our standards would be to seal the fuel tank and use a 1 psi pressure relief valve to prevent over-pressure. However, manufacturers have commented that their fuel tanks are not designed to withstand pressure and that the current molding process does not lend itself to making the fuel tanks more pressure resistant. Their fuel tanks currently deflect significantly at pressures as low as 1 psi. However, for some fuel tank constructions, a sealed system may be a viable option. For our cost analysis of this approach, we estimate the cost of a pressure relief valve to be about $1 based on products available in automotive applications. We double this cost to account for either upgrading the valve for marine applications or adding a redundant valve for safety reasons. For this case, we consider in the costs, changes in the fuel tank design to make it more able to withstand 1 psi of pressure. We estimate that if manufacturers were to make changes to the geometry of the fuel tank to help withstand 1 psi of pressure without significant deflection, it could increase the material needed by 10 to 30 percent. We include a cost estimate of $2,500 for the development of each new mold and amortize it over

100 tanks per year for 5 years. If the pressure relief valve is placed in the fill-neck cap, no vent hose would be needed, which would reduce the cost of the fuel system. For the long-term cost estimate, we consider the cost savings of removing the vent line. For this analysis, based on conversations with boat builders, we divide the aftermarket hose price[73] by four to represent the cost of the hose to the boat builder.

Diurnal emissions may also be controlled through the use of a carbon canister in the vent line. The carbon would be purged by air drawn into the fuel tank as the fuel cools. This is known as passive purge. With a canister system, no significant pressure would build up in the fuel tank. The canister would be packaged in the existing vent line and a float valve or other liquid/vapor separation device would be added to the fuel system to ensure that liquid fuel would not enter the vent line during refueling. We include a cost of $2 for this valve and $0.40 for two additional hose clamps. In our cost estimates, we consider a canister using marine grade carbon which is harder and more moisture resistant than typical carbon used in automotive applications. Data shows that about 2 liters of carbon would be necessary for a 50 gallon fuel tank.[74] We estimate the cost of a canister to vary based on size ranging from about $12 for a 20 gallon tank to about $38 for a 100 gallon tank.

Pressure could be completely eliminated using a bladder fuel tank because there would be no vapor space. Based on conversations with a manufacturer of bladder fuel tanks, the incremental cost of adding a bladder to a fuel tank would increase the fuel tank cost by 30-100 percent, depending on the size and shape of the fuel tank. As with a control strategy using a pressure relief valve in the fill neck, no vent hose would be needed with a bladder fuel tank.

Pressure in the fuel tank can be minimized by reducing the vapor space in the fuel tank. A volume compensating air bag can be used to minimize pressure. This air bag would need to be about 1/4 to 1/3 the volume of the fuel tank. For this analysis we use 1/3 the cost of the bladder fuel tank to account for the smaller bag size. We also include the cost of a low pressure psi valve which could be used in conjunction with this technology as a safety backup.

Table 6.6-4: Venting Control Cost Estimates for Typical Marine Vessels

		PorTable Fuel Tank 6 gallons	**Installed Fuel Tank** 57 gallons
pressure relief valve:	short term	$1.29	$26
	long term	$1.03	$21
passive purge canister:	short term	NA	$32
	long term	NA	$25
bladder fuel tank:	short term	NA	$259
	long term	NA	$207
volume compensating air bag:	short term	NA	$91
	long term	NA	$73

6.6.4 Certification and Compliance

We anticipate that manufacturers will use design based certification to as an alternative to emission testing to meet the diurnal emission requirements. However, they will still need to integrate the emission-control technology into their designs and there will be some engineering and clerical effort need to submit the required information for certification. We expect that in the early years, plastic fuel tank manufacturers will perform durability and permeation testing on their fuel tanks for certification. They will be able to carry over this data in future years and will be able to carry across this data to other fuel tanks made of similar materials and using the same permeation control strategy regardless of tank size or shape. Typical certification costs may be spread between the tank manufacturer, hose manufacturer, and boat builder. For the sake of this analysis we combine the tank, hose, and boat certification costs to calculate the total certification of an average fuel system. We estimate that 80 percent of fuel tank sales are plastic and about 25 percent of fuel tanks sold are porTable fuel tanks.

For the first year we estimate fuel tank durability and certification testing to cost about $15,000 per tank manufacturer on the assumption that the manufacturer will use the same materials and permeation control strategy for all of their fuel tanks to reduce costs. Low permeation fuel lines are largely established technology. However, we include a cost of $1,000 to perform certification testing on marine hose. In addition, we estimate about $10,000 for engineering and clerical work for the tank and hose manufacturers. Boat builder certification should be a simple letter referencing the tank and hose certificates and design requirements. We consider a cost of $500 for this effort.

For porTable fuel tank manufacturers we spread these costs over sales of 25,000 tanks per year. For PWC manufacturers, which are integrated manufacturers, we base the costs on average annual PWC sales which we estimate to be about 15,000 units per year. For vessels with installed fuel tanks, the same tank manufacturer will often sell to many boat builders. Therefore, we base the cost on average sales per tank manufacturer which we estimate to be about 40,000 per year. Although there is currently a limited offering of marine fuel hose products today, we conservatively use the same lower unit volumes as for fuel tanks when applying hose testing costs. This represents the scenario where porTable fuel tank manufacturers and PWC manufacturers perform their own hose testing, while smaller boat builders rely on data from the hose manufacturers. For non-integrated boat builders using installed fuel tanks, we estimate that the average sales per year is approximately 250 vessels.

As with other fixed costs, we amortized the cost over 5 years of sales to calculate per unit certification costs. Combining these costs, we get average fuel system integration and compliance costs of about $0.22 for porTable fuel tanks, $0.35 for PWC, and $0.53 for fuel systems on other vessels.

6.6.5 Operating Cost Savings

Evaporative emissions are essentially fuel that is lost to the atmosphere. Over the lifetime of a marine vessel, this can result in a significant loss of fuel. The proposed reduction in evaporative emissions would therefore result in meaningful fuel savings which can be directly related to operating cost savings based on an average density of 6 lbs/gallon for gasoline (based on lighter hydrocarbons which evaporate first) and the price of gasoline described above. Table 6.6-5 presents the estimated fuel savings for marine vessels associated with the proposed evaporative emission standards.

Table 6.6-5: Projected Evaporative Fuel Savings for Marine Vessels

	Portable	PWC	Installed
Evaporative HC Reduced [lbs/life]	88	58	247
Lifetime Gallons Saved	14	9.4	41
Lifetime Cost Savings	$26	$17	$74
Average Equipment Life [years]	12.7	9.9	17
Discounted Cost Savings (7%)	$18	$13	$45

6.6.6 Total Marine Vessel Costs

We expect that marine vessel manufactures will make use of a variety of technologies to meet the proposed fuel tank permeation and diurnal emission standards. As discussed above, many options are available so the technologies chosen will depend on the baseline fuel tank construction, the vessel type, and the manufacturer's particular preferences. The proposed hose permeation standards will likely be met through the use of barrier hose constructions.

In calculating the costs of this rule, we consider the marine vessel categories in the NONROAD model. NONROAD divides marine vessels into outboard, personal watercraft, and SD/I applications and further subdivides these applications into several engine power categories. This analysis uses the unique hose and tank sizes for each subcategory in the NONROAD model and described in Chapter 3. For this analysis, we treat all vessels with outboard engines up to 25 hp as having porTable fuel tanks made of plastic. This analysis considers all PWC to have plastic fuel tanks as well. Based on our understanding of the market share of plastic versus aluminum tanks, we use a split of 30 percent metal and 70 percent plastic for installed fuel tanks.

We base our cost analysis on likely technologies that manufactures may use. For porTable and PWC fuel tanks and, we base our tank permeation control costs on multi-layer coextrusion with an EVOH barrier. For larger installed fuel tanks, we split the costs 50/50 between dual-layer rotational-molded tanks with a nylon barrier and the use of a low-permeation epoxy coating over the tanks in a post molding process. Diurnal control costs are based on sealed systems for porTable marine tanks, current technology for PWC, and passive canister systems for vessels with installed fuel tanks. Fuel supply line costs are based on thermoelastic barrier technology. No costs or benefits are claimed for vent hose or fill neck hose.

As discussed above, our cost estimates include both variable and fixed costs, and we distinguish between near-term and long-term costs. Because our analysis amortizes fixed costs over 5 years, the long-term costs are generally made up of variable costs only. The exception to this is fuel tank permeation control strategies where more expensive molding equipment is used. We assume an equipment life of 10 years, so in the long term, the amortized additional cost of the molding equipment is half, on average, of the short-term amortized cost over 5 years (5 years of amortized payments/10 years of equipment life = ½). In addition, variable costs are lower in the long term due to the learning effect discussed in Section 6.1. Table 6.6-6 presents these average per-engine cost estimates.

Table 6.6-6: Per Vessel Evaporative Emission Cost Estimates (Without Fuel Savings)

	Short Term (years 1-5)			Long Term (years 6-10)		
	Fixed	Variable	Total	Fixed	Variable	Total
PorTable aggregate	$6.65	$5.39	$12.04	$3.21	$5.13	$8.34
tank permeation	$6.64	$1.00	$7.65	$3.21	$1.00	$4.22
hose permeation	$0.01	$3.10	$3.10	$0	$3.10	$3.10
diurnal venting	$0	$1.29	$1.29	$0	$1.03	$1.03
PWC aggregate	$12.95	$4.49	$17.43	$6.30	$4.49	$10.79
tank permeation	$12.93	$2.64	$15.58	$6.30	$2.64	$8.94
hose permeation	$0.01	$1.84	$1.86	$0	$1.84	$1.84
diurnal venting	$0	$0	$0	$0	$0	$0
Installed aggregate	$0.63	$73.55	$74.18	$0	$61.53	$61.53
tank permeation	$0.23	$35.31	$35.54	$0	$29.63	$29.63
hose permeation	$0.01	$6.54	$6.54	$0	$6.54	$6.54
diurnal venting	$0.40	$31.69	$32.09	$0	$25.35	$25.35

6.6.7 Marine Vessel Aggregate Costs

Aggregate costs are calculated by multiplying the per-engine cost estimates described above by projected vessel sales. Vessel sales are based on estimates from the National Marine Manufacturers Association (www.nmma.org) and projections for future years are based on the growth rates in the NONROAD model. A description of the sales and population data and our analysis of the data are available in the docket.[75] Fuel savings are calculated directly from the projected HC reductions due to the proposed evaporative emission standards. Table 6.6-7 presents the projected costs of the proposed rule over a 30-year time period with and without the fuel savings associated with reducing evaporative emissions. For the purposes of combining these costs with the exhaust emission costs described above, we also present the projected costs by engine type in Table 6.6-8.

The population and sales data reported by NMMA, suggest that the NONROAD model may somewhat underestimate the useful life of outboard and personal watercraft marine vessels. If useful life were back-calculated—dividing NMMA population by sales and adjusted for growth—we would get a longer average life estimate. As a result, the per-vessel fuel savings described above may be understated. Because the current approach gives us a conservative benefits estimate, and because we do not have new data on average lives for marine vessels to update the estimates in the NONROAD model, we are not proposing to update the model at this time. For this reason, the 30-year stream may give a better view of the impact of the fuel savings than the per-vessel analysis.

At a 7 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for marine evaporative emission control is $26 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from boats is $25 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for marine evaporative emission control is $26 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from boats is $29 million.

Table 6.6-7: Projected 30-Year Aggregate Cost Stream for Marine Vessels

Year	Without Fuel Savings			With Fuel Savings		
	Portable	PWC	Installed	Portable	PWC	Installed
2009	$1,964,334	$1,509,992	$2,379,818	$1,696,777	$1,460,514	$1,930,889
2010	$1,978,506	$1,520,885	$13,357,033	$1,379,654	$1,416,312	$11,782,975
2011	$1,993,040	$1,532,058	$25,957,390	$1,056,961	$1,212,780	$23,138,203
2012	$2,007,575	$1,543,230	$26,146,688	$625,447	$1,006,435	$21,066,108
2013	$2,022,109	$1,554,403	$26,335,985	$227,276	$810,625	$19,068,161
2014	$907,533	$942,509	$26,130,013	$(1,293,196)	$(4,533)	$16,685,413
2015	$914,009	$949,235	$24,043,965	$(1,691,753)	$(197,528)	$12,428,196
2016	$920,405	$955,877	$22,304,923	$(2,083,707)	$(384,702)	$8,525,783
2017	$926,801	$962,520	$22,459,914	$(2,472,693)	$(566,360)	$6,535,757
2018	$933,196	$969,162	$22,614,905	$(2,851,048)	$(739,824)	$4,561,432
2019	$939,592	$975,804	$22,769,895	$(3,222,042)	$(887,378)	$2,607,303
2020	$945,987	$982,446	$22,924,886	$(3,570,455)	$(1,018,989)	$667,034
2021	$952,383	$989,088	$23,079,877	$(3,889,105)	$(1,095,610)	$(1,268,679)
2022	$958,779	$995,730	$23,234,867	$(4,166,588)	$(1,152,037)	$(3,182,282)
2023	$965,174	$1,002,372	$23,389,858	$(4,376,235)	$(1,197,840)	$(5,033,988)
2024	$971,570	$1,009,014	$23,544,849	$(4,557,295)	$(1,236,005)	$(6,730,209)
2025	$977,966	$1,015,657	$23,699,839	$(4,719,344)	$(1,268,302)	$(8,298,019)
2026	$984,402	$1,022,341	$23,855,811	$(4,869,408)	$(1,295,056)	$(9,680,934)
2027	$990,838	$1,029,025	$24,011,783	$(5,003,979)	$(1,316,950)	$(10,889,215)
2028	$997,274	$1,035,709	$24,167,754	$(5,128,330)	$(1,334,722)	$(11,989,416)
2029	$1,003,710	$1,042,393	$24,323,726	$(5,241,868)	$(1,348,643)	$(12,990,968)
2030	$1,010,146	$1,049,077	$24,479,698	$(5,346,193)	$(1,359,565)	$(13,836,968)
2031	$1,016,582	$1,055,761	$24,635,669	$(5,435,660)	$(1,368,227)	$(14,605,420)
2032	$1,023,018	$1,062,446	$24,791,641	$(5,518,237)	$(1,376,889)	$(15,226,617)
2033	$1,029,455	$1,069,130	$24,947,612	$(5,591,777)	$(1,385,552)	$(15,772,673)
2034	$1,035,891	$1,075,814	$25,103,584	$(5,652,081)	$(1,394,215)	$(16,251,345)
2035	$1,042,327	$1,082,498	$25,259,556	$(5,706,100)	$(1,402,877)	$(16,665,147)
2036	$1,048,763	$1,089,182	$25,415,527	$(5,755,039)	$(1,411,539)	$(17,031,083)
2037	$1,055,199	$1,095,866	$25,571,499	$(5,802,545)	$(1,420,202)	$(17,357,227)
2038	$1,061,635	$1,102,551	$25,727,471	$(5,848,308)	$(1,428,864)	$(17,650,084)

Table 6.6-8: Projected 30-Year Aggregate Cost Stream for Marine Vessels by Engine Type

Year	Without Fuel Savings			With Fuel Savings		
	OB	PWC	SD/I	OB	PWC	SD/I
2009	$4,022,410	$1,509,992	$321,743	$3,335,872	$1,460,514	$291,795
2010	$10,590,973	$1,520,885	$4,744,565	$8,658,576	$1,416,312	$4,504,054
2011	$17,386,587	$1,532,058	$10,563,843	$14,085,375	$1,212,780	$10,109,789
2012	$17,513,381	$1,543,230	$10,640,881	$12,010,652	$1,006,435	$9,680,903
2013	$17,640,175	$1,554,403	$10,717,919	$10,037,991	$810,625	$9,257,446
2014	$16,093,724	$942,509	$10,943,821	$6,406,222	$(4,533)	$8,985,995
2015	$14,852,627	$949,235	$10,105,347	$3,082,863	$(197,528)	$7,653,579
2016	$13,701,910	$955,877	$9,523,418	$(139,724)	$(384,702)	$6,581,800
2017	$13,797,121	$962,520	$9,589,594	$(2,098,191)	$(566,360)	$6,161,255
2018	$13,892,332	$969,162	$9,655,769	$(4,033,918)	$(739,824)	$5,744,302
2019	$13,987,542	$975,804	$9,721,945	$(5,946,347)	$(887,378)	$5,331,609
2020	$14,082,753	$982,446	$9,788,120	$(7,826,103)	$(1,018,989)	$4,922,682
2021	$14,177,964	$989,088	$9,854,296	$(9,665,614)	$(1,095,610)	$4,507,829
2022	$14,273,174	$995,730	$9,920,472	$(11,445,138)	$(1,152,037)	$4,096,269
2023	$14,368,385	$1,002,372	$9,986,647	$(13,099,198)	$(1,197,840)	$3,688,976
2024	$14,463,596	$1,009,014	$10,052,823	$(14,574,287)	$(1,236,005)	$3,286,783
2025	$14,558,807	$1,015,657	$10,118,998	$(15,910,006)	$(1,268,302)	$2,892,643
2026	$14,654,620	$1,022,341	$10,185,593	$(17,057,085)	$(1,295,056)	$2,506,743
2027	$14,750,433	$1,029,025	$10,252,187	$(18,024,386)	$(1,316,950)	$2,131,192
2028	$14,846,247	$1,035,709	$10,318,782	$(18,887,029)	$(1,334,722)	$1,769,284
2029	$14,942,060	$1,042,393	$10,385,376	$(19,667,131)	$(1,348,643)	$1,434,296
2030	$15,037,873	$1,049,077	$10,451,970	$(20,343,387)	$(1,359,565)	$1,160,226
2031	$15,133,687	$1,055,761	$10,518,565	$(20,957,927)	$(1,368,227)	$916,847
2032	$15,229,500	$1,062,446	$10,585,159	$(21,506,331)	$(1,376,889)	$761,478
2033	$15,325,313	$1,069,130	$10,651,754	$(21,999,412)	$(1,385,552)	$634,962
2034	$15,421,127	$1,075,814	$10,718,348	$(22,427,494)	$(1,394,215)	$524,068
2035	$15,516,940	$1,082,498	$10,784,942	$(22,797,796)	$(1,402,877)	$426,549
2036	$15,612,753	$1,089,182	$10,851,537	$(23,125,550)	$(1,411,539)	$339,427
2037	$15,708,567	$1,095,866	$10,918,131	$(23,420,202)	$(1,420,202)	$260,430
2038	$15,804,380	$1,102,551	$10,984,726	$(23,687,967)	$(1,428,864)	$189,575

6.7 Cost Sensitivity Analysis

In developing the cost estimates described above, EPA used data from a wide variety of sources. These sources included conversations with manufacturers and vendors, published material costs, government cost tracking, and sales literature. In addition, we discussed many of our cost estimates with industry experts. Through this process we have received information suggesting that there is the potential for variability in some of the cost estimates used as inputs to this analysis. For instance, fuel prices have been rising over the past few years which affects the dollar value of our fuel savings estimates.

In this section, we perform an analysis of the sensitivity of our cost estimates to the observed variation in costs for several input components of the cost analysis. The input components that we are focusing on for the sensitivity analysis are those that would be expected to have a significant effect on the final cost results. These are components that we either observed high variability when collecting the data, or industry has raised issues about the uncertainty of the technology which may lead to cost uncertainty.

We are focusing on five elements of the cost analysis for this sensitivity analysis. These five elements are:

1. gasoline prices
2. precious metal costs
3. fraction of Small SI equipment manufacturers that design their own mufflers
4. electronic fuel injection on all Class II engines with multiple cylinders
5. costs of rotational-molded tank technologies

6.7.1 Gasoline Price Sensitivity

To estimate fuel savings in the above analysis, we used fuel price information obtained from the U.S. Department of Energy, Energy Information Administration.[76] Although 2004 and 2005 gasoline prices are available in published reports, 2006 gasoline prices are not expected to be reported until mid 2007. However, gasoline price samples throughout the year are available on-line.[77] Based on this information, the national average fuel price, with taxes, from January to October 2006 was $2.68 per gallon. This price estimate includes both a $0.184/gallon federal excise tax and approximately a $0.21/gallon average state excise tax.[78] Subtracting these taxes, we get a fuel cost of $2.29/gallon for 2006.

To investigate the sensitivity of the cost analysis in this chapter to gasoline fuel price, we looked at the U.S. average fuel prices for 2004 and 2006. These price estimates were calculated in the same manner as the 2005 estimate. Table 6.7-1 presents these estimates. Fuel savings are directly related to the gasoline price used in the cost analysis. Therefore, if the 2004 average gasoline price were used in the cost analysis, the estimated fuel savings would have been about 22 percent lower. If the 2006 price were used, the estimated fuel savings would have been about 27 percent higher. Because of the recent trend of increasing gasoline prices, we may be understating the fuel savings in our cost analysis. However, using the 2005 fuel price is consistent with our use of 2005 dollars for the costs in this chapter.

Table 6.7-1 U.S. Average Gasoline Prices [$/Gallon]

Year	with taxes	without taxes
2004	$1.80	$1.41
2005	$2.20	$1.81
2006 (through October)	$2.68	$2.29

6.7.2 Variation in Precious Metal Prices

Precious metal prices for Platinum and Rhodium have increased over the past 5 years.[79] Prices for palladium are currently at their 1998 levels. However, a large spike in palladium prices was seen in 2000 and 2001. Due to the high variability of this market, we get higher precious metal cost estimates if we based the price estimates on a recent single month average (September 2006). If we look at an average over a longer time period (10 years) we calculate lower platinum costs, but higher rhodium and palladium costs. These precious metal price estimates are presented in Table 6.7-2.

Table 6.7-2: Precious Metal Prices [per troy oz]

	ICF 3 year Average	September 2006	10 Year Average
Rhodium	$1,121	$4,835	$1,356
Palladium	$210	$316	$341
Platinum	$811	$1,134	$623

6.7.2.1 Sensitivity of Small SI Catalyst Costs to Precious Metal Costs

To look at the sensitivity of our cost analysis for Small SI exhaust emission control, we considered the precious metal cost variability described above. Based on the amount of each of these precious metals in our projected catalyst designs, Table 6.7-3 presents the impact on per-engine costs of using the spot price and 10 year average price in our analysis. These costs, which are broken down by class and useful life, are presented for the near term without fuel savings.

Table 6.7-3: Sensitivity of Small SI Total Per Engine Cost Estimates to Precious Metal Costs

CLASS	I	I	I	II	II	II
UL	125	250	500	250	500	1000
TECH	OHV/SV	OHV	OHV	OHV	OHV	OHV
RULE Cost/Equip (3 yr avg precious metal price)	14.12	19.82	26.07	46.21	50.83	92.17
SEPTEMBER 2006 PRICE						
Cost/Equip	$15.69	$22.60	$30.25	$47.48	$52.67	$96.11
Increase	$1.57	$2.78	$4.18	$1.27	$1.84	$3.94
% Increase	10%	12%	14%	3%	4%	4%
10 YEAR AVERAGE						
Cost/Equip	$13.91	$19.45	$25.51	45.84	$51.39	$93.80
Increase	-$0.21	-$0.37	-$0.56	$-0.37	$0.56	$1.63
%Increase	-1.5%	-1.9%	-2.2%	-1%	1%	2%

6.7.2.1 Sensitivity of SD/I Catalyst Costs to Precious Metal Costs

To look at the sensitivity of our cost analysis for SD/I exhaust emission control, we considered the precious metal cost variability described above. Based on the amount of each of these precious metals in our projected catalyst designs, Table 6.7-4 presents the impact on per-engine costs of using the spot price and 10 year average price in our analysis. These costs, which are presented for each of the engine sizes used above for the primary cost analysis, are near term costs without fuel savings.

Table 6.7-4: Sensitivity of SD/I Cost Estimates to Precious Metal Costs

	3.0L I4	**4.3L V6**	**5.0L V8**	**5.7L V8**	**8.1L V8**	**Aggregate**
Primary Analysis	$483	$396	$317	$300	$377	$360
September 2006 Precious Metal Prices						
Cost	$511	$417	$342	$328	$416	$386
Increase	$28	$21	$24	$28	$39	$25
% Increase	5%	5%	7%	8%	9%	7%
10 Year Average Precious Metal Prices						
Cost	$479	$393	$314	$296	$371	$357
Increase	-$4	-$3	-$4	-$4	-$6	-$4
% Increase	-1%	-1%	-1%	-1%	-2%	-1%

Catalyst manufacturers usually buy precious metals on contract, not at the market spot price. Our primary analysis values appear reasonable.

6.7.3 Portion of Equipment Manufacturers Designing Own Muffler System and Recertifying the Engine

This analysis considers that equipment manufacturers will purchase the muffler design provided by the engine manufacturer in the engine's certified engine configuration. However, due to the fact that engine manufacturers will likely not be able to provide catalysts in all of the muffler designs used by equipment manufacturers, the smaller volume equipment manufacturer will need to pick their muffler from the limited offerings of the engine manufacturer.

The muffler designs may or may not fit into the equipment produced by the equipment manufacturer. If it does not, then the equipment manufacturer may choose to utilize the catalyst brick from their engine manufacturer and work with a muffler manufacturer to redesign their existing muffler. If they choose this option, then they must undergo expenses to redesign the muffler and heat shield to apply the catalyst safely. The equipment manufacturer must also pay for emission test of the new engine/muffler configuration as well as pay the certification fee to EPA for engine certification.

Applications which may find issues using a predetermined muffler design include those that have close coupled equipment shrouding or a closed equipment structure. EPA estimates that 10 percent of equipment companies will find themselves in this situation with at least one piece of equipment in their product line. Given there are an estimated 413 companies, 41 companies with three differently designed models each yields 123 models. Given that there are at times more than one engine used in an equipment design, we can assume two engine types per model - this yields a total of 246 redesigns and certifications. The fixed costs for this work are listed in Table 6.7-5.

Table 6.7-5: Costs for Equipment Manufacturers to Perform Engine Certification, Class II OHV

	Fixed Costs
Muffler/Heat Shield Design	$75,000
Emission Test per Certified Engine Configuration	$2012
Estimated EPA Certification Fee	$800
TOTAL Per Equipment Model Per Engine Type	$77,812
10% of Equipment Manufacturers = 41 (x41)	41
Three equipment models per equipment mfr.	123
Two engine types per Equipment Model (x2)	246
TOTAL ESTIMATED COST	$19,141,752

If this occurred it would add about $19 million dollars to the total compliance cost or about 0.86 percent of the total 30 year cost net present value.

6.7.4 Electronic Fuel Injection on Class II Engines with Multiple Cylinders

The current proposal states that only a portion of an engine manufacturers Class II engine families of two or more cylinders per engine will incorporate electronic fuel injection. In the event that success with the technology results in all Class II engines of two or more cylinders using the technology, then the cost stream of this rulemaking will change. Table 6.7-6 compares the estimated costs of catalysts and fuel injection.

Table 6.7-6: Cost Comparison Between Catalyst and EFI

Technology	Class II V-twin		
	250	500	1000
Variable Costs			
V-Twin Catalyst	$49.59	$53.47	$62.32
Electronic Fuel Injection	$78.99	$78.99	$78.99
Difference	$28.40	$25.52	$16.67
Fixed Costs			
V-Twin Catalyst	$364,133	$364,133	$364,133
Electronic Fuel Injection	$103,020	$103,020	$103,020
Difference	-$261,113	-$261,113	-$261,113

The resultant change in cost/equipment for this is shown in Table 6.7-7. The costs presented here are for the near term and long term without fuel savings. The reason that costs do not change very much overall is due to the fact that there is still a significant portion of Class II engines that are single cylinder whose costs estimates are not changing.

Table 6.7-7
Sales Weighted Average Cost Per Class II Equipment

	250	500	1000
Short Term (first year - includes fixed cost)			
Proposal	$46.21	$50.83	$92.17
All Class II V-Twin to EFI	$46.80	$49.71	$91.55
Difference	$0.59 1.3%	-$1.12 2.2%	-$0.62 0.67%
Long Term (6th year and beyond)			
Proposal	$32.56	$27.13	$49.80
All Class II V-Twin to EFI	$33.16	$27.15	$50.62
Difference	$0.60 1.8%	$0.02 0.07%	$0.82 1.6%

The estimated fuel savings for a residential riding mower is $39.00 net present value over its lifetime. EFI is estimated to cost $79.00 after consideration of the savings from removal of the existing carburetor. Therefore, the increase in the overall hardware cost with fuel savings is $40.00.

6.7.5 Costs of Rotational-Molded Tank Technologies

Many of the fuel tank permeation control technologies discussed in Chapter 5 are used widely today. One exception is multi-layer rotationally-molded fuel tanks. One tank manufacturer is currently producing fuel tanks for Small SI equipment with a nylon inner layer. This manufacturer has stated that they are able to produce these fuel tanks using the normal molding process without additional equipment. However, other manufacturers who sell tanks into Small SI and marine applications have expressed concern that they do not know how to mold tanks with nylon inner liners without the use of a drop box. As described above, a drop box is an added component on a mold that opens during the molding process to add a second layer of material into the mold. These manufacturers have indicated that they are working with another material, CBT (discussed above and in Chapter 5), that would not require a drop box. However, they have not finished their evaluation of this technology. Marine fuel tank manufacturers have expressed the concern that if the cost of plastic fuel tanks were too high, that more boat builders may begin using aluminum fuel tanks.

To examine the uncertainty in what technologies will be used to reduce permeation from rotationally molded fuel tanks, we considered three factors listed below. As with the analysis above, we present costs for typical fuel tank sizes rather than trying to present every fuel tank size considered in the cost model. The two fuel tank sizes used here are a 5 gallon tank for Small SI equipment and a 57 gallon fuel tank for boats.

1. Cost of using a drop box in the rotational-molding process
2. Sensitivity to variations in material costs
3. Consideration of replacing plastic with metal fuel tanks in marine industry

In the analysis described above, we include a $5,000 cost per mold in the near term to account for the cost using drop boxes. This cost was based on a range of cost estimates supplied by tank manufacturers ranging from $1,000 to nearly $9,000 per mold for adding drop boxes. In the long term we projected that tank manufacturers would all be able to mold fuel tanks without the use of a drop box. This projection was based on the current practices of one manufacturer and on alternative processes that other manufacturers are investigating today. To look at the sensitivity of tank permeation control costs for rotationally-molded fuel tanks, we consider costs without drop boxes and with $9,000 drop boxes.

Table 6.7-8: Sensitivity of Rotomolded Tank Cost Estimates to Drop Box Cost

	5 Gallon Small SI Tank	57 Gallon Boat Tank
Primary Analysis ($5,000 drop box)	$5.54	$81
Without Drop Box		
Cost Increase % Increase	$4.25 ($1.29) -23%	$68 ($13) -16%
With $9,000 Drop Box		
Cost Increase % Increase	$6.58 1.04 19%	$92 $10 13%

The analysis above considers three multi-layer approaches to rotationally-molded fuel tanks. These approaches are molding with a nylon inner layer using a drop box, molding with a slightly more expensive CBT layer without a drop box, and a post processing epoxy coating. All three of these approaches would be sensitive to changes in barrier material prices. Because these are new materials for fuel tank applications, it would be possible that material costs would decrease over time with increased production volumes. At the same time, increases in material costs could occur, especially for materials with prices tied closely to petroleum prices (such as polyethylene). To consider the sensitivity of fuel tank cost to material costs, we consider the fuel tank construction with a nylon barrier. Here we consider both a 20 percent decrease and a 20 percent increase in material costs, both for the nylon and the cross-link polyethylene. This translates a cross-link polyethylene cost ranging from $0.96 to $1.44/lb. and nylon costs ranging from to a nylon cost ranging from $3.20 to $4.80/lb. for Small SI and $4.8 to $7.2/lb. for marine fuel tanks.

Table 6.7-9: Sensitivity of Rotomolded Tank Cost Estimates to Material Cost

	5 Gallon Small SI Tank	57 Gallon Boat Tank
Primary Analysis	$5.54	$81
20% Decrease in Material Costs		
Cost Increase % Increase	$5.18 ($0.85) -15%	$68 ($14) -17%
20% Increase in Material Costs		
Cost Increase % Increase	$6.40 $0.86 15%	$95 ($14) 17%

Marine fuel tanks that are installed in marine vessels are primarily rotationally-molded out of cross-link polyethylene. However, many fuel tank are also made of aluminum. Very large fuel tanks (typically greater in size than rotationally-molded fuel tanks) are often made out of fiberglass. Marine fuel tank manufacturers making rotationally-molded fuel tanks have expressed the concern that if the costs were to increase too high, that many boat builders would switch to using aluminum fuel tanks. Based on conversations with industry, plastic fuel tanks sell for about 2/3 to 3/4 the price of aluminum fuel tanks.

One manufacturer of multi-layer rotationally-molded fuel tanks with a nylon inner layer has stated that they sell these fuel tanks at a price about 50 percent higher than traditional mono-layer fuel tanks. Although this puts the plastic tanks into the price range of metal fuel tanks, there are other downstream costs that would also need to be considered. Boat builders have indicated that it is common for aluminum fuel tanks to corrode when exposed to water. For this reason, they typically include a large access panel to the fuel tank when metal fuel tanks are used. The use of an access panel greatly reduces the cost of replacing a fuel tank if necessary. This access panel adds cost and complexity to the boat and may affect where the fuel tank can be positioned in the boat. Boat manufacturers have indicated that, when plastic fuel tanks are used, the only access required is to the hose connections on one end of the fuel tank.

In addition to the cost of an access panel for removing corroded tanks, the cost of replacing the fuel tank must be considered. This would essentially double the price of the metal tank, even without considering labor costs. In addition, fuel spills could create other damage in the boat or even a safety hazard. Repeated problems with fuel tank corrosion could hurt the reputation of the boat builder and leave them open to litigation. For these reasons, many boat builders that have already chosen to use plastic fuel tanks would be expected to continue to use these fuel tanks, even if they were roughly the same cost as metal fuel tanks.

We analyzed at two effects that could have an impact on our estimate of the price of low permeation plastic fuel tanks. It seems unlikely that a high cost drop box would be necessary given that one manufacturer is already producing multi-layer tanks without using a drop box. In addition, the CBT technology is designed to not require the use of a drop box. While material costs may fluctuate, it is not likely that a 20 percent increase in nylon would be observed. The volume of this material sold is large and this rule would not be expected to limit availability of the material. In addition, manufacturers have indicated that nylon prices have not risen greatly with increased petroleum costs. Even with a 20 percent material price increase it seems unlikely that boat builders would switch to using metal tanks. Manufacturers using plastic tanks have indicated that they do so more for durability advantages with respect to corrosion than for a price savings. In addition, the life time cost savings of plastic fuel tanks would outweigh the material price increase. These lifetime cost savings include the installation of access ports to allow replacement of the tanks, actual replacement of corroded tanks, and customer perception of poor quality if tanks were to corrode.

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CHAPTER 7: Cost Per Ton

This Chapter will present the cost effectiveness analysis we completed for our proposed small spark ignition engine (<19 kW) and recreational marine (personal water craft, sterndrive/inboard and outboard) emission standards. Under Clean Air Act section 213, we are required to promulgate standards which reflect the greatest degree of emission reduction achievable, giving appropriate consideration to cost, energy, and safety factors. The standards setting process is not necessarily premised on setting the most cost effective standards, even though this is a significant factor. Cost-effectiveness is a useful tool in evaluating the appropriateness of our standards.

The cost-effectiveness analysis described in this chapter relies in part on cost information from Chapter 6 and emissions information from Chapter 3 to estimate the dollars per ton of emission reductions produced from our proposed standards. We have calculated the cost effectiveness using a 30-year net present value approach that accounts for all costs and emission reductions over a 30-year period. Finally, this chapter compares the cost effectiveness of the new provisions with the cost effectiveness of other control strategies from previous and potential future EPA programs.

Section 7.1 describes the calculation behind the 30 year net present value cost effectiveness and Section 7.2 lists the results of the calculations for our combined small spark ignition standards (exhaust and evaporative) and marine engines (exhaust and evaporative). Table 7.2-.5 lists the results for the 30-year net present value cost effectiveness analysis for Small SI and Marine. The results of the cost-effectiveness of comparative programs are listed in Table 7.2-6.

7.1 30-Year Net Present Value Cost Effectiveness (Cost per Ton)

We have calculated the cost effectiveness of our program using a “30-year net present value” approach that includes all nationwide emission reductions and costs for a 30 year period. This timeframe captures both the early period of the program when only the new equipment/engines meeting our standards will be in the fleet, and the later period when essentially all vehicles/engines in the fleet will meet our standards. The 30-year net present value approach does have one important drawback in that it includes the engine costs for engines sold 30 years after the program goes into effect, but includes almost none of the emission benefits from those engines. Thus the 30-year net present value approach does not necessarily match all costs with all the emission reductions that those costs are intended to produce. It is presented here, nevertheless, as a reasonable means by which to assess the cost effectiveness of these programs.

We have calculated this “30-year net present value” cost-effectiveness using the net present value of the annual emission reductions and costs described in Chapters 3 and 6, respectively. The calculation of 30-year net present value cost-effectiveness follows the pattern described above for the per-engine analysis:

$$\mathrm{DNAE} = \sum (\mathrm{NE})_i / (1.07)^{i-2008}$$

Where:

DNAE = Reduction in nationwide 30-year net present value emissions in tons
$(\mathrm{NE})_i$ = Reduction in nationwide emissions in tons for year i of the program
i = Year of the program, counting from year 1 to year 30

and

$$\mathrm{DNAC} = \sum (\mathrm{NC})_i / (1.07)^{i-2008}$$

Where:

DNAC = Nationwide 30-year net present value costs in dollars
$(\mathrm{NC})_i$ = Nationwide costs in dollars for year i of the program
i = Year of the program from year 1 to year 30

The 30-year net present value cost-effectiveness is produced by dividing DNAC by DNAE. The nationwide reductions in emissions for each year are given in Chapter 3. The results are given in Tables within the following section.

7.2 Results

We calculated the cost-effectiveness of our program on a 30-year net present value basis separately for our proposed Small SI standards <19kW and recreational marine standards. To do this, we summed net present value of total costs from Chapter 6, and divided by the sum of the net present value of tons reduced from Chapter 3. These costs and emission reductions are repeated in Appendices 7-A and 7-B. The results are given in Table 7.2-1 to 7.2-2 for Small SI engines and equipment and 7.2-3 and 7.2-4 for recreational marine engines and vessels.

Table 7.2-1: 30-year Net Present Value Cost-effectiveness of the Standards for Small SI Engines <19kW Without Fuel Savings (7 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$3,315	1,785,000	$1860
Evaporative	$829	1,074,000	$770
Exhaust + Evap	$4,144	2,860,000	$1450

Table 7.2-2: 30-year Net Present Value Cost-effectiveness of the Standards for Small SI Engines <19kW With Fuel Savings (7 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$2,539	1,785,000	$1420
Evaporative	$186	1,074,000	$170
Exhaust + Evap	$2,725	2,860,000	$950

Table 7.2-3: 30-year Net Present Value Cost-effectiveness of the Standards for Marine Engines Without Fuel Savings (7 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$1,748	2,140,000	$820
Evaporative	$324	510,000	$630
Exhaust + Evap	$2,071	2,650,000	$780

Table 7.2-4: 30-year Net Present Value Cost-effectiveness of the Standards for Marine Engines With Fuel Savings (7 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$917	2,140,000	$430
Evaporative	$18	510,000	$35
Exhaust + Evap	$934	2,650,000	$350

Because many of the benefits and costs are manifest in future years, we apply discounting methods to adjust the dollar values of these effects to reflect the finding that society as a whole typically values the realization (or avoidance) of a given effect differently depending on when the effect occurs. In the discounting calculations used to produce the net present values that were used in our cost-effectiveness calculations, we used a discount rate of 7 percent, consistent with the 7 percent rate reflected in the cost-effectiveness analyses for other recent mobile source programs. OMB Circular A-94 requires us to generate benefit and cost estimates reflecting a 7 percent rate.

However, the cost and cost-effectiveness estimates for future proposed mobile source programs could also reflect a 3 percent discount rate. The 3 percent rate is in the 2 to 3 percent range recommended by the Science Advisory Board's Environmental Economics Advisory Committee for use in EPA social benefit-cost analyses, a recommendation incorporated in EPA's new *Guidelines for Preparing Economic Analyses (November 2000)*. Therefore, we have also calculated the overall cost-effectiveness of today's rule based on a 3 percent rate to facilitate comparison of the cost-effectiveness of this rule with future proposed rules which use the 3 percent rate. The results are shown in Tables 7.2-5 through 7.2-8.

Table 7.2-5: 30-year Net Present Value Cost-effectiveness of the Standards for Small SI Engines <19kW Without Fuel Savings (3 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$5,502	3,228,000	$1,700
Evaporative	$1,367	1,893,000	$720
Exhaust + Evap	$6,869	5,121,000	$1,340

Table 7.2-6: 30-year Net Present Value Cost-effectiveness of the Standards for Small SI Engines <19kW With Fuel Savings (3 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$4,109	3,228,000	$1,270
Evaporative	$234	1,893,000	$120
Exhaust + Evap	$4,342	5,121,000	$850

Table 7.2-7: 30-year Net Present Value Cost-effectiveness of the Standards for Marine Engines Without Fuel Savings (3 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$2,632	3,824,000	$690
Evaporative	$505	954,000	$530
Exhaust + Evap	$3,137	4,778,000	$660

Table 7.2-8: 30-year Net Present Value Cost-effectiveness of the Standards for Marine Engines With Fuel Savings (3 percent discount rate)

Pollutants HC+NOx	*NPV Costs (million $)*	*NPV Reduction (tons)*	*Cost per Ton*
Exhaust	$1,145	3,824,000	$300
Evaporative	($66)	954,000	($70)
Exhaust + Evap	$1,079	4,778,000	$230

Because one primary purpose of cost-effectiveness is to compare our program to alternative programs, we listed the cost effectiveness of several previous EPA actions for controlled emissions from mobile sources for NOx and NMHC in Table 7.2-9. The programs shown in these tables are those for which cost-effectiveness was calculated in a similar manner allowing for a comparison. (Note: costs adjusted to 2005 dollars.)

Table 7.2-9: Cost-effectiveness of Recent Mobile Source Exhaust Emission Programs for HC+NOx, 2005$ (7 percent discount with fuel savings)

Program	$/ton
2002 HH engines Phase 2	840
2001 NHH Engines Phase 2	neg*
1998 Marine SI engines	1900
2004 Comm Marine CI	200
2007 Large SI exhaust	80
2006 ATV exhaust	300
2006 off-highway motorcycle	290
2006 recreational marine CI	700
2010 snowmobile	1430
2006 <50cc highway motorcycle	1860
2010 Class 3 highway motorcycle	1650

* fuel savings outweigh engineering/hardware costs
Costs adjusted to 2005$ using http://www1.jsc.nasa.gov/bu2/inflateGDP.html

Permeation and other evaporative emission control measures we have implemented for highway and off-highway motorcycles, large SI engines, ATVs, and snowmobiles have all had cost effectiveness values of less than $0/ton due to the fuel savings.

The analyses supporting the values in Table 7.2-6 were conducted over the past ten years and thus not all were done on a purely identical basis in terms of their analytical approach (e.g., factors such as cost streams and cost recovery). By comparing values in Table 7.2-6 for NOx+HC to those presented above we can see that the cost-effectiveness of our proposed Small

SI and recreational Marine SI standards fall within the range of these other programs. Some previous programs have been more cost effective (lower $/ton) than the program we are proposing today. However, it should be expected that the next generation of standards will be more expensive than the last, because earlier reductions are usually easier and less expensive to achieve and the least costly means for reducing emissions is generally pursued first.

This proposed rule also will bring environmental benefits related to reductions in carbon monoxide (CO) emissions and emissions of direct particulate matter (PM). We have elected to base our cost effectiveness analysis solely on HC+NOx for two reasons. First, with regard to PM and CO, no new or additional technology beyond that needed to achieve the proposed HC+NOx standards is expected to be required. These reductions will occur as part of the technology and related efforts to meet the HC+NOx standards. Second, in the case of PM, we are not setting standards but do expect reductions to occur as a result of engine changes and in some cases the use of aftertreatment. In neither case is significant additional effort needed.

CHAPTER 8: Cost-Benefit Analysis

8.1 Overview

Mobile sources are significant contributors to air pollutant emissions across the country and into the future. The Agency has determined that these emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, and is therefore establishing standards to control these emissions. The health- and environmentally-related effects associated with these emissions are a classic example of an externality-related market failure. An externality occurs when one party's actions impose uncompensated costs on another party. The proposed Small SI and Marine SI engine standards will help correct this market failure.

EPA is required by Executive Order (E.O.) 12866 to estimate the benefits and costs of major new pollution control regulations. Accordingly, the analysis presented here attempts to answer three questions: (1) what are the physical health and welfare effects of changes in ambient air quality resulting from particulate matter (PM) and ozone precursor emission reductions (direct PM, NO_x and VOC)? (2) what is the monetary value of the changes in these effects attributable to the proposed rule? and (3) how do the monetized benefits compare to the costs? It constitutes one part of EPA's thorough examination of the relative merits of this regulation.

This chapter presents our analysis of the health and environmental benefits that can be expected to occur as a result of the proposed standards throughout the period from initial implementation through 2030. Nationwide, the engines subject to the proposed emission standards in this rule are a significant source of mobile source air pollution. The proposed standards would reduce exposure to VOC, direct $PM_{2.5}$, NOx and CO emissions and help avoid a range of adverse health effects associated with ambient ozone and $PM_{2.5}$ levels. In addition, the proposed standards would help reduce exposure to CO, air toxics, and $PM_{2.5}$ for persons who operate or who work with or are otherwise active in close proximity to these engines.

The analysis presented in this chapter uses a methodology generally consistent with benefits analyses performed for the recent analysis of the the Clean Air Nonroad Diesel Rule (CAND) and the Mobile Source Air Toxics Rule (MSAT).[1,2] To the extent possible, we also incorporate benefits analysis methods consistent with the approach used in the recent RIA for the PM NAAQS.[3] For this reason, the current chapter avoids repeating this information and refers to the appropriate sections of each RIA. The benefits analysis relies on two major components:

1) Calculation of the impact of the proposed standards on the national direct PM and NOx emissions inventories for two future years (2020 and 2030).
2) A benefits analysis to determine the changes in human health, both in terms of physical effects and monetary value, based on a PM benefits transfer approach that scales CAND results (see Section 8.2).

It should be noted that since the CAND rule, EPA's Office of Air and Radiation (OAR) has adopted a different format for its benefits analysis in which characterization of uncertainty is integrated into the main benefits analysis. The benefits scaling approach used in the analysis of the proposed standards limits our ability to integrate uncertainty into the main analysis. For the benefits analysis of the final standards, we will adopt this integrated uncertainty approach. Please see the PM NAAQS RIA for an indication of the uncertainty present in the base estimate of benefits and the sensitivity of our results to the use of alternative concentration-response functions.

A wide range of human health and welfare effects are linked to the emissions of VOCs, direct PM and NOx and the resulting impact on ambient concentrations of ozone and $PM_{2.5}$. Recent studies have linked short-term ozone exposures with premature mortality. Exposure to ozone has also been linked to a variety of respiratory effects including hospital admissions and illnesses resulting in school absences. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis). Welfare effects potentially linked to PM include materials damage and visibility impacts, while ozone can adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests.

EPA typically quantifies PM- and ozone-related benefits in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments. In addition, the Agency has sought advice on characterizing and communicating the uncertainty associated with each of these aspects in health benefit analyses.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed locomotive and marine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. Our analysis, however, indicates that the rule's monetized $PM_{2.5}$ benefits alone substantially exceed our estimate of the costs.

Table 8.1-1 summarizes the annual monetized health and welfare benefits associated with the proposed standards for two years, 2020 and 2030. The $PM_{2.5}$ benefits are scaled based on relative changes in direct PM and NOx emissions between this rule and the proposed Clean Air Nonroad Diesel (CAND) rule.[A] As explained in Section 8.2.1 of this chapter, the $PM_{2.5}$ benefits scaling approach is limited to those studies, health impacts, and assumptions that were used in the proposed CAND analysis. As a result, PM-related premature mortality is based on the updated analysis of the American Cancer Society cohort (ACS; Pope et al., 2002). However, it is important to note that since the CAND rule, EPA's Office of Air and Radiation (OAR) has adopted a different format for its benefits analysis in which characterization of the uncertainty in the concentration-response function is integrated into the main benefits analysis. Within this context, additional data sources are available, including a recent expert elicitation and updated analysis of the Six-Cities Study cohort (Laden et al., 2006). Please see the PM NAAQS RIA for an indication of the sensitivity of our results to use of alternative concentration-response functions.

The analysis presented here assumes a PM threshold of 3 $\mu g/m^3$, equivalent to background. Through the RIA for CAIR, EPA's consistent approach had been to model premature mortality associated with PM exposure as a nonthreshold effect; that is, with harmful effects to exposed populations modeled regardless of the absolute level of ambient PM concentrations. This approach had been supported by advice from EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). However, EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies," (p. 9-44).[4] Furthermore, in the RIA for the PM NAAQS we used a threshold of 10 $\mu g/m^3$ based on recommendations by CASAC for the Staff Paper analysis. We consider the impact of a potential, assumed threshold in the PM-mortality concentration response function in Section 8.6.2.2 of the RIA.

[A] Due to time and resource constraints, EPA scaled the final CAND benefits estimates from the benefits estimated for the CAND proposal. The scaling approach used in that analysis, and applied here, is described in the RIA for the final CAND rule.[2]

Table 8.1-1. Estimated Monetized PM-Related Health Benefits of the Proposed Standards

	Total Benefits[a, b, c] (billions 2003$)	
	2020	**2030**
Using a 3% discount rate	$2.1 + B	$3.4 + B
Using a 7% discount rate	$1.9 + B	$3.1 + B

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints. PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 μg/m^3). There is uncertainty about which assumed threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 8.6.2.2 of the RIA.

[b] For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. A detailed listing of unquantified health and welfare effects is provided in Table 8.1-2 of the RIA.

[c] Results reflect the use of two different discount rates: 3 and 7 percent, which are recommended by EPA's *Guidelines for Preparing Economic Analyses*[5] and OMB Circular A-4.[6] Results are rounded to two significant digits for ease of presentation and computation.

Table 8.1-2 lists the full complement of human health and welfare effects associated with PM, ozone and air toxics, and identifies those effects that are quantified for the primary estimate and those that remain unquantified because of current limitations in methods or available data.

Table 8.1-2. Human Health and Welfare Effects of Pollutants Affected by the Proposed Standards

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects - Changes in:
PM/Health[b]	Premature mortality based on cohort study estimates[c] Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Premature mortality: short-term exposures[d] Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects - Changes in:
PM/Welfare		Visibility in Southeastern Class I areas Visibility in northeastern and Midwestern Class I areas Household soiling Visibility in western U.S. Class I areas Visibility in residential and non-Class I areas UVb exposure (+/-)[e]
Ozone/Health[f]		Premature mortality: short-term exposures[g] Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Cardiovascular emergency room visits Acute respiratory symptoms Chronic respiratory damage Premature aging of the lungs Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare		Decreased outdoor worker productivity Yields for: - Commercial forests - Fruits and vegetables, and - Other commercial and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]
MSAT Health[h]		Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein) Neurotoxicity (n-hexane, toluene, xylenes)
MSAT Welfare[h]		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the proposed standards.

[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[c] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter-term exposures (see Kunzli, 2001 for a discussion of this issue).[7]
[d] While some of the effects of short-term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short-term PM exposure not captured in the cohort estimates included in the primary analysis.
[e] May result in benefits or disbenefits. See Section 8.5.3. for more details.
[f] In addition to primary economic endpoints, there are a number of biological responses that have been associated with ozone health including increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[g] EPA sponsored a series of meta-analyses of the ozone mortality epidemiology literature, published in the July 2005 volume of the journal Epidemiology, which found that short-term exposures to ozone may have a significant effect on daily mortality rates, independent of exposure to PM. EPA is currently considering how to include an estimate of ozone mortality in its benefits analyses.
[h] The categorization of unquantified toxic health and welfare effects is not exhaustive.

Figure 8.1-1 illustrates the major steps in the PM benefits analysis. Given the change in direct PM and NOx emissions modeled for the proposed standards, we use a benefits transfer approach to scale PM benefits estimated for the CAND analysis (see Section 8.2 for a description of the scaling approach). For the CAND analysis, EPA ran a sophisticated photochemical air quality model, the Regional Modeling System for Aerosols and Deposition (REMSAD), to estimate baseline and post-control ambient concentrations of PM for each future year (2020 and 2030). The estimated changes in ambient concentrations were then combined with population projections to estimate population-level potential exposures to changes in ambient concentrations. Changes in population exposure to ambient air pollution were then input to impact functions[B] to generate changes in the incidence of health effects. The resulting changes in incidence were then assigned monetary values, taking into account adjustments to values for growth in real income out to the year of analysis (values for health and welfare effects are in general positively related to real income levels). Values for individual health and welfare effects were summed to obtain an estimate of the total monetary value of the changes in emissions. Finally, we scale the CAND results to reflect the magnitude of the direct PM and NOx emissions changes we estimate will occur as a result of the proposed standards.

Benefits estimates calculated for the CAND analysis, and scaled for the proposed

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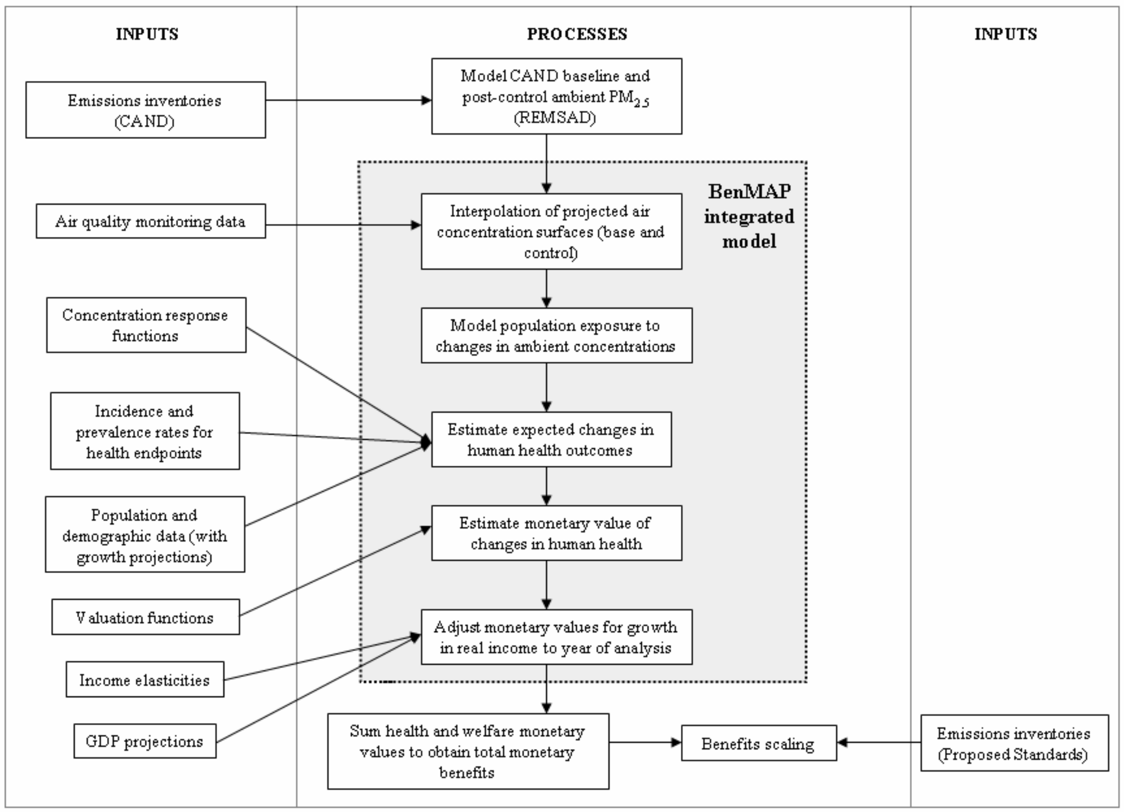
[B] The term “impact function” as used here refers to the combination of a) an effect estimate obtained from the epidemiological literature, b) the baseline incidence estimate for the health effect of interest in the modeled population, c) the size of that modeled population, and d) the change in the ambient air pollution metric of interest. These elements are combined in the impact function to generate estimates of changes in incidence of the health effect. The impact function is distinct from the C-R function, which strictly refers to the estimated equation from the epidemiological study relating incidence of the health effect and ambient pollution. We refer to the specific value of the relative risk or estimated coefficients in the epidemiological study as the “effect estimate.” In referencing the functions used to generate changes in incidence of health effects for this RIA, we use the term “impact function” rather than C-R function because “impact function” includes all key input parameters used in the incidence calculation.

standards, were generated using the Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIA's (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effect incidence estimates and monetized benefit estimates. Interested parties may wish to consult the webpage http://www.epa.gov/ttn/ecas/benmodels.html for more information.

Figure 8.1-1. Key Steps in Air Quality Modeling Based Benefits Analysis



All of the benefit estimates for the proposed control options in this analysis are based on an analytical structure and sequence similar to that used in the benefits analyses for the CAND final rule, the CAIR rule, and, when feasible, the final PM NAAQS analysis.[C] By adopting the major design elements, models, and assumptions developed in recent RIAs, we rely on methods that have already received extensive review by the independent Science Advisory Board (SAB),

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[C] See: Clean Air Nonroad Diesel final rule (69 FR 38958, June 29, 2004); Clean Air Interstate final rule (70 FR 25162, May 12, 2005); PM NAAQS (71 FR 61144, Oct. 17, 2006).

by the public, and by other federal agencies. In addition, we will be working through the next section 812 prospective study to enhance our methods.[D]

This chapter is organized as follows. In Section 8.2, we provide an overview of the air quality impacts modeled for the proposed standards that are used as inputs to the benefits analysis. In Section 8.3, we document key differences between this benefits analysis and the benefits analysis completed for the final CAIR and CAND rules. This section also presents and discusses the key inputs and methods used in the benefits analysis. In Section 8.4, we report the results of the analysis for human health and welfare effects. Section 8.5 qualitatively describes benefits categories that are omitted from this analysis, due either to inadequate methods or resources. Section 8.6 discusses how we incorporate uncertainty into our analysis. Section 8.7 discusses the health-based cost-effectiveness analysis for the proposed standards. Finally, in Section 8.8, we present a comparison of the costs and benefits associated with the proposed standards.

8.2 Air Quality Impacts

This section summarizes the methods for and results of estimating air quality for the 2020 and 2030 base case and proposed control scenario for the purposes of the benefits analysis. EPA has focused on the health, welfare, and ecological effects that have been linked to ambient changes in $PM_{2.5}$ related to direct PM and NOx emission reductions estimated to occur due to the proposed standards. We do this by scaling the modeled relationship between emissions and ambient PM concentrations observed for the CAND analysis.[8]

8.2.1 PM Air Quality Impact Estimation

To estimate $PM_{2.5}$ benefits from the proposed standards, we rely on a benefits transfer technique. The benefits transfer approach uses as its foundation the relationship between emission reductions and ambient $PM_{2.5}$ concentrations modeled for the Clean Air Nonroad Diesel (CAND) proposal.[E] For a given future year, we first calculate the ratio between CAND $PM_{2.5}$ precursor emission reductions (direct PM and NOx) and $PM_{2.5}$ precursor emission reductions associated with the proposed standards (proposed emission reductions/CAND emission reductions, displayed in Table 8.2-1). We multiply these ratios by the percent that each $PM_{2.5}$ precursor contributes towards population-weighted reductions in total $PM_{2.5}$ due to the CAND standards (displayed in Table 8.2-2). This calculation results in a "benefits apportionment factor" for the relationship between direct PM emissions and ambient $PM_{2.5}$ and NOx emissions and ambient $PM_{2.5}$ (displayed in Table 8.2-3). The benefits apportionment factors are then applied to the BenMAP-based incidence and monetized benefits from the CAND proposal. In this way, we apportion the results of the proposed CAND analysis to its underlying $PM_{2.5}$ precursor emission reductions and scale the apportioned benefits to reflect differences in

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[D] Interested parties may want to consult the webpage: http://www.epa.gov/science1 regarding components of the 812 prospective analytical blueprint.

[E] See 68 FR 28327, May 23, 2003.

emission reductions between the two rules.[F] This benefits transfer method is consistent with the approach used in other recent mobile and stationary source rules.[G] We refer the reader to the final CAND RIA for more details on this benefits transfer approach.[9]

Table 8.2-1. Comparison of 48-state Emission Reductions in 2020 and 2030 Between the CAND Rule and Proposed Standards

Emissions Species	Reduction from Baseline (tons)		Ratio of Reductions (Proposal/ CAND)
	CAND Modeling Inputs[a]	Small SI/Marine SI Emissions Changes[b]	
2020			
NOx	663,618	72,257	0.11
Direct $PM_{2.5}$	98,121	4,896	0.05
2030			
NOx	1,009,774	98,146	0.10
Direct $PM_{2.5}$	138,208	6,299	0.05

[a] Includes all affected nonroad sources: land-based, recreational marine, commercial marine, and locomotives. See the CAND RIA for more information regarding the CAND emission inventories.

[b] Includes changes to the small spark ignition engine inventory (lawn and garden equipment) and recreational marine spark ignition engine inventory.

[F] Note that while the proposed regulations also control VOCs, which contribute to PM formation, the benefits transfer scaling approach only scales benefits based on NOx, SO2, and direct PM emission reductions. PM benefits will likely be underestimated as a result, though we are unable to estimate the magnitude of the underestimation.

[G] See: Clean Air Nonroad Diesel final rule (69 FR 38958, June 29, 2004); Nonroad Large Spark-Ignition Engines and Recreational Engines standards (67 FR 68241, November 8, 2002); Final Industrial Boilers and Process Heaters NESHAP (69 FR 55217, September 13, 2004); Final Reciprocating Internal Combustion Engines NESHAP (69 FR 33473, June 15, 2004); Final Clean Air Visibility Rule (EPA-452/R-05-004, June 15, 2005); Ozone Implementation Rule (70 FR 71611, November 29, 2005).

Table 8.2-2. Apportionment of Modeled CAND Preliminary Control Option Population-weighted Change in Ambient $PM_{2.5}$ to Nitrate, Sulfate, and Primary Particles

	2020		2030	
	Population-weighted Change (µg/m3)	Percent of Total Change	Population-weighted Change (µg/m3)	Percent of Total Change
Total $PM_{2.5}$	0.316	--	0.438	--
Sulfate	0.071	22.5%	0.090	20.5%
Nitrate	0.041	13.1%	0.073	16.8%
Primary PM	0.203	64.4%	0.274	62.7%

Source: CAND RIA, Chapter 9.

Table 8.2-3. Calculation of $PM_{2.5}$ Benefits Apportionment Factors for the Proposed Emission Reductions

	2020			2030		
	Ratio of Emission Reductions[a] (1)	% of Total Ambient Change[b] (2)	Benefits Apportionment Factor (1*2)	Ratio of Emission Reductions[a] (3)	% of Total Ambient Change[b] (4)	Benefits Apportionment Factor (3*4)
NOx Emissions	0.11	0.131	0.014	0.10	0.168	0.016
Direct PM Emissions	0.05	0.644	0.032	0.05	0.627	0.029

[a] Calculated by dividing the small SI and marine SI engine emission reductions by CAND emission reductions. See Table 8.2-1.

[b] See Table 8.2-2.

8.3 PM-Related Health Benefits Estimation - Methods and Inputs

The analytical approach used in this benefits analysis is largely the same approach used in the Final CAND benefits analysis and the reader is referred to that RIA for details on the benefits methods and inputs. This analysis, however, also reflects some advances in data and methods in epidemiology, economics, and health impact estimation consistent with the approach used in the recent RIA for the PM NAAQS. Updates to the assumptions and methods used in estimating $PM_{2.5}$-related benefits since the analysis for the CAND rule include the following:

- Consistent with the approach used in the recent RIA for the PM NAAQS, we have updated our projections of mortality incidence rates to be consistent with the U.S. Census population projections that form the basis of our future population estimates. Compared to the methodology used in the CAIR analysis, this change will result in a reduction in mortality impacts in future years, as overall mortality rates are projected to decline for most age groups. A memorandum drafted by Abt Associates (Abt Associates, 2005) contains complete details regarding the derivation of mortality rate adjustment factors, and estimation of future-year mortality rates used in the analysis.[10] The scaled mortality benefits for the proposed standards have been updated accordingly.

- Consistent with the approach used in the recent RIA for the PM NAAQS, we use a revised mortality lag assumption. In the Final CAND, we used a five-year segmented lag. Since that analysis, upon which the PM benefits transfer scaling approach is based, the SAB Health Effects Subcommittee (HES) recommended that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. For future analyses, the specific distribution of deaths over time will need to be determined through research on causes of death and progression of diseases associated with air pollution. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths. This approach is different than the 5-year segmented lag used in the CAND analysis, and the scaled benefits analysis of the proposed standards has been updated accordingly.

For the purposes of this RIA, the health impacts analysis is limited to those health effects that are directly linked to ambient levels of air pollution and specifically to those linked to PM. The specific studies from which effect estimates for the primary analysis are drawn are included in Table 8.3-1. The specific unit values used for economic valuation of health endpoints are included in Table 8.3-2.

Table 8.3-1. Endpoints and Studies Used to Calculate Total Monetized Health Benefits[a]

Endpoint	Pollutant	Study	Study Population
Premature Mortality			
Premature mortality — ACS cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[11]	>29 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[12]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[13]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[14]	Adults
Hospital Admissions			
Respiratory	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)[15]—ICD 490-496 (COPD) Ito (2003)[16]—ICD 490-496 (COPD)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)[17]—ICD 490-496 (COPD)	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)[18]—ICD 493 (asthma)	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	$PM_{2.5}$	Norris et al. (1999)[19]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[20]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[21]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[22]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[23] (cough, wheeze and shortness of breath) Vedal et al. (1998)[24] (cough)	6–18 years[b]
Work loss days	$PM_{2.5}$	Ostro (1987)[25]	18–65 years
MRADs	$PM_{2.5}$	Ostro and Rothschild (1989)[26]	18–65 years

[a] The endpoints and studies used for the primary estimate of benefits associated with the proposed rule have been subject to external technical guidance and review, including the Health Effects Subgroup (HES) of the EPA's Science Advisory Board (SAB) and the Office of Management and Budget (OMB).

[b] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the SAB-HES, we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group.

Table 8.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Premature Mortality (Value of a Statistical Life)	$5,500,000	$6,600,000	$6,800,000	Point estimate is the mean of a normal distribution with a 95 percent confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002)[27] meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003)[28] meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000	Point estimate is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., [1991][29]) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Nonfatal Myocardial Infarction (heart attack)				Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[30] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[31] and Wittels et al. (1990).[32] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25-44 $8,774 $7,855 45-54 $12,932 $11,578 55-65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($102,658—no discounting) 2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
3% discount rate				
Age 0–24	$66,902	$66,902	$66,902	
Age 25–44	$74,676	$74,676	$74,676	
Age 45–54	$78,834	$78,834	$78,834	
Age 55–65	$140,649	$140,649	$140,649	
Age 66 and over	$66,902	$66,902	$66,902	
7% discount rate				
Age 0–24	$65,293	$65,293	$65,293	
Age 25–44	$73,149	$73,149	$73,149	
Age 45–54	$76,871	$76,871	$76,871	
Age 55–65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	

(continued)

Table 8.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000)[33] (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Emergency Room Visits for Asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997)[34] and (2) $260.67, from Stanford et al. (1999).[35]

(continued)

Table 8.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994)[36] to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the seven different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Asthma Exacerbations	$42	$45	$45	Asthma exacerbations are valued at $42 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[37] This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma attack is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study.
Acute Bronchitis	$360	$380	$390	Assumes a 6-day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann et al. (1994).[38]

(continued)

Table 8.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median =)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[39]

[a] Although the unit values presented in this table are in year 2000 dollars, all monetized annual benefit estimates associated with the proposed standards have been inflated to reflect values in year 2005 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2005 dollars from 2000 dollars.[40] For WTP-based estimates, we use an inflation factor of 1.13 based on the CPI-U for “all items.” For COI-based estimates, we use an inflation factor of 1.24 based on the CPI-U for medical care.

[b] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For a complete discussion of how these adjustment factors were derived, we refer the reader to Chapter 9 of the CAND regulatory impact analysis (EPA, 2004). Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

EPA typically estimates the welfare impacts of effects such as changes in recreational visibility (related to reductions in ambient PM) and agricultural productivity (related to reductions in ambient ozone) in its RIAs of air quality policy. For the analysis of the proposed standards, however, we are unable to quantitatively characterize these impacts because of limited data availability; we are not quantifying ozone benefits related to the proposed standards and the PM scaling approach does not provide the spatial detail necessary to attribute specific air quality improvements to specific areas of visual interest (Class I areas). Instead, we discuss these welfare effects qualitatively in Section 8.5 of this chapter. We also qualitatively describe the impacts of other environmental and ecological effects for which we do not have an economic value.

8.4 Benefits Analysis Results for the Proposed Standards

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ associated with the proposed standards results in estimates of the changes in physical damages (e.g., premature mortalities, cases, admissions) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 8.4-1. Monetized values for those health endpoints are presented in Table 8.4-2, along with total aggregate monetized benefits. All of the monetary benefits are in constant-year 2005 dollars.

Table 8.4-1. Estimated Reduction in Incidence of Adverse Health Effects Related to the Proposed Standards[a]

Health Effect	2020 Incidence Reduction	2030 Incidence Reduction
PM-Related Endpoints		
Premature Mortality[b,c]		
Adult, age 30+ and Infant, age <1 year	290	450
Chronic bronchitis (adult, age 26 and over)	200	290
Nonfatal myocardial infarction (adults, age 18 and older)	490	800
Hospital admissions—respiratory (all ages)[d]	160	270
Hospital admissions—cardiovascular (adults, age >18)[e]	130	200
Emergency room visits for asthma (age 18 years and younger)	210	310
Acute bronchitis (children, age 8–12)	470	700
Lower respiratory symptoms (children, age 7–14)	5,600	8,300
Upper respiratory symptoms (asthmatic children, age 9–18)	4,300	6,300
Asthma exacerbation (asthmatic children, age 6–18)	7,000	10,000
Work loss days (adults, age 18–65)	38,000	52,000
Minor restricted-activity days (adults, age 18–65)	220,000	310,000

[a] Incidences are rounded to two significant digits. PM estimates are nationwide.

[b] PM premature mortality impacts for adults are based on application of the effect estimate derived from the ACS cohort study (Pope et al., 2002).[41] Infant premature mortality based upon studies by Woodruff, et al 1997.[42]

[c] PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 $\mu g/m^3$). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 8.6.2.2 of the RIA.

[d] Respiratory hospital admissions for PM include admissions for COPD, pneumonia, and asthma.

[e] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 8.4-2. Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2005$)[a,b]

PM-Related Health Effect	2020 Estimated Value of Reductions	2030 Estimated Value of Reductions
Premature mortality[c,d,e]		
Adult, age 30+ and Infant, < 1 year		
3% discount rate	$2,000	$3,100
7% discount rate	$1,800	$2,800
Chronic bronchitis (adults, 26 and over)	$94	$140
Non-fatal acute myocardial infarctions		
3% discount rate	$50	$77
7% discount rate	$48	$75
Hospital admissions for respiratory causes	$2.9	$5.0
Hospital admissions for cardiovascular causes	$3.1	$4.7
Emergency room visits for asthma	$0.07	$0.11
Acute bronchitis (children, age 8–12)	$0.20	$0.30
Lower respiratory symptoms (children, 7–14)	$0.11	$0.16
Upper respiratory symptoms (asthma, 9–11)	$0.13	$0.19
Asthma exacerbations	$0.36	$0.54
Work loss days	$5.8	$7.0
Minor restricted-activity days (MRADs)	$14	$19
Monetized Total [f]		
Base Estimate:		
3% discount rate	$2,100+ B	$3,400+ B
7% discount rate	$1,900+ B	$3,100+ B

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM benefits are nationwide.

[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030)

[c] PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 μg/m^3). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 8.6.2.2 of the RIA.

[d] Valuation assumes discounting over the SAB recommended 20-year segmented lag structure described earlier. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).[43,44]

[e] Adult premature mortality estimates based upon the ACS cohort study (Pope et al., 2002).[45] Infant premature mortality based upon Woodruff et al 1997.[46]

[f] B represents the monetary value of health and welfare benefits and disbenefits not monetized. A detailed listing is provided in Table 8.1-2.

In addition to omitted benefits categories such as air toxics, ozone, and various welfare effects, not all known PM-related health and welfare effects could be quantified or monetized. Furthermore, we did not quantify reductions in secondary $PM_{2.5}$ and the associated health and welfare effects. The monetized value of all of these unquantified effects is represented by adding an unknown “B” to the aggregate total. The estimate of total monetized health benefits of the proposed control package is thus equal to the subset of monetized PM-related health benefits plus B, the sum of the nonmonetized health and welfare benefits.

Total monetized benefits are dominated by benefits of mortality risk reductions. The primary estimate projects that the proposed standards will result in 290 avoided premature deaths annually in 2020 and 450 avoided premature deaths annually in 2030. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from the proposed standards, as well as increases in total population and the average age (and thus baseline mortality risk) of the population.

Our estimate of total monetized benefits in 2020 for the proposed standards is $2.1 billion using a three percent discount rate and $1.9 billion using a seven percent discount rate. In 2030, the monetized benefits are estimated at $3.4 billion using a three percent discount rate and $3.1 billion using a seven percent discount rate. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for $2.0 billion in 2020 and $3.1 billion in 2030 (assuming a three percent discount rate), is over 90 percent of total monetized health benefits. The next largest benefit is for reductions in chronic illness (CB and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are over 100 times more work loss days than premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (e.g., cost-of-illness).[H] As such, the full value of these effects may be higher than that reported in Table 8.4-2.

8.5 Unquantified Health and Welfare Effects

In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting the analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the effects listed in Table 8.1-2. For many health and welfare effects, such as changes in health effects due to reductions in air toxics exposure, changes in ecosystem functions and PM-related materials damage, reliable impact functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefit categories, the benefits estimates presented in this analysis would increase, although the magnitude of such an increase is highly uncertain.

Other welfare effects that EPA has monetized in past RIAs, such as recreational visibility, are omitted from the current analysis. Due to time and resource constraints, we did not

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[H] See Table 12.3-2 for a description of how each particular endpoint is valued.

run the full-scale PM air quality modeling needed to estimate this benefit category. Instead, we relied on the PM scaling benefits transfer approach that provides analytical efficiency but sacrifices the full range of outputs typically generated when models such as the Community Multiscale Air Quality (CMAQ) model or the Regional Modeling System for Aerosols and Deposition (REMSAD) are run.

Unquantified benefits are qualitatively discussed in the following health and welfare effects sections. In addition to unquantified benefits, there may also be environmental costs (disbenefits) that we are unable to quantify, which we qualitatively discuss as well. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects. Although we are not currently able to estimate the magnitude of these unquantified and unmonetized benefits, specific categories merit further discussion. EPA believes, however, the unquantified benefits associated with health and non-health benefit categories are likely significant and that their omission lends a downward bias to the monetized benefits presented in this analysis.

8.5.1 Human Health Impact Assessment

In addition to the $PM_{2.5}$ health effects discussed above, there is emerging evidence that human exposure to PM may be associated a number of health effects not quantified in this analysis (see Table 8.1-2). An improvement in ambient $PM_{2.5}$ concentrations may reduce the number of incidences within each of these unquantified effect categories that the U.S. population would experience. Although these health effects are believed to be PM-induced, effect estimates are not available for quantifying the benefits associated with reducing these effects. Furthermore, the health effects associated with reductions in air toxics are not quantified in this analysis.

The proposed standards will also reduce the national emissions inventory of precursors to ozone, such as VOCs. Exposure to ozone has been linked to a variety of respiratory effects including hospital admissions, emergency room visits, minor restricted activity days, worker productivity and illnesses resulting in school absences. Emerging evidence has also shown that human exposure to ozone may be associated with a number of other health effects not quantified in this analysis (see Table 8.1-2). Ozone can also adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests. Although ozone benefits are typically quantified in regulatory impact analyses, we have chosen not to evaluate them for this analysis. As discussed in Chapter 2, the ozone modeling conducted for the proposed standards results in a net reduction in ambient concentrations of ozone in 2020 and 2030. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards.

8.5.2 Welfare Impact Assessment

For many welfare effects, such as changes in ecosystem functions and PM-related materials damage, reliable impact functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefit categories, the benefits estimates presented in this analysis would increase, although the magnitude of such an increase is highly uncertain.

8.5.2.1 Visibility Benefits

Changes in the level of ambient $PM_{2.5}$ caused by the proposed standards will change the level of visibility in much of the United States. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Great Smoky Mountains National Park. Though not quantified in this analysis, the value of improvements in visibility monetized for regulatory analyses such as the final CAIR are significant. We refer the reader to that analysis for a complete description of the methods used to value visibility.[47]

8.5.2.2 gricultural and Forestry Benefits

The Ozone Criteria Document notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant" (EPA, 1996, page 5-11).[48] Though we do not quantify the potential improvements in ambient ozone concentrations associated with the proposed standards, it is possible that yields will improve in areas of agricultural or forestry production impacted by the standards.

Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of planting decisions, yield response functions, and agricultural products' supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs. Models also exist to measure benefits to silvicultural producers and consumers. However, these models have not been adapted for use in analyzing ozone-related forest impacts. Because of resource limitations, we are unable to provide agricultural or forestry benefits estimates for the proposed standards.

8.5.2.2.1 Agricultural Benefits

Laboratory and field experiments have shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN), examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the United States."[54] In addition, economic studies have shown a relationship between observed ozone levels and crop yields.[49]

8.5.2.2.2 Forestry Benefits

Ozone also has been shown conclusively to cause discernible injury to forest trees (EPA, 1996; Fox and Mickler, 1996).[54,50] In our previous analysis of the Heavy-Duty Engine/Diesel Fuel rule, we were able to quantify the effects of changes in ozone concentrations on tree growth for a limited set of species.

8.5.2.3 Benefits from Reductions in Materials Damage

The proposed standards that we modeled are expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. PM also has corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefits analyses have been able to provide quantitative estimates of household soiling damage. Consistent with SAB advice, we determined that the existing data (based on consumer expenditures from the early 1970s) are too out of date to provide a reliable estimate of current household soiling damages (EPA-SAB-COUNCIL-ADV-98-003, 1998).[51]

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994)[52] indicate that these benefits could be an order of magnitude larger than household soiling benefits.

8.5.3 UVb Exposure

In contrast to the unquantified benefits of the proposed standards discussed above, it is also possible that this rule will result in disbenefits in some areas of the United States. The effects of ozone and PM on radiative transfer in the atmosphere can lead to effects of uncertain magnitude and direction on the penetration of ultraviolet light and climate. Ground level ozone makes up a small percentage of total atmospheric ozone (including the stratospheric layer) that attenuates penetration of ultraviolet - b (UVb) radiation to the ground. EPA’s past evaluation of the information indicates that potential disbenefits would be small, variable, and with too many uncertainties to attempt quantification of relatively small changes in average ozone levels over the course of a year.[53] EPA’s most recent provisional assessment of the currently available information indicates that potential but unquantifiable benefits may also arise from ozone-related attenuation of UVb radiation.[54] EPA believes that we are unable to quantify any net climate-related disbenefit or benefit associated with the combined ozone and PM reductions in this rule.

8.6 Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the benefits estimate, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain and, depending on its role in the benefits analysis, may have a disproportionately large impact on estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. Some of the key uncertainties in the quantified benefits analysis are presented in Table 8.6-1.

Table 8.6-1. Primary Sources of Uncertainty in the Quantified Benefits Analysis

1. Uncertainties Associated with Impact Functions
- The value of the PM effect estimate in each impact function.
- Application of a single impact function to pollutant changes and populations in all locations.
- Similarity of future-year impact functions to current impact functions.
- Correct functional form of each impact function.
- Extrapolation of effect estimates beyond the range of PM concentrations observed in the source epidemiological study.
- Application of some impact functions only to those subpopulations matching the original study population.

2. Uncertainties Associated with PM Concentrations
- Responsiveness of the models to changes in precursor emissions resulting from the control policy.
- Projections of future levels of precursor emissions, especially organic carbonaceous particle emissions.
- Model chemistry for the formation of ambient nitrate concentrations.
- Lack of speciation monitors in some areas requires extrapolation of observed speciation data.
- CMAQ model performance in the Western U.S., especially California indicates significant underprediction of PM$_{2.5}$.

3. Uncertainties Associated with PM Mortality Risk
- Differential toxicity of specific component species within the complex mixture of PM has not been determined.
- The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures.
- The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.
- Reliability of the limited ambient PM$_{2.5}$ monitoring data in reflecting actual PM$_{2.5}$ exposures.

5. Uncertainties Associated with Possible Lagged Effects
- The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.

6. Uncertainties Associated with Baseline Incidence Rates

- Some baseline incidence rates are not location specific (e.g., those taken from studies) and therefore may not accurately represent the actual location-specific rates.
- Current baseline incidence rates may not approximate well baseline incidence rates in 2020 and 2030.
- Projected population and demographics may not represent well future-year population and demographics.

7. Uncertainties Associated with Economic Valuation

- Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them.
- Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates because of differences in income or other factors.

8. Uncertainties Associated with Aggregation of Monetized Benefits

- Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

As part of EPA's approach to characterizing uncertainties in the benefits assessment, we generate a probabilistic estimate of statistical uncertainty based on standard errors reported in the underlying studies used in the benefits modeling framework, with particular emphasis on the health impact functions. Using a Monte Carlo procedure, the distribution of each health endpoint and its unit dollar value is characterized by the reported mean and standard error derived from the epidemiology and valuation literature. Details on the distributions used to value individual health endpoints are provided in Section 8.6.1, as well as in the CAIR RIA (Appendix B; EPA, 2005).[55] It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters (described in Table 8.6-1). Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards. Issues such as correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements will be addressed in future versions of the uncertainty framework.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, in characterizing the uncertainty related to the estimates of total benefits it is particularly important to attempt to characterize the uncertainties associated with this endpoint. As such, we specifically discuss the uncertainty related to PM-related premature mortality in Section 8.6.2.

8.6.1 Analysis of Statistical Uncertainty

For the proposed standards, we did not attempt to assign probabilities to all of the uncertain parameters in the model because of a lack of resources and reliable methods. At this time, we simply generate estimates of the distributions of dollar benefits for PM health effects and for total dollar benefits. For all quantified PM endpoints, we scaled the likelihood distributions of the benefit estimates from the CAND uncertainty analysis,[I] based on the same

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[I] U.S. Environmental Protection Agency. May 2004. *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*. Prepared by: Office of Air and Radiation. Available at http://www.epa.gov/nonroad-diesel/2004fr.htm#documents. Accessed December 15, 2005.

benefits transfer approach we used to estimate the benefits of the standards presented in Section 8.2. The CAND likelihood distributions were based solely on the statistical uncertainty surrounding the estimated C-R functions and the assumed distributions around the unit values. We use the benefits transfer approach to scale those distributions to reflect the predicted PM precursor emission reductions of the proposed standards. Though the scaling approach adds another element of uncertainty that we cannot characterize in the distributions, we believe the scaled uncertainty is a reasonable approximation of the statistical uncertainty based on standard errors reported in the underlying epidemiological and valuation studies.

Our scaled estimates of the likelihood distributions for health-related PM benefits should be viewed as incomplete because of the wide range of sources of uncertainty that we have not incorporated. The 5th and 95th percentile points of our scaled estimate are based on statistical error, and cross-study variability provides some insight into how uncertain our estimate is with regard to those sources of uncertainty. However, it does not capture other sources of uncertainty regarding the benefits transfer scaling approach or the inputs to the CAND modeling upon which the scaling is based, including emissions, air quality, baseline population incidence, and projected exposures. It also does not account for aspects of the health science not captured in the studies, such as the likelihood that PM is causally related to premature mortality and other serious health effects. Thus, a likelihood description based on the standard error would provide a misleading picture about the overall uncertainty in the estimates.

Both the uncertainty about incidence changes[J] and uncertainty about unit dollar values can be characterized by *distributions*. Each “likelihood distribution” characterizes our beliefs about what the true value of an unknown variable (e.g., the true change in incidence of a given health effect in relation to PM exposure) is likely to be, based on the available information from relevant studies.[K] Unlike a sampling distribution (which describes the possible values that an *estimator* of an unknown variable might take on), this likelihood distribution describes our beliefs about what values the unknown variable itself might be. Such likelihood distributions can be constructed for each underlying unknown variable (such as a particular pollutant coefficient for a particular location) or for a function of several underlying unknown variables (such as the total dollar benefit of a regulation). In either case, a likelihood distribution is a characterization of our beliefs about what the unknown variable (or the function of unknown variables) is likely to be, based on all the available relevant information. A likelihood description based on such distributions is typically expressed as the interval from the 5th percentile point of the likelihood distribution to the 95th percentile point. If all uncertainty had been included, this range would be the “credible range” within which we believe the true value is likely to lie with 90 percent probability.

[J] Because this is a national analysis in which, for each endpoint, a single C-R function is applied everywhere, there are two sources of uncertainty about incidence: statistical uncertainty (due to sampling error) about the true value of the pollutant coefficient in the location where the C-R function was estimated and uncertainty about how well any given pollutant coefficient approximates β^*.

[K] Although such a “likelihood distribution” is not formally a Bayesian posterior distribution, it is very similar in concept and function (see, for example, the discussion of the Bayesian approach in Kennedy, 1990. A Guide to Econometrics. 2nd ed. MIT Press: Cambridge, MA., pp. 168-172).

8.6.1.1 Monte Carlo Approach

The uncertainty about the total dollar benefit associated with any single endpoint combines the uncertainties from these two sources (the C-R relationship and the valuation) and is estimated with a Monte Carlo method. In each iteration of the Monte Carlo procedure, a value is randomly drawn from the incidence distribution, another value is randomly drawn from the unit dollar value distribution; the total dollar benefit for that iteration is the product of the two.[L] When this is repeated for many (e.g., thousands of) iterations, the distribution of total dollar benefits associated with the endpoint is generated.

Using this Monte Carlo procedure, a distribution of dollar benefits can be generated for each endpoint. As the number of Monte Carlo draws gets larger and larger, the Monte Carlo-generated distribution becomes a better and better approximation of a joint likelihood distribution (for the considered parameters) making up the total monetary benefits for the endpoint.

After endpoint-specific distributions are generated, the same Monte Carlo procedure can then be used to combine the dollar benefits from different (nonoverlapping) endpoints to generate a distribution of total dollar benefits.

The estimate of total benefits may be thought of as the end result of a sequential process in which, at each step, the estimate of benefits from an additional source is added. Each time an estimate of dollar benefits from a new source (e.g., a new health endpoint) is added to the previous estimate of total dollar benefits, the estimated total dollar benefits increases. However, our bounding or likelihood description of where the true total value lies also increases as we add more sources.

As an example, consider the benefits from reductions in PM-related hospital admissions for cardiovascular disease. Because the actual dollar value is unknown, it may be described using a variable, with a distribution describing the possible values it might have. If this variable is denoted as X1, then the mean of the distribution, E(X1) and the variance of X1, denoted Var(X1), and the 5th and 95th percentile points of the distribution (related to Var(X1)), are ways to describe the likelihood for the true but unknown value for the benefits reduction.

Now suppose the benefits from reductions in PM-related hospital admissions for respiratory diseases are added. Like the benefits from reductions in PM-related hospital admissions for cardiovascular disease, the likelihood distribution for where we expect the true value to be may be considered a variable, with a distribution. Denoting this variable as X2, the benefits from reductions in the incidence of both types of hospital admissions is X1 + X2. This variable has a distribution with mean E(X1 + X2) = E(X1) + E(X2), and a variance of Var(X1 +

[L] This method assumes that the incidence change and the unit dollar value for an endpoint are stochastically independent.

$X2) = Var(X1) + Var(X2) + 2Cov(X1,X2)$; if X1 and X2 are stochastically independent, then it has a variance of $Var(X1 + X2) = Var(X1) + Var(X2)$, and the covariance term is zero.

The benefits from reductions in all nonoverlapping PM-related health and welfare endpoints are $(Xm+1, ..., Xn)$ is $X = X1 + ... + Xn$. The mean of the distribution of total benefits, X, is

$$E(X) = E(X1) + E(X2) + ... + E(Xn)$$

and the variance of the distribution of total benefits—assuming that the components are stochastically independent of each other (i.e., no covariance between variables), is

$$Var(X) = Var(X1) + Var(X2) + ... + Var(Xn)$$

If all the means are positive, then each additional source of benefits increases the point estimate (mean) of total benefits. However, with the addition of each new source of benefits, the variance of the estimate of total benefits also increases. That is,

$$E(X1) < E(X1 + X2) < E(X1 + X2 + X3) < ... < E(X1 + ... + Xn) = E(X)$$

$$Var(X1) < Var(X1 + X2) < Var(X1 + X2 + X3) < ... < Var(X1 + ... + Xn) = Var(X)$$

That is, the addition of each new source of benefits results in a larger mean estimate of total benefits (as more and more sources of benefits are included in the total) about which there is less certainty. This phenomenon occurs whenever estimates of benefits are added.

Calculated with a Monte Carlo procedure, the distribution of X is composed of random draws from the components of X. In the first draw, a value is drawn from each of the distributions, X1, X2, through Xn; these values are summed; and the procedure is repeated again, with the number of repetitions set at a high enough value (e.g., 5,000) to reasonably trace out the distribution of X. The 5th percentile point of the distribution of X will be composed of points pulled from all points along the distributions of the individual components and not simply from the 5th percentile. Although the sum of the 5th percentiles of the components would be represented in the distribution of X generated by the Monte Carlo, it is likely that this value would occur at a significantly lower percentile. For a similar reason, the 95th percentile of X will be less than the sum of the 95th percentiles of the components, and instead the 95th percentile of X will be composed of component values that are significantly lower than the 95th percentiles.

The physical effects estimated in this analysis are assumed to occur independently. It is possible that, for any given pollution level, there is some correlation between the occurrence of physical effects, due to say avoidance behavior or common causal pathways and treatments (e.g., stroke, some kidney disease, and heart attack are related to treatable blood pressure). Estimating accurately any such correlation, however, is beyond the scope of this analysis, and instead it is simply assumed that the physical effects occur independently.

8.6.1.2 Monte Carlo Results

Based on the Monte Carlo techniques and benefits transfer methods described above, we scaled the CAND likelihood distributions for the dollar value of total PM health-related benefits for the proposed standards. For this analysis, the likelihood descriptions for the true value of each of the health endpoint incidence estimates, including premature mortality, were based on classical statistical uncertainty measures. The measures include the mean and standard deviation of the C-R relationships in the epidemiological literature, and assumptions of particular likelihood distribution shapes for the valuation of each health endpoint value based on reported values in the economic literature. The distributions for the value used to represent incidence of a health effect in the total benefits valuation represent both the simple statistical uncertainty surrounding individual effect estimates and, for those health endpoints with multiple effects from different epidemiology studies, interstudy variability. Distributions for unit dollar values are summarized in Table 8.3-2.

Results of the scaled Monte Carlo simulations are presented in Table 8.6-2. The table provides the scaled means of the distributions and the estimated 5th and 95th percentiles of the distributions. The contribution of mortality to the mean benefits and to both the 5th and 95th percentiles of total benefits is substantial, with mortality accounting for over 90 percent of the mean estimate, and even the 5th percentile of mortality benefits dominating close to the 95th percentile of all other benefit categories. Thus, the choice of value and the shape for likelihood distribution for VSL should be examined closely and is key information to provide to decision makers for any decision involving this variable. The 95th percentile of total benefits is approximately twice the mean, while the 5th percentile is approximately one-fourth of the mean. The overall range from 5th to 95th represents about one order of magnitude.

Table 8.6-2. Distribution of Value of Annual PM-Related Human Health Benefits in 2030 for the Proposed Standards[a]

Endpoint	Monetary Benefits[b, c] (Millions 2003$, Adjusted for Income Growth)		
	5th Percentile	Mean	95th Percentile
Premature mortality[c], Long-term exposure			
Adults, 30+ yrs and Infants, <1yr			
3% Discount Rate	$750	$3,100	$6,200
7% Discount Rate	$680	$2,800	$5,600
Chronic bronchitis (adults, 26 and over)	$7.0	$140	$480
Nonfatal myocardial infarctions			
3% Discount Rate	$18	$77	$180
7% Discount Rate	$17	$75	$180
Hospital admissions from respiratory causes	$1.6	$5.0	$8.0
Hospital admissions from cardiovascular causes	$2.8	$4.7	$7.0
Emergency room visits for asthma	$0.07	$0.11	$0.16
Acute bronchitis (children, aged 8–12)	$0	$0.30	$0.70
Lower respiratory symptoms (children, aged 7–14)	$0.06	$0.16	$0.29
Upper respiratory symptoms (asthmatic children, aged 9–11)	$0.05	$0.19	$0.42
Asthma exacerbations	$0.01	$0.54	$1.5
Work loss days (adults, aged 18–65)	$6	$7	$8
Minor restricted-activity days (adults, aged 18–65)	$11	$19	$27
Monetized Total[d]			
3% Discount Rate	$800 + B	$3,400 + B	$7,000 + B
7% Discount Rate	$720 + B	$3,100 + B	$6,300 + B

[a] Monetary benefits are rounded to two significant digits.

[b] Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and 2030.

[c] Results show 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).

[d] B represents the monetary value of the nonmonetized health and welfare benefits. A detailed listing of unquantified PM-, ozone-, and air toxics-related health effects is provided in Table 8.1-2.

8.6.2 Additional Approaches to Characterizing Uncertainty Related to PM-Mortality

As part of an overall program to improve the Agency's characterization of uncertainties in health benefits analyses, we attempt to address uncertainties associated with the $PM_{2.5}$ mortality health impact function relationship and valuation. Use of the ACS cohort (Pope et al., 2002) mortality function to support this analysis does not address uncertainty associated with: (a) potential of the study to incompletely capture short-term exposure-related mortality effects, (b) potential mis-match between study and analysis populations which introduces various forms of bias into the results, (c) failure to identify all key confounders and effects modifiers, which could result in incorrect effects estimates relating mortality to $PM_{2.5}$ exposure, and (d) model uncertainty. EPA is researching methods to characterize all elements of uncertainty in the dose-response function for mortality.

As is discussed in detail in the final PM NAAQS RIA, EPA uses three methods to quantify uncertainties in the mortality function, including: the statistical uncertainty derived from the standard errors reported in the ACS cohort study, the presentation of additional estimates of mortality based upon the peer-reviewed literature, and the use of results of an expert elicitation conducted to explore a more thorough characterization of uncertainties in the mortality estimate. Because this analysis utilizes the PM scaling benefits transfer approach to estimate mortality incidence for the proposed standards, we cannot quantify the PM mortality uncertainty to the same extent as was done for the CAIR or PM NAAQS analyses. However, in a similar fashion to the analysis conducted for the Clean Air Visibility Rule (CAVR),[56] we can scale the results of the CAND mortality uncertainty analysis to the PM precursor emission changes modeled for the proposed standards.

8.6.2.1 Uncertainty Associated with the Concentration-Response Function

In the benefit analysis of the CAND 2030 emission control standards, the statistical uncertainty represented by the standard error of the American Cancer Society cohort study (Pope et al, 2002) was one and one-half times the mean benefit estimate at the 95th percentile and less than one-half of the mean at the 5th percentile. The CAND analysis also derived mortality from the reanalysis of the Harvard Six-Cities study (Krewski et al., 2000).[57] At the time of the CAND analysis, EPA's Science Advisory Board provided guidance stating, "The Six-Cities estimates may be used in a sensitivity analysis to demonstrate that with different but also plausible selection criteria for C-R functions, benefits may be considerably larger than suggested by the ACS study." (EPA-SAB-COUNCIL-ADV-04-002).[58] In the CAND analysis, the Harvard Six-Cities mean benefits estimate was over twice the size of the mean estimate of mortality benefits derived from the ACS study.

Recently, a new peer-reviewed extension of the Six-Cities study has been published (Laden et al., 2006).[59] This follow-up to the Harvard Six-Cities study both confirmed the effect size from the first analysis and provided additional evidence that reductions in $PM_{2.5}$ are likely associations with reductions in the risk of premature death. This additional evidence stems from the observed reductions in $PM_{2.5}$ in each city during the extended follow-up period. Laden et al. (2006) found that mortality rates consistently went down at a rate proportionate to the observed reductions in $PM_{2.5}$. In the recently finalized PM NAAQS RIA, results from this study were presented as an additional estimate of premature mortality benefits along with the benefits derived from the ACS study. The mean benefits estimate derived from the Six-Cities study was more than twice the size of the mean estimate of mortality benefits derived from the ACS study. Because this study was not available during the CAND analysis, from which the benefits of the proposed standards are scaled, we are unable to provide an estimate of mortality benefits based on the Six-Cities study for this proposed analysis. However, based on the relationship between the Six-Cities study and the ACS cohort study observed in the final PM NAAQS RIA, we can surmise that the mean estimate of PM-related mortality associated with the proposed standards could be approximately twice as large. For a full discussion of the epidemiological basis of EPA's premature mortality estimates, we refer the reader to Chapter 5.1 of the final PM NAAQS RIA.

EPA recently completed a full-scale expert elicitation that incorporated peer-review comments on the pilot application used in CAND, and that provides a more robust characterization of the uncertainty in the premature mortality function. This expert elicitation was designed to evaluate uncertainty in the underlying causal relationship, the form of the mortality impact function (e.g., threshold versus linear models) and the fit of a specific model to the data (e.g., confidence bounds for specific percentiles of the mortality effect estimates). Additional issues, such as the ability of long-term cohort studies to capture premature mortality resulting from short-term peak PM exposures, were also addressed in the expert elicitation. The recently published RIA supporting the Particulate Matter National Ambient Air Quality Standards (PM NAAQS) used the results of this expert elicitation to quantitatively characterize uncertainty.

Due to the analytical constraints associated with the PM benefits scaling approach, we are unable to assess the premature mortality health impacts derived from the formally elicited expert judgments. Compared to the final PM NAAQS estimate of mean premature mortality derived from the ACS cohort study, however, expert-based mortality incidence ranged from approximately 50 percent of the mean ACS estimate to approximately five times the size of the mean ACS estimate. In total, PM-related premature mortality derived from eleven of the experts was greater than the ACS estimate, while one expert-based estimate fell below the ACS result.

8.6.2.2 $PM_{2.5}$-Mortality Cutpoint/Threshold Analysis

Another source of uncertainty that has received recent attention from several scientific review panels is the shape of the concentration-response function for PM-related mortality, and specifically whether there exists a threshold below which there would be no benefit to further reductions in $PM_{2.5}$. The consistent advice from EPA's SAB[M] has been to model premature

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[M] The advice from the 2004 SAB-HES (EPA-SAB-COUNCIL-ADV-04-002)[69] is characterized by the following: "For the studies of long-term exposure, the HES notes that Krewski et al. (2000) have conducted the most careful mortality associated with PM exposure as a nonthreshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations. However, EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies."[60] Some researchers have hypothesized the presence of a threshold relationship. That is, the hypothesized relationship includes the possibility that there exists a PM concentration level below which further reductions no longer yield premature mortality reduction benefits.

To consider the impact of a threshold in the response function for the chronic mortality endpoint, the final PM NAAQS RIA[61] constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, the PM NAAQS analysis adjusted the mortality function slopes accordingly.[N] Five cutpoints (including the base case assumption) were included in the sensitivity analysis: (a) 14 $\mu g/m^3$ (assumes no impacts below a level being considered at the time for the annual $PM_{2.5}$ NAAQS), (b) 12 $\mu g/m^3$ (c) 10 $\mu g/m^3$ (reflects comments from CASAC, 2005), [62] (d) 7.5 $\mu g/m^3$ (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the ACS cohort study (Pope et al., 2002) used as the basis for modeling chronic mortality) [63] and (e) background or 3 $\mu g/m^3$ (reflects NRC recommendation to consider effects all the way to background).[64] The results of the sensitivity analysis displayed the change in avoided mortality cases and associated monetary benefits associated with the alternative cutpoints (see the final PM NAAQS RIA, Chapter 5.1 and Tables 5-28 to 5-31).

A sensitivity analysis such as this can be difficult to interpret, because when a threshold above the lowest observed level of $PM_{2.5}$ in the underlying ACS cohort study (Pope et al., 2002) is assumed, the slope of the concentration-response function above that level must be adjusted upwards to account for the assumed threshold.[O] Depending on the amount of slope adjustment and the proportion of the population exposed above the assumed threshold, the estimated mortality impact can either be lower (if most of the exposures occur below the threshold) or higher (if most of the exposures occur above the threshold). To demonstrate this, we present an example from the proposed PM NAAQS RIA. In its examination of the benefits of attaining alternative PM NAAQS in Chicago,[P] the analysis found that, because annual mean levels are generally higher in Chicago, there was a two-part pattern to the relationship between assumed

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work on this issue. They report that the associations between $PM_{2.5}$ and both all-cause and cardiopulmonary mortality were near linear within the relevant ranges, with no apparent threshold. Graphical analyses of these studies (Dockery et al., 1993, Figure 3, and Krewski et al., 2000, page 162) also suggest a continuum of effects down to lower levels. Therefore, it is reasonable for EPA to assume a no threshold model down to, at least, the low end of the concentrations reported in the studies."

[N] Note that the PM NAAQS analysis only adjusted the mortality slopes for the 10 $\mu g/m^3$, 12 $\mu g/m^3$ and 14 $\mu g/m^3$ cutpoints since the 7.5 $\mu g/m^3$ and background cutpoints were at or below the lowest measured exposure levels reported in the Pope et al. (2002) study for the combined exposure dataset.

[O] See NAS (2002)[71] and CASAC (2005)[68] for discussions of this issue.

[P] See the proposed PM NAAQS RIA (2005),[67] Appendix A, pp. A63-A64.

threshold and mortality impacts. As the threshold increased from background to 7.5 μg/m^3, the mortality impact fell (because there is no slope adjustment). However, at an assumed threshold of 10 μg/m^3, estimated mortality impacts actually increased, because the populations exposed above 10 μg/m^3 were assumed to have a larger response to particulate matter reductions (due to the increased slope above the assumed threshold). And finally, mortality impacts again fell to zero if a 15 μg/m^3 threshold was assumed, because these impacts were measured incremental to attainment of the current standard.

We are unable to do this type of sensitivity analysis for the analysis of the proposed standards because of the analytical limitations of the PM benefits scaling procedure. When EPA conducted the CAND analysis (from which the primary estimates of benefits for the proposed standards are based), there were no PM mortality concentration-response functions with the slope adjusted upwards to account for an assumed threshold. Instead, our primary PM benefits estimate for the proposed standards reflects a background threshold assumption of 3 μg/m^3. We present in Table 8.6-3 the results of our scaled PM-related mortality benefits in the context of its relationship to other cutpoints.

Table 8.6-3. PM-Related Mortality Benefits of the Proposed Standards: Cutpoint Sensitivity Analysis[a]

Certainty that Benefits are At Least Specified Value	*Level of Assumed Threshold*	*Discount Rate*	**PM Mortality Benefits (Billion 2003$)**	
			2020	2030
More Certain that Benefits Are at Least as Large	14 μg/m^3 [c]	3%	N/A[b]	
		7%		
↓	12 μg/m^3	3%	N/A	
		7%		
	10 μg/m^3 [d]	3%	N/A	
		7%		
	7.5 μg/m^3 [e]	3%	N/A	
		7%		
Less Certain that Benefits Are at Least as Large	3 μg/m^3 [f]	3%	$3.3	$6.3
		7%	$3.0	$5.7

[a] Note that this table only presents the effects of a cutpoint on PM-related mortality incidence and valuation estimates.

[b] Not Available. We are unable to provide cutpoint analysis results for the proposed standards because of the analytical limitations of the PM benefits scaling procedure.

[c] EPA intends to analyze a cutpoint between 12 μg/m^3 and 15 μg/m^3 for the final RIA.

[d] CASAC (2005)[68]

[e] SAB-HES (2004)[69]

[f] NAS (2002)[71]

8.7 Health-Based Cost Effectiveness Analysis

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. The Office of Management and Budget (OMB) issued Circular A-4 guidance on regulatory analyses, requiring Federal agencies to "prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes." Environmental quality improvements may have multiple health and ecological benefits, making application of CEA more difficult and less straightforward. For the CAIR analysis, the first to incorporate an analysis of this kind, CEA provided a useful framework for evaluation: nonhealth benefits were substantial, but the majority of quantified benefits came from health effects. EPA included in the CAIR RIA a preliminary and experimental application of one type of CEA—a modified quality-adjusted life-years (QALYs) approach. For CAIR, EPA concluded that the direct usefulness of cost-effectiveness analysis is mitigated by the lack of rule alternatives to compare relative effectiveness, but that comparisons could still be made to other benchmarks bearing in mind methodological differences.

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA of environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for nonhealth benefits, such as improved visibility.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled "Valuing Health for Regulatory Cost-Effectiveness Analysis," which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006).[65] They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses.

In Appendix G of the RIA for the CAIR,[63] EPA conducted an extensive cost-effectiveness analysis using morbidity inclusive life years (MILY). That analysis concluded that reductions in $PM_{2.5}$ associated with CAIR were expected to be cost-saving (because the value of expenditures on illnesses and non-health benefits exceeded costs), and that costs of the CAIR could have been significantly higher and still result in cost-effective improvements in public health. Because the current analysis relies on a benefits transfer approach to estimate PM-related benefits, scaling PM benefits from the CAND rule, we do not have the necessary inputs to develop a valid cost-effectiveness measure for the proposed standards. Furthermore, the CAND analysis did not include a health-based CEA, the results of which might have been scaled in a similar fashion to the benefits.

For the CAVR rule, EPA was able to draw inferences from the CAIR CEA by scaling the relative magnitude of the costs and health impacts between the two rules.[66] While the CAVR was not expected to be cost-saving like CAIR, EPA expected that CAVR was likely to have a relatively low cost per MILY. For the proposed standards, however, it is difficult to draw similar inferences with CAIR because the geographic distribution of emission changes, the distribution of those changes over time, and the age distribution of the mortality and chronic disease reductions are all expected to differ between the two rules. For these reasons, we do not scale the CAIR health-based cost-effectiveness analysis for the proposed standards.

8.8 Comparison of Costs and Benefits

The proposed rule establishes separate standards that reduce the evaporative and exhaust emissions from small SI and marine SI engines. A full appreciation of the overall economic consequences of these provisions requires consideration of the benefits and costs expected to result from each standard. Due to limitations in data availability and analytical methods, however, we are only able to present the benefits of the entire proposed rule in the aggregate for both $PM_{2.5}$ and ozone. There are also a number of health and environmental effects associated with the proposed standards that we were unable to quantify or monetize (see Table 8.1-2).

Table 8.8-1 contains the estimates of monetized benefits of the proposed standards and estimated social welfare costs for each of the proposed control programs.[Q] The annual social welfare costs of all provisions of this proposed rule are described more fully in Chapter 9. The results in Table 8.8-1 suggest that the 2020 and 2030 monetized benefits of the proposed standards are much greater than the expected social welfare costs. Specifically, the annual benefits of the program would be approximately $2.1 + B billion annually in 2020 using a three percent discount rate (or $1.9 + B billion using a seven percent discount rate), compared to estimated social welfare costs of approximately $252 million in that same year. The net benefits are expected to increase to $3.4 + B billion annually in 2030 using a three percent discount rate (or $3.1 + B billion using a seven percent discount rate), even as the social welfare costs of that program fall to $241 million.

In Table 8.8-1, we present the costs and PM-related benefits related to each of the two broad engine classes regulated by the proposed standards: Small SI and Marine SI engines. Table 8.8-1 also presents the costs and PM-related benefits related to the specific engine classes regulated by the proposed standards: Small SI – Class I, Class II, and Handheld (HH); Marine SI

[Q] Social costs represent the welfare costs of the rule to society. These social costs do not consider transfer payments (such as taxes) that are simply redistributions of wealth.

– Sterndrive/Inboard (SD/I), and Outboard/Personal Water Craft (OB/PWC). Using the same PM scaling approach described in Section 8.2.2., we are able to split out the estimated PM benefits related to the different Small SI and Marine SI engine classes. One can see that in all cases, the PM benefits accrued by the engine classes are greater than the costs, even when fuel savings is not factored into the cost estimate. The benefit-to-cost ratio would be even greater if we estimated the ozone benefits related to the proposed standards.

Table 8.8-1. Summary of Annual Benefits and Costs of the Proposed Standards[a] (Millions of 2005 dollars)

Description	2020 (Millions of 2005 dollars)	2030 (Millions of 2005 dollars)
Estimated Social Welfare Costs[b,c]		
Small SI	**$351**	**$404**
Class I	$145	$167
Class II	$199	$229
HH[d]	$7	$8
Marine SI	**$154**	**$164**
SD/I	$41	$44
OB/PWC	$113	$120
Total	**$505**	**$569**
Fuel Savings	**$(253)**	**$(327)**
Total Social Welfare Costs	**$252**	**$241**
Estimated Benefits[e,f]		
PM-Only Small SI Benefits		
3 percent discount rate	**$861**	**$1,280**
7 percent discount rate	**$782**	**$1,160**
Class I		
3 percent discount rate	$478	$647
7 percent discount rate	$434	$587
Class II		
3 percent discount rate	$383	$627
7 percent discount rate	$348	$570
PM-Only Marine SI Benefits		
3 percent discount rate	**$1,280**	**$2,110**
7 percent discount rate	**$1,160**	**$1,190**
SD/I		
3 percent discount rate	$209	$487
7 percent discount rate	$190	$442
OB/PWC		
3 percent discount rate	$1,070	$1,620
7 percent discount rate	$969	$1,470
Total Benefits[g]		
3 percent discount rate	**$2,140+B**	**$3,380+B**
7 percent discount rate	**$1,940+B**	**$3,070+B**
Annual Net Benefits (Total Benefits-Total Costs)[g]		
3 percent discount rate	**$1,890+B**	**$3,140+B**
7 percent discount rate	**$1,690+B**	**$2,830+B**

[a] All estimates are rounded to three significant digits and represent annualized benefits and costs anticipated for the years 2020 and 2030. Columnar totals may not sum due to rounding.
[b] Note that costs are the annual total costs of reducing all pollutants associated with each provision of the proposed control package, while the benefits reflect the value of reductions in $PM_{2.5}$ only.
[c] To calculate annual fixed costs, we use a 7 percent average before-tax rate of return on private capital (see Chapter 9). We do not present annual costs using an alternative rate of return. In Chapter 9, however, we use both a 3 percent and 7 percent social discount rate to calculate the net present value of total social costs consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).[R,S]
[d] Handheld emission reductions associated with the proposed standards, volatile organic hydrocarbons, are not accounted for in the PM benefits scaling approach. The PM benefit scaling approach is based upon changes in NOx and direct $PM_{2.5}$ (see section 8.2). We therefore do not estimate any PM-related benefits associated with emission reductions in the handheld engine class.
[e] PM-related benefits in this table are nationwide.
[f] Valuation of premature mortality based on long-term PM exposure assumes discounting over the SAB recommended 20-year segmented lag structure described in section 8.3. Valuation of non-fatal myocardial infarctions is based on the cost-of-illness over a 5-year period after the incident. The valuation of both endpoints therefore requires the use of a discount rate. We present the PM-related benefits results using a 3 percent and 7 percent social discount rate consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).
[g] Not all possible benefits or disbenefits are quantified and monetized in this analysis. B is the sum of all unquantified benefits and disbenefits. Potential benefit categories that have not been quantified and monetized are listed in Table 8.1-2.

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CHAPTER 9: Economic Impact Analysis

We prepared a draft Economic Impact Analysis (EIA) to estimate the economic impacts of the proposed emission control program on the Small SI and Marine SI engine and equipment markets. In this chapter we describe the Economic Impact Model (EIM) developed to estimate the market-level changes in price and outputs for affected markets and the social costs of the program as well as the expected distribution of those costs across affected economic sectors. We also present the results of our analysis.

We estimate the net social costs of the proposed program to be about $241 million in 2030.[1, 2] This estimate reflects the estimated compliance costs associated with the Small SI and Marine SI engine standards and the expected fuel savings from improved evaporative controls. When the fuel savings are not taken into account, the results of the economic impact modeling suggest that the social costs of these programs are expected to be about $569 million in 2030. Consumers of Small SI and Marine products are expected to bear about 75 percent of these costs. Small SI engine and equipment manufacturers are expected to bear 6 percent and 19 percent, respectively. We estimate fuel savings of about $327 million in 2030, which will accrue to consumers.

With regard to market-level impacts in 2030, the average price increase for Small SI engines is expected to be about 9.1 percent ($17 per unit). The average price increase for Marine SI engines is expected to be about 1.7 percent ($195 per unit). The largest average price increase for Small SI equipment is expected to be about 5.6 percent ($15 per unit) for Class I equipment. The largest average price increase for Marine SI vessels is expected to be about 2.1 percent ($178 per unit) for Personal Watercraft.

9.1 Overview and Results

9.1.1 What is an Economic Impact Analysis?

An Economic Impact Analysis (EIA) is prepared to inform decision makers about the potential economic consequences of a regulatory action. The analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders. These estimated social costs can then be compared with estimated social benefits (as presented in Chapter 8). As defined in EPA's *Guidelines for Preparing Economic Analyses* (EPA 2000, p

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[1] All estimates presented in this section are in 2005$.

[2] This analysis is based on an earlier version of the engineering costs developed for this rule. The net present value of the engineering costs used in this analysis (without taking the fuel savings into account, at a 3 percent discount rate over the period of the analysis) is $10.0 billion, which is about $100 million less than the net present value of the final estimated engineering costs, $10.1 billion. We do not expect that a difference of this magnitude would change the overall results of this economic impact analysis, in terms of market impacts and how the costs are expected to be shared among stakeholders.

113), *social costs* are the value of the goods and services lost by society resulting from a) the use of resources to comply with and implement a regulation and b) reductions in output. In this analysis, social costs are explored in two steps. In the *market analysis*, we estimate how prices and quantities of goods affected by the proposed emission control program can be expected to change once the program goes into effect. In the *economic welfare analysis*, we look at the total social costs associated with the program and their distribution across stakeholders.

9.1.2 What Methodology Did EPA Use in this Economic Impact Assessment?

The Economic Impact Model (EIM) is a behavioral model developed for this proposal to estimate price and quantity changes and total social costs associated with the emission controls under consideration. The model relies on basic microeconomic theory to simulate how producers and consumers of affected products can be expected to respond to an increase in production costs as a result of the proposed emission control program. The economic theory that underlies the model is described in detail in Section 9.2.

The EIM is designed to estimate the economic impacts of the proposed program by simulating economic behavior. This is done by creating a model of the initial, pre-control market for a product, shocking it by the estimated compliance costs, and observing the impacts on the market. At the initial, pre-control market equilibrium, a market is characterized by a price and quantity combination at which consumers are willing to purchase the same amount of a product that producers are willing to produce at that price (demand is equal to supply). The control program under consideration would increase the production costs of affected goods by the amount of the compliance costs. This generates a “shock” to the initial equilibrium market conditions. Producers of affected products will try to pass some or all of the increased costs on to the consumers of these goods through price increases. In response to the price increases, consumers will decrease their demand for the affected goods. Producers will react to the decrease in quantity demanded by decreasing the quantity they produce; the market will react by setting a higher price for those fewer units. These interactions continue until a new market equilibrium price and quantity combination is achieved. The amount of the compliance costs that can be passed on to consumers is ultimately limited by the price sensitivity of purchasers and producers in the relevant market (price elasticity of demand and supply). The EIM explicitly models these behavioral responses and estimates new equilibrium prices and output and the resulting distribution of social costs across these stakeholders (producers and consumers).

The EIM is a behavioral model. The estimated social costs of this emission control program are a function of the ways in which producers and consumers of the engines and equipment affected by the standards change their behavior in response to the costs incurred in complying with the standards. These behavioral responses are incorporated in the EIM through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves), which measure the price sensitivity of consumers and producers. An “inelastic” price elasticity (less than one) means that supply or demand is not very responsive to price changes (a one percent change in price leads to less than one percent change in demand). An “elastic” price elasticity (more than one) means that supply or demand is sensitive to price changes (a one percent change in price leads to more than one percent change in demand). A price elasticity of one is unit elastic, meaning there is a one-to-one correspondence between a change in price and change in demand. The price elasticities used in this analysis are described in Section 9.3 andwere estimated using well-established econometric methods. It should be noted that demand in the engine markets is internally derived from the Small SI equipment and Marine SI vessel markets as part of the process of running the model. This is an important feature of the EIM, which allows it to link the engine and equipment components of each model and simulate how compliance costs can be expected to ripple through the affected market.

9.1.3 What Economic Sectors are Included in the Economic Impact Model?

There are two broad economic sectors affected by the emission control program described in this proposal: (1) Small SI engines and equipment, and (2) Marine SI engines and equipment. For Small SI engines and equipment we model one integrated handheld engine and equipment category. On the nonhandheld side, the model distinguishes between 6 engine categories, depending on engine class and useful life (Class I: UL125, UL250, and UL500; Class II: UL250, UL500, UL1000), and 8 nonhandheld equipment categories (agriculture/construction/ general industrial; utility and recreational vehicles; lawn mowers; tractors; other lawn and garden; gensets/welders; pumps/compressors/pressure washers; and snowblowers). For Marine SI engines and equipment, the model distinguishes between sterndrives and inboards (SD/I), outboards (OB), and personal watercraft (PWC); SD/I and OB are further classified by whether they are luxury or not. These markets are described in Section 9.3 and in more detail in the industry characterizations prepared for this proposal.

This analysis assumes that the all of these products are purchased and used by residential households. This means that to model the behavior change associated with proposed standards we model all uses as residential lawn and garden care, power generation (Small SI) or personal recreation (Marine SI). We do not explicitly model commercial uses (how the costs of complying with the proposed programs may affect the production of goods and services that use Small SI or Marine SI engines or equipment as production inputs); we treat all commercial uses as if they were residential uses. We believe this approach is reasonable because the commercial share of the end use markets for both Small SI and Marine SI equipment is very small (see Section 9.3.1.1). In addition, for any commercial uses of these products the share of the cost of these products to total production costs is also small (e.g., the cost of a Small SI generator is only a very small part of the total production costs for a construction firm). Therefore, a price increase of the magnitude anticipated for this control program is not expected to have a noticeable impact on prices or quantities of goods or services produced using Small SI or Marine SI equipment as inputs (e.g., commercial turf care, construction, or fishing).

In the EIM the Small SI and Marine SI markets are not linked (there is no feedback mechanism between the Small SI and Marine SI market segments). This is appropriate because the affected equipment is not interchangeable and because there is very little overlap between the engine producers in each market. These two sectors represent different aspects of economic activity (lawn and garden care and power generation as opposed to recreational marine) and production and consumption of one product is not affected by the other. In other words, an increase in the price of lawnmowers is not expected to have an impact on the production and supply of personal watercraft, and vice versa. Production and consumption of each of these products are the results of other factors that have little crossover impacts (the need for residential garden upkeep or power generation; the desire for personal recreation).

Consistent with the proposed emission controls, this Economic Impact Analysis covers engines sold in 49 states. California engines are not included because California has its own state-level controls for Small SI and Marine SI engines. The sole exceptions are Small SI engines used in agriculture and construction applications in California: these engines are included in the control program of this analysis because the Clean Air Act preempts California from setting standards for those engines.

Table 9.1-1 summarizes the markets included in this Economic Impact Analysis. More detailed information on the markets and model data inputs is provided in Section 9.3.3, and in the industry profiles prepared for this proposal (See Chapter 1, & RTI, 2006).

In the EIM, the Small SI and Marine SI markets are not linked (there is no feedback mechanism between the Small SI and Marine SI market segments). This is appropriate because the affected equipment is not interchangeable and because there is very little overlap between the engine producers in each market. These two sectors represent different aspects of economic activity (lawn and garden care and power generation as opposed to recreational marine) and production and consumption of one product is not affected by the other. In other words, an increase in the price of lawnmowers is not expected to have an impact on the production and supply of personal watercraft, and vice versa. Production and consumption of each of these productions are the results of other factors that have little cross-over impacts (the need for residential garden upkeep or power generation; the desire for personal recreation).

Table 9.1-1: Summary of Markets in Economic Impact Model

Model Dimension	**Small SI**	**Marine SI**
Description of Markets	HANDHELD No distinction between engine and equipment types for this analysis NONHANDHELD Engine types Class I (125, 250, 500 hours) Class II (250, 500, 1000 hours) Equipment types Lawn mowers Lawn and garden tractors Pumps/compressors/pressure washers Agriculture/construction/industrial Other lawn and garden Gensets/welders Snowblowers Utility and recreational vehicles	Engine and equipment types SD/I recreational (runabouts, airboats, jetboats) SD/I luxury (yachts, cruisers, offshore) OB recreational (runabouts, pontoons, fishing) OB luxury (yacht, cruiser, express fish) Personal watercraft (PWC) Engine sizes Less than 25 hp 26 to 50 hp 51 to 100 hp 101 to 175 hp 176 to 300 hp Greater than 300 hp
Geographic scope	49 state, plus agriculture and construction for California	49 state (no California engines or equipment)
Market structure	Perfectly competitive	Perfectly competitive
Baseline population	EPA certification database PSR OE Link sales database	EPA and CARB certification database NMMA published statistical data
Growth projections	EPA's 2005 Nonroad model	EPA's 2005 Nonroad model
Supply elasticity	Econometric estimate (elastic)	Econometric estimate (elastic)
Demand elasticity	Econometric estimate Gensets, all handheld: elastic Lawn mowers: inelastic All others: unit elastic	Econometric estimate (elastic)
Regulatory shock	**Handheld (integrated market):** direct compliance costs (fixed + variable) cause shift in supply function **Nonhandheld:** Engine: direct compliance costs cause shift in supply function Equipment (Class I): no direct compliance costs but higher engine prices cause shift in supply function Equipment (Class II): direct compliance costs plus higher engine prices cause shift in supply function	**PWC (integrated):** direct compliance costs (fixed + variable) cause shift in supply function **SD/I and Outboard luxury:** Engine: direct compliance costs cause shift in supply function Vessel: direct compliance costs plus higher engine prices cause shift in supply function **Outboard recreational:** Engine: direct compliance costs cause shift in supply function Vessel: direct compliance costs cause shift in supply function

9.1.4 Summary of Results

The EIA consists of two parts: a market analysis and welfare analysis. The market analysis looks at expected changes in prices and quantities for affected products. The welfare analysis looks at economic impacts in terms of annual and present value changes in social costs.

We performed a market analysis for all years and all engines and equipment markets. In this section we present summarized results for selected markets and years. More detail can be found in the appendices to this chapter and in the docket for this rule (Li, 2007). Also included in Appendix 9H are sensitivity analyses for several key inputs.

In this analysis, initial market equilibrium conditions are shocked by the sum of fixed and variable costs. For the market analysis, this leads to a small increase in estimated price impacts for the years 2011 through 2016, the period during which fixed costs are recovered. The increase is small because, for many elements of the program, annual per unit fixed costs are smaller than annual per unit variable costs. For the welfare analysis, applying both fixed and variable costs means that the burden of the social costs attributable to producers and consumers remains fixed throughout the period of analysis. This is because producers pass the fixed costs to consumers at the same rate as the variable costs instead of having to absorb them internally.

9.1.4.1 Market Analysis Results

In the market analysis, we estimate how prices and quantities of goods affected by the proposed emission control program can be expected to change once the program goes into effect. The analysis relies on the initial market equilibrium prices and quantities for each type of equipment and the price elasticity of supply and demand. It predicts market reactions to the increase in production costs due to the new compliance costs (variable and fixed). It should be noted that this analysis does not allow any other factors of production to vary. In other words, it does not consider that manufacturers may adjust their production processes or marketing strategies in response to the control program. Also, as explained above, while the markets are shocked by both fixed and variable costs, the market shock is not offset by fuel savings.

A summary of the estimated market impacts is presented in Table 9.1-2 for 2013, 2018, and 2030. These years were chosen because 2013 is the year of highest compliance; after 2018, the fixed costs are recovered and the market impacts reflect variable costs as well as growth in equipment population; and 2030 illustrates the long-term impacts of the program.

Market level impacts are reported for the engine and equipment markets separately. This is because the EIM is a two-level model that treats these markets separately. However, changes in equipment prices and quantities are due to impacts of both direct equipment compliance costs and indirect engine compliance costs that are passed through to the equipment market from the engine market through higher engine prices.

The average market-level impacts presented in this section are designed to provide a broad overview of the expected market impacts that is useful when considering the impacts of the rule on the economy as a whole. The average price impacts are product-weighted averages of the results for the individual engine and equipment categories included in that sub-sector (e.g., the estimated Marine SI engine price and quantity changes are weighted averages of the estimated results for all of the Marine SI engine markets). The average quantity impacts are the sum of the decrease in units produced units across sub-markets. Price increases and quantity decreases for specific types of engines and equipment are likely to be different.

Although each of the affected equipment in this analysis generally require one engine (the exception being Marine SI sterndrive/inboards), the estimated decrease in the number of engines produced in Table 9.1-2 is less than the estimated decrease in the number of equipment produced. At first glance, this result seems counterintuitive because it does not reflect the approximate one-to-one correspondence between engines and equipment. This discrepancy occurs because the engine market-level analysis examines only output changes for engines that are produced by independent engine manufacturers and subsequently sold to independent equipment manufacturers. Engines produced and consumed by vertically integrated equipment/engine manufactures are not explicitly modeled. Therefore, the market-level analysis only reflects engines sold on the "open market," and estimates of output changes for engines consumed internally are not reflected in this number.[3] Despite the fact that changes in consumption of internally consumed engines in not directly reported in the market-level analysis results, the costs associated with these engines are included in the market-level analysis (as supply shift for the equipment markets). In addition, the cost and welfare analyses include the compliance costs associated with internally consumed engines.

9.1.4.1.1 Marine SI Market Analysis

The average price increase for Marine SI engines in 2013, the high cost year, is estimated to be about 2.3 percent, or $257. By 2018, this average price increase is expected to decline to about 1.7 percent, or $196, and remain at that level for later years. The market impact analysis predicts that with these increases in engine prices the expected average decrease in total sales in 2013 is about 2.0 percent, or 8,800 engines. This decreases to about 1.6 percent in 2018, or about 7,000 engines.

On the vessel side, the average price change reflects the direct equipment compliance costs plus the portion of the engine costs that are passed on to the equipment purchaser (via higher engine prices). The average price increase in 2013 is expected to be about 1.3 percent, or $232. By 2018, this average price increase is expected to decline to about 1 percent, or $178. These price increases are expected to vary across vessel categories. The category with the largest price increase in 2013 is expected to be personal watercraft engines, with an estimated price increase of about 2.8 percent in 2013; this is expected to decrease to 2.1 percent in 2018.

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[3] For example, PWC and handheld equipment producers generally integrate equipment and engine manufacturing processes and are included in the EIM as one-level equipment markets. Since there is no engine market for these engines, the EIM does not include PWC and handheld engine consumption changes in engine market-level results.

The smallest expected change in 2013 is expected to be for sterndrive/inboards and outboard recreational vessels, which are expected to see price increases of about 0.7 percent. The market impact analysis predicts that with these increases in vessel prices the expected average decrease in quantity produced in 2013 is about 2.7 percent, or 11,000 vessels. This is expected to decrease to about 2.0 percent in 2018, or about 8,600 vessels. The personal watercraft category is expected to experience the largest decline in 2013, about 5.6 percent (4,800 vessels). The smallest percentage decrease in production is expected for sterndrive/inboards at 1.4 percent (1,300 vessels); the smallest absolute decrease in quantity is expected for outboard recreational vessels, at 113 vessels (1.5 percent).

9.1.4.1.2 Small SI Market Analysis

The average price increase for Small SI engines in 2013, the high cost year, is estimated to be about 11.7 percent, or $22. By 2018, this average price increase is expected to decline to about 9.1 percent, or $17, and remain at that level for later years. The market impact analysis predicts that with these increases in engine prices the expected average decrease in total sales in 2013 is expected to be about 2.3 percent, or 371,000 engines. This is expected to decrease to about 1.7 percent in 2018, or about 299,000 engines.

On the equipment side, the average price change reflects the direct equipment compliance costs plus the portion of the engine costs that are passed on to the equipment purchaser (via higher engine prices). The average price increase for all Small SI equipment in 2013 is expected to be about 3.1 percent, or $14. By 2018, this average price increase is expected to decline to about 2.4 percent, or $10. The average price increase and quantity decrease differs by category of equipment. As shown in Table XII.F-2, the price increase for Class I equipment is estimated to be about 6.9 percent ($19) in 2013, decreasing to 5.5 percent ($15) in 2018. The market impact analysis predicts that with these increases in equipment prices the expected average decrease in the quantity of Class I equipment produced in 2013 is about 2.2 percent, or 219,400 units. This is expected to decrease to about 1.8 percent in 2018, or about 189,700 units. For Class II equipment, a higher price increase is expected, about 3.9 percent ($41) in 2013, decreasing to 2.6 percent ($25) in 2018. The expected average decrease in the quantity of Class II equipment produced in 2013 is about 4.3 percent, or 157,300 units, decreasing to 2.8 percent, or about 114,000 units, in 2018.

For the handheld equipment market, prices are expected to increase about 0.3 percent for all years, and quantities are expected to decrease about 0.6 percent.

Table 9.1-2: Summary of Estimated Market Impacts for 2013, 2018, 2030 (2005$)

Market	Change in Price		Change in Quantity	
	Absolute	Percent	Absolute	Percent
		2013		
Marine				
Engines	*$257*	*2.3%*	*-8,846*	*-2.0%*
Equipment	*$232*	*1.3%*	*-10,847*	*-2.7%*
SD/I	*$252*	*0.7%*	*-1,336*	*-1.4%*
OB Recreational	*$638*	*0.7%*	*-113*	*-1.5%*
OB Luxury	*$206*	*1.1%*	*-4,579*	*-2.1%*
PWC	*$237*	*2.8%*	*-4,819*	*-5.6%*
Small SI				
Engines	*$22*	*11.7%*	*-371,097*	*-2.3%*
Equipment	*$14*	*3.1%*	*-482,942*	*-1.9%*
Class I	*$19*	*6.9%*	*-219,400*	*-2.2%*
Class II	*$41*	*3.9%*	*-157,306*	*-4.3%*
HH	*$0.3*	*0.3%*	*-106,236*	*-0.6%*
		2018		
Marine				
Engines	*$196*	*1.7%*	*-7,002*	*-1.6%*
Equipment	*$178*	*1.0%*	*-8,563*	*-2.0%*
SD/I	*$195*	*0.5%*	*-1,072*	*-1.1%*
OB Recreational	*$496*	*0.6%*	*-91*	*-1.1%*
OB Luxury	*$160*	*0.8%*	*-3,634*	*-1.6%*
PWC	*$178*	*2.1%*	*-3,766*	*-4.2%*
Small SI				
Engines	*$17*	*9.1%*	*-298,988*	*-1.7%*
Equipment	*$10*	*2.4%*	*-401,025*	*-1.4%*
Class I	*$15*	*5.5%*	*-189,771*	*-1.8%*
Class II	*$25*	*2.6%*	*-113,999*	*-2.8%*
HH	*$0.2*	*0.3%*	*-97,255*	*-0.5%*
		2030		
Marine				
Engines	*$195*	*1.7%*	*-7,728*	*-1.6%*
Equipment	*$179*	*1.0%*	*-9,333*	*-2.0%*
SD/I	*$195*	*0.5%*	*-1,161*	*-1.1%*
OB Recreational	*$496*	*0.6%*	*-98*	*-1.1%*
OB Luxury	*$160*	*0.8%*	*-3,998*	*-1.7%*
PWC	*$178*	*2.1%*	*-4,076*	*-4.2%*
Small SI				
Engines	*$17*	*9.1%*	*-354,915*	*-1.7%*
Equipment	*$10*	*2.4%*	*-475,825*	*-1.4%*
Class I	*$15*	*5.6%*	*-225,168*	*-1.8%*
Class II	*$25*	*2.6%*	*-135,400*	*-2.8%*
HH	*$0.2*	*0.3%*	*-115,257*	*-0.5%*

9.1.4.2 Economic Welfare Results

In the economic welfare analysis we look at the costs to society of the proposed program in terms of losses to consumer and producer surplus. These surplus losses are combined with estimated fuel savings to estimate the net economic welfare impacts of the program. Estimated annual net social costs for selected years are presented in Table 9.1-3. This table shows that total social costs for each year are slightly less than the total engineering costs. This is because the total engineering costs do not reflect the decreased sales of engines and equipment that are incorporated in the total social costs.

Table 9.1-3: Estimated Annual Engineering and Social Costs Through 2038 (2005$, $million)

Year	Total Engineering Costs	Total Social Costs	Fuel Savings	Net Engineering Costs (including fuel savings)	Net Social Costs (including fuel savings)
2008	$9.5	$9.5	$3.1	$6.4	$6.4
2009	$171.7	$168.8	$13.7	$157.9	$155.1
2010	$191.1	$188.0	$25.4	$165.7	$162.6
2011	$470.5	$463.4	$64.9	$405.7	$398.5
2012	$647.3	$638.2	$103.5	$543.8	$534.7
2013	$652.5	$643.4	$136.5	$516.0	$506.9
2014	$621.1	$613.1	$161.2	$459.9	$451.9
2015	$627.0	$619.0	$182.3	$444.7	$436.7
2016	$520.9	$515.2	$200.9	$320.0	$314.2
2017	$492.6	$487.5	$216.2	$276.4	$271.3
2018	$497.2	$492.0	$229.9	$267.3	$262.1
2019	$503.6	$498.4	$242.1	$261.5	$256.2
2020	$510.0	$504.7	$253.1	$256.9	$251.6
2021	$516.4	$511.0	$263.3	$253.1	$247.8
2022	$522.7	$517.3	$272.9	$249.8	$244.4
2023	$529.1	$523.7	$281.4	$247.7	$242.3
2024	$535.8	$530.3	$289.3	$246.5	$241.0
2025	$542.3	$536.7	$296.6	$245.6	$240.0
2026	$548.7	$543.1	$303.6	$245.1	$239.5
2027	$555.2	$549.4	$310.1	$245.1	$239.3
2028	$561.6	$555.8	$316.3	$245.3	$239.5
2029	$568.0	$562.2	$322.0	$246.1	$240.2
2030	$574.5	$568.6	$327.3	$247.2	$241.3
2031	$580.9	$575.0	$332.3	$248.6	$242.6
2032	$587.4	$581.3	$337.1	$250.3	$244.2
2033	$593.8	$587.7	$341.7	$252.1	$246.0
2034	$600.3	$594.1	$346.1	$254.2	$248.0
2035	$606.7	$600.5	$350.4	$256.3	$250.1
2036	$613.1	$606.9	$354.5	$258.6	$252.3
2037	$619.6	$613.2	$358.5	$261.1	$254.7
2038	$626.0	$619.6	$362.5	$263.6	$257.1
NPV at 3%[a]	$9,996.2	$9,882.2	$4,356.2	$5,640.1	$5,562.0
NPV at 7%[a]	$5,863.6	$5,794.1	$2,291.5	$3,572.1	$3,502.6

[a] EPA EPA presents the present value of cost and benefits estimates using both a three percent and a seven percent social discount rate. According to OMB Circular A-4, "the 3 percent discount rate represents the 'social rate of time preference'… [which] means the rate at which 'society' discounts future consumption flows to their present value"; "the seven percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy … [that] approximates the opportunity cost of capital."

Figure 9.1-1: Estimated Engineering, Total Social, Net Social Costs and Fuel Savings

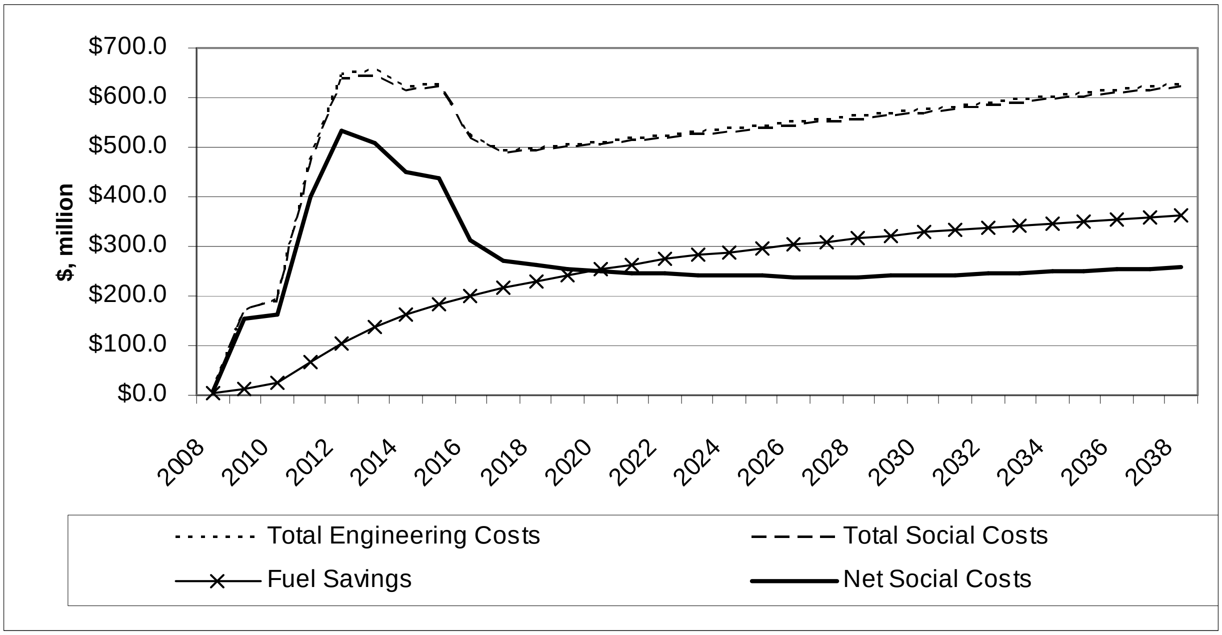

Table 9.1-4 shows how total social costs are expected to be shared across stakeholders, for selected years. According to these results, consumers in the Marine SI market are expected to bear approximately 66 percent of the cost of the Marine SI program. This is expected to be offset by the fuel savings. Vessel manufacturers are expected to bear about 22 percent of that program, and engine manufacturers the remaining 11 percent. In the Small SI market, consumers are expected to bear 79 percent of the cost of the Small SI program. This will also be offset by the fuel savings. Equipment manufacturers are expected to bear about 17 percent of that program, and engine manufacturers the remaining 4 percent. The estimated percentage changes in surplus are the same for all years because the initial equilibrium conditions are shocked by both fixed and variable costs; producers would pass the fixed costs to consumers at the same rate as the variable costs.

Table 9.1-4: Summary of Estimated Social Costs for 2013, 2018, 2030 (2005$, $million)

Market	Absolute Change in Surplus	Percent Change in Surplus	Fuel Savings	Total Change in Surplus
2013				
Marine SI				
Engine Manufacturers	-$21.54	11%		-$21.54
Equipment Manufacturers	-$42.23	22%		-$42.23
End User (Households)	-$125.14	66%	$42.27	-$82.87
Subtotal	-$188.91			-$146.64
Small SI				
Engine Manufacturers	-$18.36	4%		-$18.36
Equipment Manufacturers	-$80.16	18%		-$80.16
End User (Households)	-$355.95	78%	$94.26	-$261.69
Subtotal	-$454.47			-$360.21
TOTAL	**-$643.38**		**$136.53**	**-$506.85**
2018				
Marine SI				
Engine Manufacturers	-$17.29	11%		-$17.29
Equipment Manufacturers	-$34.02	22%		-$34.02
End User (Households)	-$100.19	66%	$87.12	-$13.07
Subtotal	-$151.50			-$64.38
Small SI				
Engine Manufacturers	-$13.89	4%		-$13.89
Equipment Manufacturers	-$57.65	17%		-$57.65
End User (Households)	-$268.95	79%	$142.78	-$126.17
Subtotal	-$340.49			-$197.71
TOTAL	**-$491.99**		**$229.90**	**-$262.09**
2030				
Marine SI				
Engine Manufacturers	-$18.81	11%		-$18.81
Equipment Manufacturers	-$36.97	23%		-$36.97
End User (Households)	-$108.52	66%	$149.36	$40.84
Subtotal	-$164.30			-$14.94
Small SI				
Engine Manufacturers	-$16.49	4%		-$16.49
Equipment Manufacturers	-$68.45	17%		-$68.45
End User (Households)	-$319.31	79%	$177.89	-$141.42
Subtotal	-$404.25			-$226.36
TOTAL	**-$568.55**		**$327.25**	**-$241.30**

Table 9.1-5 contains more detailed information on the sources of the social costs for 2013. This table shows that vessel and equipment manufacturers are expected to bear more of the burden of the program than engine manufacturers. On the marine side, the loss of producer surplus for the vessel manufacturers has two sources. First, they would bear part of the burden of the equipment costs. Second, they would also bear part of the engine costs, which are passed on to vessel manufacturers in the form of higher engine prices. Vessel manufacturers would not be able to pass along a greater share of the engine and vessel compliance costs to end consumers due to the elastic price elasticity of demand for consumers of these vessels. On the Small SI side, equipment manufacturers can pass on more of the compliance costs to end consumers

because the price elasticity of demand in these markets is less elastic.

Table 9.1-5: Estimated Surplus Changes by Market and Stakeholder for 2013 (2005$, $million)

Scenario	Engineering Compliance Costs	Producer Surplus	Consumer Surplus	Total Surplus	Fuel Savings	Net Surplus
Marine SI						
Engine Manufacturers	$133.2	-$21.5		-$21.5		-$21.5
Equipment Manufacturers	$59.1	-$42.2		-$42.2		-$42.2
Engine Price Changes		*-$18.7*				
Equipment Cost Changes		*-$23.6*				
End User (Households)			-$125.1	-$125.1	$42.3	-$82.8
Engine Price Changes			*-$91.8*			
Equipment Price Changes			*-$33.3*			
Subtotal	**$192.2**	**-$63.8**	**-$125.1**	**-$188.9**	**$42.3**	**-$146.6**
Small SI						
Engine Manufacturers	$371.9	-$18.4		-$18.4		-$18.4
Equipment Manufacturers	$88.4	-$80.2		-$80.2		-$80.2
Engine Price Changes		*-$59.0*				
Equipment Cost Changes		*-$21.1*				
End User (Households)			-$355.9	-$355.9	$94.3	-$261.7
Engine Price Changes			*-$289.8*			
Equipment Cost Changes			*-$66.1*			
Subtotal	**$460.3**	**-$98.5**	**-$355.9**	**-$454.5**	**$94.3**	**-$360.2**
TOTAL	**$652.5**	**-$162.3**	**-$481.1**	**-$643.4**	**$136.6**	**-$506.8**

The present value of net social costs of the proposed standards through 2038 at a 3 percent discount rate, shown in Table XII.F-6, is estimated to be $5.5 billion, taking the fuel savings into account. We also performed an analysis using a 7 percent social discount rate. Using that discount rate, the present value of the net social costs through 2038 is estimated to be $3.5 billion, including the fuel savings.

Table 9.1-6. Estimated Net Social Costs Through 2038 by Stakeholder (2005$, $million)

Market	Total Change in Surplus	Percentage Change in Total Surplus	Fuel Savings	Net Change in Surplus
	Net Present Value 3%			
Marine SI				
Engine Manufacturers	-$354.4	11%		-$354.4
Equipment Manufacturers	-$688.8	22%		-$688.8
End User (Households)	-$2,058.8	66%	$1,831.3	-$227.5
Subtotal	-$3,102.0		$1,831.3	-$1,270.7
Small SI				
Engine Manufacturers	-$275.0	4%		-$275.0
Equipment Manufacturers	-$1,171.8	17%		-$1,171.8
End User (Households)	-$5,333.4	79%	$2,524.8	-$2,808.6
Subtotal	-$6,780.2		$2,524.8	-$4,255.4
TOTAL	**-$9,882.2**		**$4,356.1**	**-$5,526.1**
	Net Present Value 7%			
Marine SI				
Engine Manufacturers	-$216.4	11%		-$216.4
Equipment Manufacturers	-$417.6	22%		-$471.6
End User (Households)	-$1,259.9	66%	$937.1	-$322.8
Subtotal	-$1,893.8		$937.1	-$956.8
Small SI				
Engine Manufacturers	-$157.8	4%		-$157.8
Equipment Manufacturers	-$680.4	17%	$1,354.4	-$680.4
End User (Households)	-$3,062.1	79%	$1,354.4	-$1,707.7
Subtotal	-$3,900.3			-$2,545.9
TOTAL	**-$5,794.2**		**$2,291.5**	**-$3,502.6**

9.2 Economic Methodology

Economic impact analysis uses a combination of theory and econometric modeling to evaluate potential behavior changes associated with a new regulatory program. As noted above, the goal is to estimate the impact of the regulatory program on producers and consumers. This is done by creating a mathematical model based on economic theory and populating the model using publically available price and quantity data. A key factor in this type of analysis is the responsiveness of the quantity of engines and equipment demanded by consumers or supplied by producers to a change in the price of that product. This relationship is called the elasticity of demand or supply.

The EIM's methodology is rooted in applied microeconomic theory and was developed following the *OAQPS Economic Analysis Resource Document* (EPA 1999). This section discusses the economic theory underlying the modeling for this EIA and several key issues that affect the way the model was developed.

9.2.1 Behavioral Economic Models

Models incorporating different levels of economic decision making can generally be categorized as *with*-behavior responses or *without*-behavior responses. The EIM is a behavioral model.

Engineering cost analysis is an example of the latter and provides detailed estimates of the cost of a regulation based on the projected number of affected units and engineering estimates of the annualized costs. The result is an estimate of the total compliance costs for a program. However, these models do not attempt to estimate how a regulatory program will change the prices or output of an affected industry. Therefore, the results may over-estimate the total costs of a program because they do not take decreases in quantity produced into account.

The *with*-behavior response approach builds on the engineering cost analysis and incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox (1999) note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers. In behavioral models, manufacturers of goods affected by a regulation are economic agents that can make adjustments, such as changing production rates or altering input mixes, that will generally affect the market environment in which they operate. As producers change their production levels in response to a new regulation, consumers of the affected goods are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output resulting from the market adjustments are used to estimate the distribution of social costs between consumers and producers.

If markets are competitive and per-unit regulatory costs are small, the behavioral approach will yield approximately the same total cost impact as the engineering cost approach. However, the advantage of the *with*-behavior response approach is that it illustrate how the costs flow through the economic system and it identifies which stakeholders, producers, and consumers are most likely to be affected.

9.2.2 What Is the Economic Theory Underlying the EIM?

The EIM is a multi-market partial-equilibrium numerical simulation model that estimates price and quantity changes in the intermediate run under competitive market conditions. Each of these model features is described in this section.

9.2.2.1 Partial Equilibrium Multi-Market Model

In the broadest sense, all markets are directly or indirectly linked in the economy, and a new regulatory program will theoretically affect all commodities and markets to some extent. However, not all regulatory programs have noticeable impacts on all markets. For example, a regulation that imposes significant per unit compliance costs on an important manufacturing input, such as steel, will have a larger impact on the national economy. A regulation that imposes a small direct compliance cost on an important input, or any direct compliance costs on an input that is only a small share of production costs, would be expected to have less of an impact on all markets in the economy.

The appropriate level of market interactions to be included in an economic impact analysis is determined by the number of industries directly affected by the requirements and the ability of affected firms to pass along the regulatory costs in the form of higher prices. There are at least three alternative approaches for modeling interactions between economic sectors, that reflect three different levels of analysis.

In a *partial equilibrium* model, individual markets are modeled in isolation. The only factor affecting the market is the cost of the regulation on facilities in the industry being modeled; there are no interaction effects with other markets. Conditions in other markets are assumed either to be unaffected by a policy or unimportant for cost estimation.

In a *multi-market* model, a subset of related markets is modeled together, with sector linkages, and hence selected interaction effects, explicitly specified. This approach represents an intermediate step between a simple, single-market partial equilibrium approach and a full general equilibrium approach. This technique has most recently been referred to in the literature as "partial equilibrium analysis of multiple markets" (Berck and Hoffmann, 2002).

In a *general equilibrium* model, all sectors of the economy are modeled together, incorporating interaction effects between all sectors included in the model. General equilibrium models operationalize neoclassical microeconomic theory by modeling not only the direct effects of control costs but also potential input substitution effects, changes in production levels associated with changes in market prices across all sectors, and the associated changes in welfare economy-wide. A disadvantage of general equilibrium modeling is that substantial time and resources are required to develop a new model or tailor an existing model for analyzing regulatory alternatives.

This analysis uses a partial equilibrium approach in that it models only those markets that are directly affected by the proposed emission control program: the Small SI and Marine SI markets. In addition, these markets are modeled separately. This approach is appropriate because the Small SI and Marine SI sector represent different activities (residential garden care and personal recreation), and production and consumption of one is not affected by the other. In other words, an increase in the price of lawnmowers is not expected to have an impact on the production and supply of recreational marine vessels, and vice versa. Production and consumption of these products are the result of other factors that have little cross-over impacts.

The EIM uses a single-market approach for some sectors (Small SI handheld, Class I nonhandheld, personal watercraft, outboards recreational) and a two-market approach for the others (Small SI Class II nonhandheld; sterndrive/inboards; and outboards luxury) reflecting whether the markets are integrated and whether the controls affect only engines or both engines and equipment. The advantage of a two-market approach is that it allows us to describe the expected distribution of the program’s effects across equipment and engine markets as well as the effects on purchasers of these engines and equipment. To simulate these relationships, the EIM consists of a series of standard partial equilibrium models that are linked through interactions between the equipment and engine markets. As a result, the model estimates changes in prices and quantities across all markets *simultaneously* for each of the linked engine and equipment markets.

The EIM does not specifically estimate potential price and quantity impacts on final goods and services that may be produced by equipment that would be subject to the proposed controls in the agricultural and construction sectors. This is appropriate because the vast majority of engines and equipment that would be subject to the proposed standards are purchased for residential use (recreational marine; home lawn and garden and residential utility uses; see Section 9.3 and the industry characterization prepared for this rule). Not only is the share of commercial users of this equipment small, but such equipment represents only a small portion of the total production costs for application markets such as agriculture, construction or manufacturing. The proposed standards would affect only a very small part of total inputs for those markets and would not be expected to result in an adverse impact on output and prices of goods produced in these commercial application sectors.

It should also be noted that the economic impact model employed for this analysis estimates the market-level economic impacts of the rule. It is not a firm-level analysis and therefore the impact for any particular manufacturer may be greater or less than the average impact for the market as a whole. This difference can be important, particularly where the rule affects different firms’ costs over different volumes of production. However, to the extent there are differential effects, EPA believes that the wide array of flexibilities provided in this rule are adequate to address any cost inequities that are likely to arise.

9.2.2.2 Perfect Competition Model

For all markets that are modeled, the analyst must characterize the degree of competition within each market. The discussion generally focuses on perfect competition (price-taking behavior) versus imperfect competition (the lack of price-taking behavior). This EIM is abased on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices.

In a perfectly competitive market at equilibrium the market price equals the value society (consumers) places on the marginal product, as well as the marginal cost to society (producers). Producers are price takers, in that they respond to the value that consumers put on the product. It should be noted that the perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[4] Finally, according to contestable market theory, oligopolies and even monopolies will behave very much like firms in a competitive market if it is possible to enter particular markets costlessly (i.e., there are no sunk costs associated with market entry or exit). This would be the case, for example, when products are substantially similar.

In contrast, imperfect competition implies firms have some ability to influence the market price of output they produce. One of the classic reasons firms may be able to do this is their ability to produce commodities with unique attributes that differentiate them from competitors' products. This allows them to limit supply, which in turn increases the market price, given the traditional downward-sloping demand curve. Decreasing the quantity produced increases the monopolist's profits but decreases total social surplus because a less than optimal amount of the product is being consumed. In the monopolistic equilibrium, the value society (consumers) places on the marginal product exceeds the marginal cost to society (producers) of producing the last unit. Thus, social welfare would be increased by inducing the monopolist to increase production. Social cost estimates associated with a proposed regulation are larger with monopolistic market structures and other forms of imperfect competition because the regulation exacerbates the existing social inefficiency of too little output from a social perspective. The Office of Management and Budget (OMB) explicitly mentions the need to consider these market power-related welfare costs in evaluating regulations under Executive Order 12866 (OMB, 1996).

Perfect competition is a widely accepted economic practice for this type of analysis and only in rare cases are other approaches used (EPA 2000, p. 126). For the markets under consideration in this EIA, we assume the perfectly competitive market structure. This is because these markets do not exhibit evidence of noncompetitive behavior: there are no indications of barriers to entry, the firms in these markets are not price setters, and there is no evidence of high levels of strategic behavior in the price and quantity decisions of the firms.

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[4] The number of firms in a market is not a necessary condition for a perfectly competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Incl., p. 33.

As described in the industry profiles for this proposed regulation (RTI, 2004), several of the recreational marine and Small SI sectors are highly concentrated and thus have the potential for the emergence of imperfect competition and price-setting behavior. Nonetheless, our analysis suggests that mitigating factors will limit this potential for raising price above marginal cost and thus that the assumption of perfect competition is justified. Among the mitigating factors are the presence of substantial import competition, relative ease of entry, existing excess production capacity, and a historical tendency of market participants to compete on price. These markets are also mature markets, as evidenced by unit sales growing at the rate of population increases. Pricing power in such markets is typically limited, and empirical data indicates that price pressure has existed in these markets for years and firms in these markets are price takers.[5] In addition, the products produced within each market are somewhat homogeneous in that engines and equipment from one firm can be purchased instead of engines and equipment from another firm, enhancing competition.

According to contestable market theory, oligopolies and even monopolies will behave very much like firms in a competitive market if it is possible to enter particular markets costlessly (i.e., there are no sunk costs associated with market entry or exit). This is the case with these markets as there is significant excess production capacity in both the Small SI and Marine SI industries, in part due to improved productivity and efficiency in current plants. Data on domestic plant capacity utilization rates are published by the U.S. Census (U.S. Census, 2005). The full production capability is defined as "the maximum level of production that an establishment could reasonably expect to attain under normal and realistic operating conditions fully utilizing the machinery and equipment in place." Recent domestic data for 2000 to 2004 indicate the internal combustion engine industry (NAICS 333618 Other Equipment Manufacturing) operated at 53 to 73 percent of full production capability. Similar data for vessels (NAICS 336612 Boat Building) indicate this industry operated between 59 and 62 percent of full production capability. The small SI equipment industry (NAICS 333112, lawn & garden tractor and home & lawn garden equipment manufacturing) operated at 50 to 65 percent of full production capability. Idle production capacity also limits the ability of firms to raise prices, since competitors can easily capture market share by increasing their production at the expense of a producer that increases its prices.

Finally, domestic producers face substantial competition from foreign manufacturers (RTI, 2006). These overseas firms may have strong incentives to compete vigorously on price with the well-established U.S. firms. For all of these reasons it is appropriate to use a perfect competition model to estimate the economic impacts of this proposal.

9.2.2.3 Intermediate-Run Model

In developing the multi-market partial equilibrium model, the choices available to producers must be considered. For example, are producers able to increase their factors of

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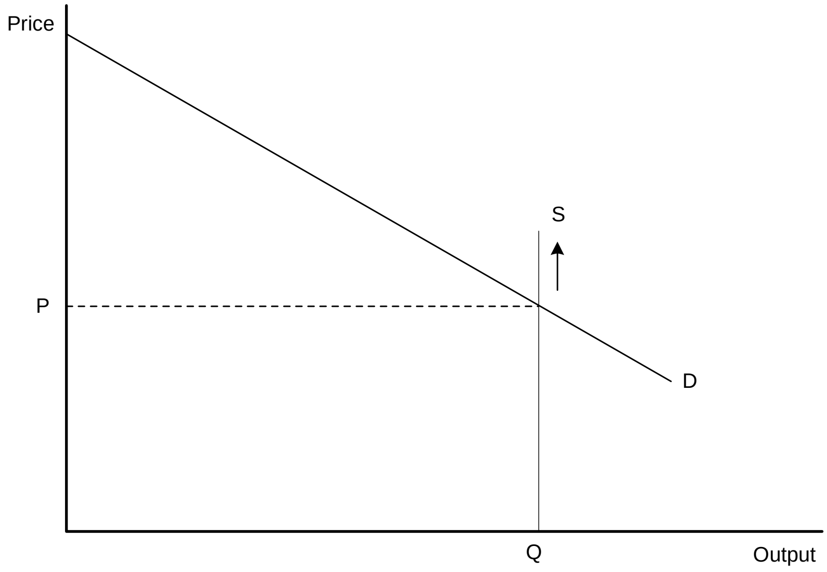
[5] RTI (2006). Historical Market Data and Trends, Industry Profile for Small SI Engines and Equipment, Section 2.5. Draft Report

production (e.g., increase production capacity) or alter their production mix (e.g., substitution between materials, labor, and capital)? These modeling issues are largely dependent on the time horizon for which the analysis is performed. Three benchmark time horizons are discussed below: the very short run, the long run, and the intermediate run. This discussion relies in large part on the material contained in the *OAQPS Economic Analysis Resource Guide* (U.S. EPA, 1999).

The EIM models market impacts in the intermediate run. The use of the intermediate run means that some factors of production are fixed and some are variable. This modeling period allows analysis of the economic effects of the rule's compliance costs on current producers. As described below, a short-run analysis imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

In the very short run, all factors of production are assumed to be fixed, leaving the directly affected entity with no means to respond to increased costs associated with the regulation (e.g., they cannot adjust labor or capital inputs). Within a very short time horizon, regulated producers are constrained in their ability to adjust inputs or outputs due to contractual, institutional, or other factors and can be represented by a vertical supply curve, as shown in Figure 9.2-1. In essence, this is equivalent to the nonbehavioral model described earlier. Neither the price nor quantity changes and the manufacturer’s compliance costs become fixed or sunk costs. Under this time horizon, the impacts of the regulation fall entirely on the regulated entity. Producers incur the entire regulatory burden as a one-to-one reduction in their profit. This is referred to as the “full-cost absorption” scenario and is equivalent to the engineering cost estimates. Although there is no hard and fast rule for determining what length of time constitutes the very short run, it is inappropriate to use this time horizon for this analysis because it assumes economic entities have no flexibility to adjust factors of production.

Figure 9.2-1: Short Run: All Costs Born by Producers



In the long run, all factors of production are variable, and producers can be expected to adjust production plans in response to cost changes imposed by a regulation (e.g., using a different labor/capital mix). Figure 9.2-2 illustrates a typical, if somewhat simplified, long-run industry supply function. The function is horizontal, indicating that the marginal and average costs of production are constant with respect to output.[6] This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market.

Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation’s effect on production costs. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P to P′). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q to Q′). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P ac P′). In the nomenclature of EIAs, this long-run scenario is typically referred to as “full-cost pass-through” and is illustrated in Figure 9.2-2.

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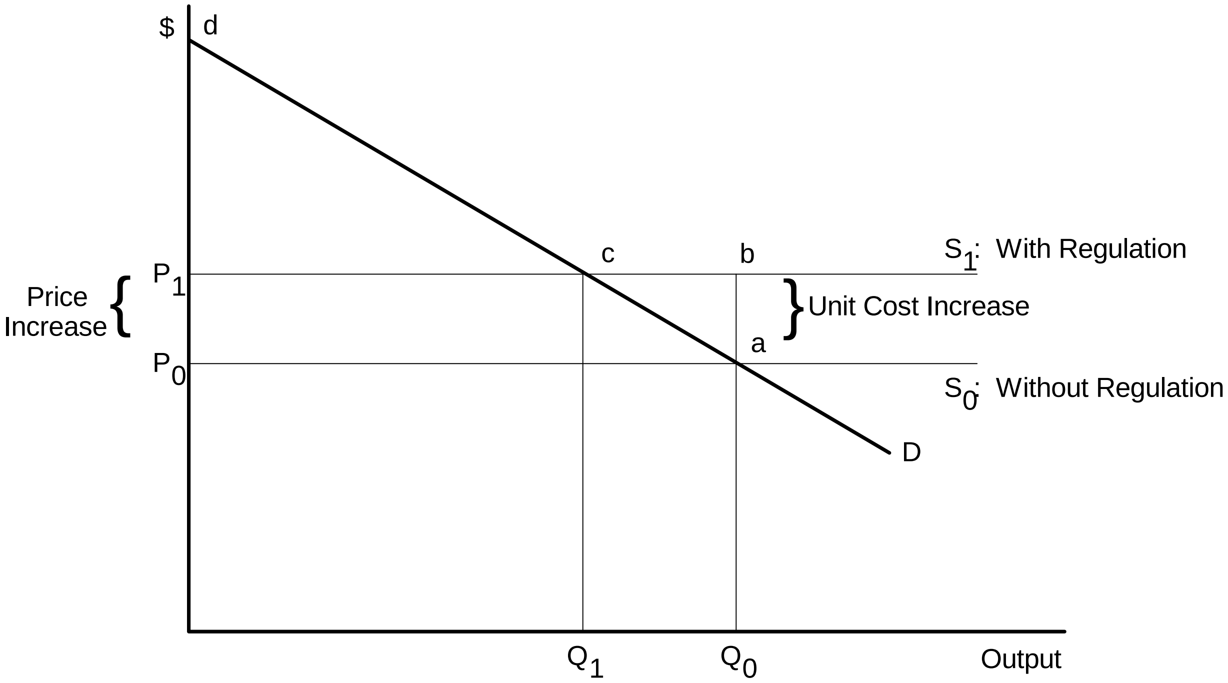
[6] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

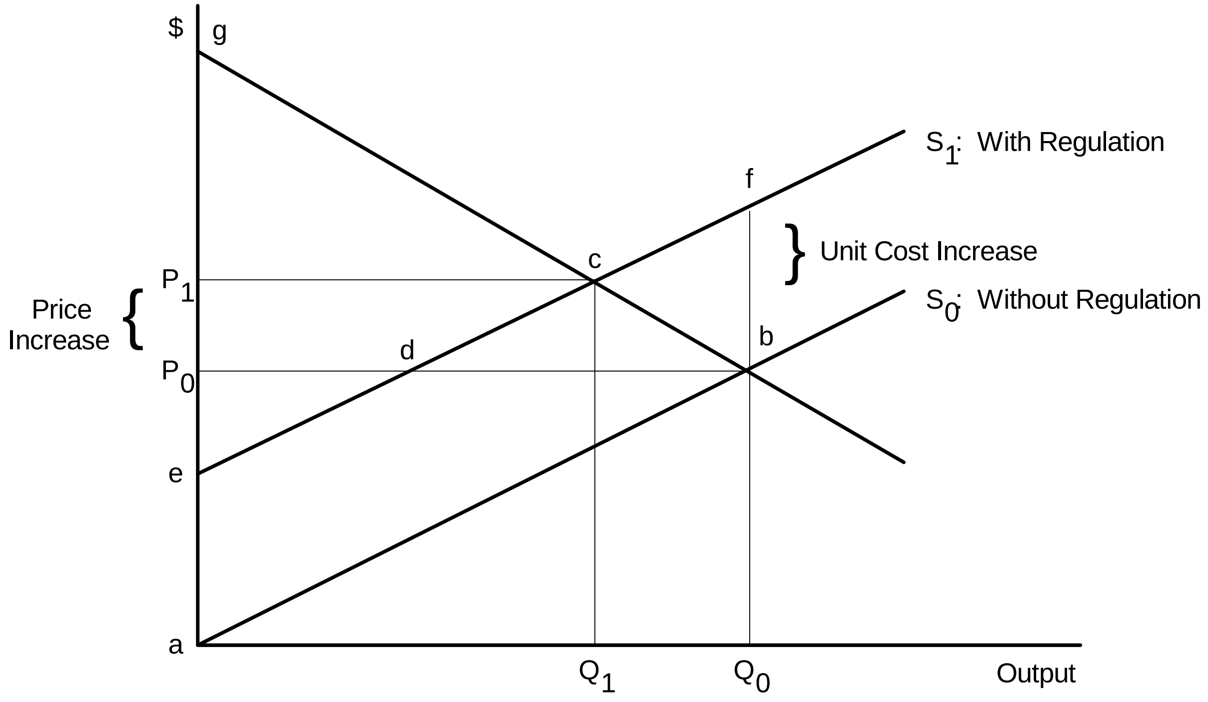
Figure 9.2-2: Long Run: Full-Cost Pass-Through



Taken together, impacts modeled under the long-run/full-cost-pass-through scenario reveal an important point: under fairly general economic conditions, a regulation's impact on producers is transitory. Ultimately, the costs are passed on to consumers in the form of higher prices. However, this does not mean that the impacts of a regulation will have no impact on producers of goods and services affected by a regulation. For example, the long run may cover the time taken to retire all of today's capital vintage, which could take decades. Therefore, transitory impacts could be protracted and could dominate long-run impacts in terms of present value. In addition, to evaluate impacts on current producers, the long-run approach is not appropriate. Consequently a time horizon that falls between the very short-run/full-cost-absorption case and the long-run/full-cost-pass-through case is most appropriate for this EIA.

The intermediate run time frame allows examination of impacts of a regulatory program during the transition between the short run and the long run. In the intermediate run, some factors are fixed; some are variable. In other words, producers can adjust some, but not all, factors of production, meaning they will bear some portion of the costs of the regulatory program. The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost (supply) function that rises with the output rate, as shown in Figure 9.2-3.

Figure 9.2-3: Intermediate Run: Partial-Cost Pass-Through



Again, the regulation causes an upward shift in the supply function. The lack of resource mobility may cause producers to suffer profit (producer surplus) losses in the face of regulation; however, producers are able to pass through some of the associated costs to consumers, to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P to P′) that is less than the per-unit increase in costs, so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In other words, there is a loss of both producer and consumer surplus.

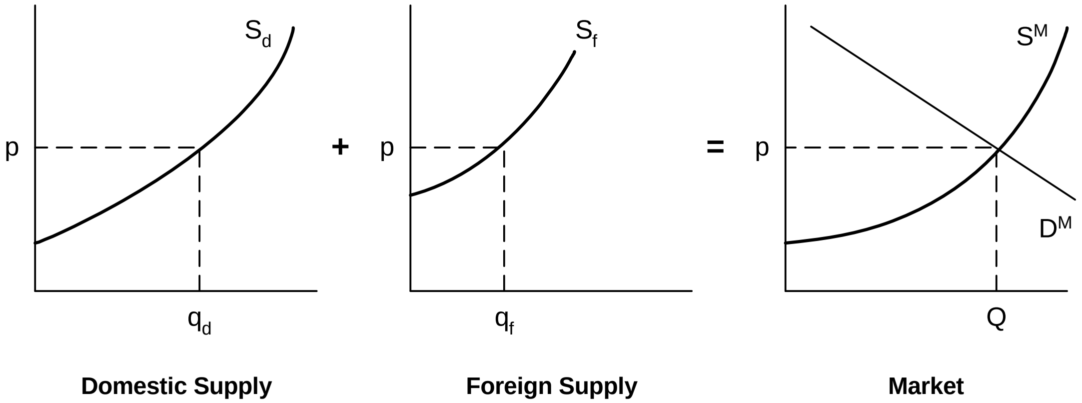
Consistent with other economic impact analyses performed by EPA, this EIM uses an intermediate run approach. This approach allows us to examine the market and social welfare impacts of the program as producers adjust their output and consumers adjust their consumption of affected products in response to the increased production costs. During this period, the distribution of the welfare losses between producer and consumer depends in large part on the relative supply and demand elasticity parameters used in the model. For example, if demand for Small SI equipment is relatively inelastic (i.e., demand does not decrease much as price increases), then most of the direct compliance cost on refiners will be passed along to Small SI equipment consumers in the form of higher prices.

9.2.3 How is the EIM Used to Estimate Economic Impacts?

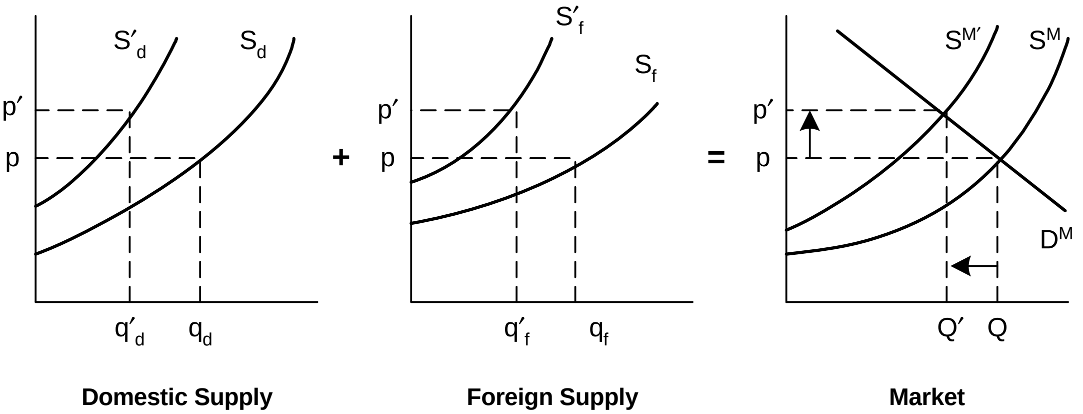
9.2.3.1 Estimation of Market Impacts (Single Market)

A graphical representation of a general economic competitive model of price formation, as shown in Figure 9.2-4(a), posits that market prices and quantities are determined by the intersection of the market supply and market demand curves. Under the baseline scenario, a market price and quantity (p,Q) are determined by the intersection of the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M). The market supply curve reflects the sum of the domestic (S_d) and import (S_i) supply curves.

Figure 9.2-4: Market Equilibrium without and with Regulation



a) Baseline Equilibrium



b) With-Regulation Equilibrium

With the regulation, the costs of production increase for suppliers. The imposition of these regulatory control costs is represented as an upward shift in the supply curve for domestic and import supply by the estimated compliance costs. As a result of the upward shift in the supply curve, the market supply curve will also shift upward as shown in Figure 9.2-3(b) to reflect the increased costs of production.

At baseline without the proposed rule, the industry produces total output, Q, at price, p, with domestic producers supplying the amount q_d and imports accounting for Q minus q_d, or q_f. With the regulation, the market price increases from p to p′, and market output (as determined from the market demand curve) decreases from Q to Q′. This reduction in market output is the net result of reductions in domestic and import supply.

As indicated in Figure 9.2-4, when the proposed standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however, does not shift in this analysis. This is explained by the dynamics underlying the demand curve. The demand curve represents the relationship between prices and quantity demanded. Changes in prices lead to changes in the quantity demanded and are illustrated by *movements along* a fixed demand curve. In contrast, changes in any of the other variables would lead to change in demand and are illustrated as *shifts* in the position of the demand curve.[7] For example, an increase in the number of consumers in a market would cause the demand curve to shift outward because there are more individuals willing to buy the good at every price. Similarly, an exogenous increase in nominal income would also lead the demand curve to shift outward as people choose to buy more of a good at a given price. Changes in the prices of related good and tastes or preferences can also lead to demand curve shifts.

The proposed standards are expected to increase the costs of production in the Small SI engine and equipment and Marine SI engine vessel markets and ultimately lead to higher equilibrium prices in the affected markets. As these prices increase, the quantity demanded falls (i.e., the price change leads to a movement along the demand curve).[8] However, the proposed program is not expected to lead to shifts in the demand curve for several reasons. First, the assume the program will not *directly* influence prices of related goods (i.e., prices of any potential substitutes remain constant in the analysis). In addition, the program will not change nominal incomes through public finance mechanisms (e.g., lump sum subsidies/taxes) or change labor supply decisions. Finally, we assume tastes and preference will not change during the period of analysis. For all of these reasons, it would be inappropriate to shift the demand curve for this analysis.

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[7] An accessible detailed discussion of these concepts can be found in Chapter 5-7 of Nicholson's (1998) intermediate microeconomics textbook.

[8] Nicholson (1998) provides an example of the effects of a price increase on the quantity consumed (p: 134-135). Throughout this discussion, we use uncompensated Marshallian demand functions. As a result, a price increase will also change an individual's "real" income and reinforce substitution quantity responses to a good's price change through an "income" effect. Both substitution and (real) income effects are therefore built in the Marshallian demand function used for this analysis. It is important to note, however, that this type of "income" effect is conceptually different from an exogenous change in nominal income that leads to a shift in a demand function.

9.2.3.2 Incorporating Multi-Market Interactions

The above description is typical of the expected market effects for a single product markets (e.g., Small SI handheld and Class I nonhandheld; personal watercraft) considered in isolation. However, several of the markets considered in this EIA are more complicated because the engine and equipment manufacturers are not integrated.

When both engine and equipment markets are considered separately, the regulatory program will affect equipment producers in two ways. First, equipment producers are affected by higher input costs (increases in the price of gasoline engines) associated with the rule. Second, the standards will also impose additional production costs on equipment producers associated with equipment changes necessary to accommodate changes in engine design. In the sections that follow, we describe the demand relationships between these markets and how they are incorporated in the economic model.

In markets such as Class II nonhandheld or SD/I marine, the demand for engines is directly linked to the production of equipment or vessels that uses those engines.[9] This means that it is reasonable to assume that the input-output relationship between the gasoline engines and the equipment is strictly fixed and that the demand for engines varies directly with the demand for equipment.[10] A demand curve specified in terms of its downstream consumption is referred to as a derived demand curve. Figure 9.2-5 illustrates how a derived demand curve is identified.

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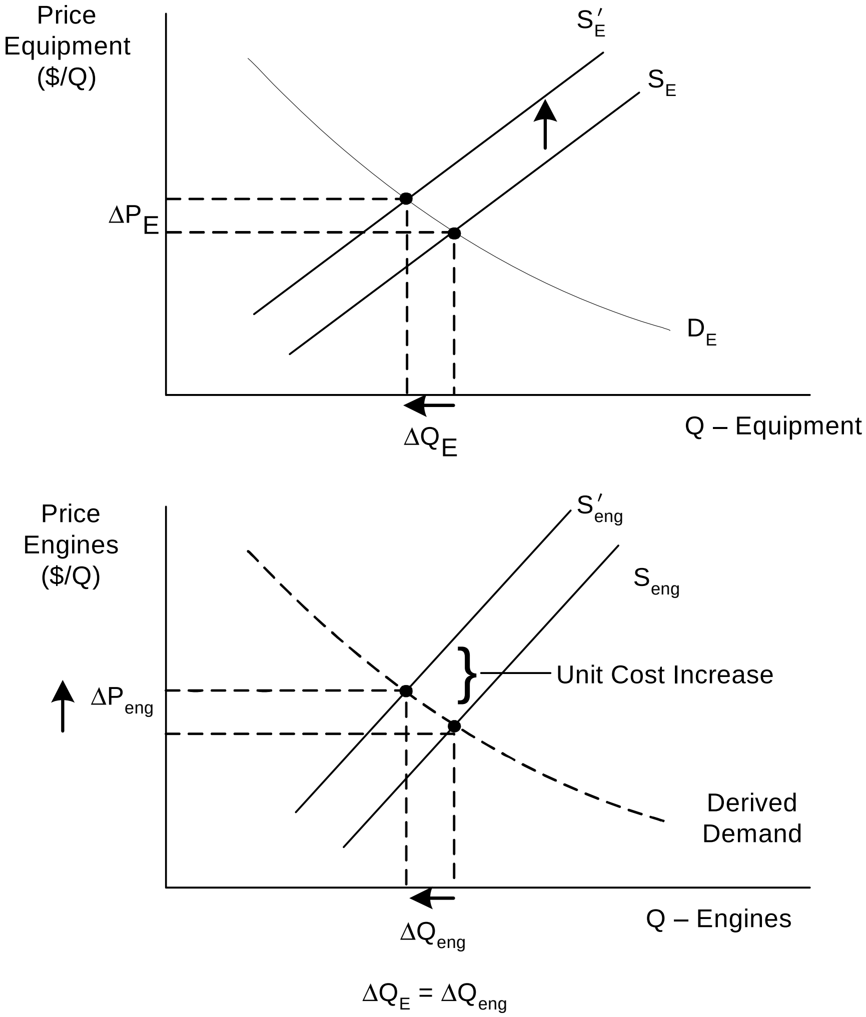
[9] In marine applications, one or two engines are used per boat, depending on its intrinsic design, and this configuration is insensitive to small changes in engine used. In the case of Small SI equipment, the one-to-one correspondence is exact. Furthermore, there is no potential for technical substitution, i.e., to make gasoline equipment one needs a gasoline engine.

[10] This one-to-one relationship holds for engines sold on the market and for engines consumed internally by integrated engine/equipment manufacturers.

Figure 9.2-5: Derived Demand for Engines



Consider an event in the marine equipment market that causes the price of equipment to increase by ΔP (such as an increase in the price of engines). This increase in the price of equipment will cause the supply curve in the equipment market to shift up, leading to a decreased quantity (ΔQ_E). The change in equipment production leads to a decrease in the demand for engines (ΔQ_{Eng}). The new point ($Q_E - \Delta Q_E$, $P - \Delta P$) traces out the derived demand curve. Note that the supply and demand curves in the marine equipment markets are needed to identify the derived demand in the engine market. All of the market supply and demand curves and the elasticity parameters used in the EIM are described in Appendix 9E

9.2.3.3 Estimation of Social Costs

The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net "surplus" changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred to as the "social cost" of a regulation. It is important to emphasize that this measure does not include the benefits that occur outside of the market, that is, the value of the reduced levels of air pollution with the regulation. Including this benefit will reduce the net cost of the regulation and even make it positive.

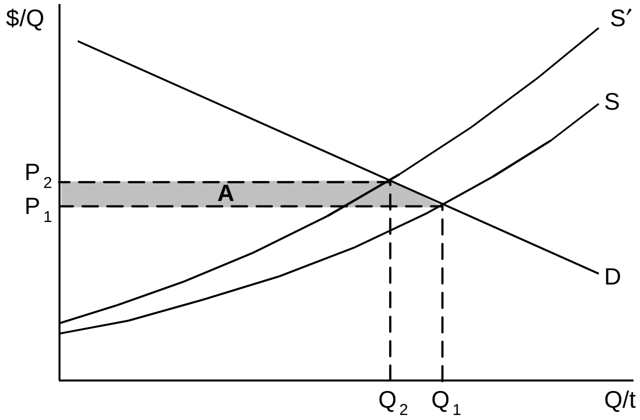
The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 9.2-6).

The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as "consumer surplus." Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as "producer surplus." Producer surplus is measured as the area above the supply curve below the price of the product. These areas can be thought of as consumers' net benefits of consumption and producers' net benefits of production, respectively.

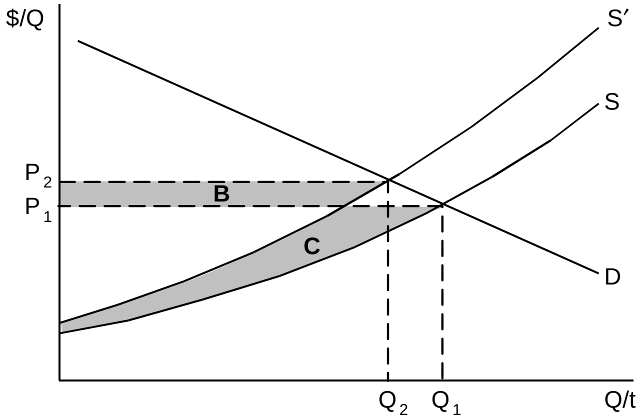
In Figure 9.2-6, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_1 with quantity Q_1. The increased cost of production with the regulation will cause the market supply curve to shift upward to S'. The new equilibrium price of the product is P_2. With a higher price for the product there is less consumer welfare, all else being unchanged. In Figure 9.2-6(a), area A represents the dollar value of the annual net loss in consumers' welfare associated with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed due to the price increase, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, $Q_1 – Q_2$.

In addition to the changes in consumers' welfare, there are also changes in producers' welfare with the regulatory action. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure 9.2-6(b), area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producers' welfare is represented by area B – C.

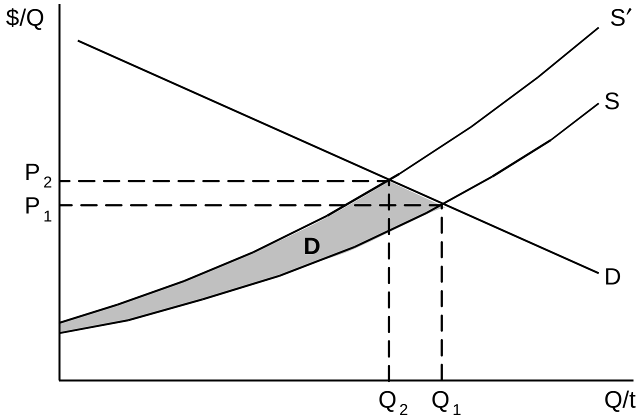
Figure 9.2-6: Market Surplus Changes with Regulations Consumer and Producer Surplus



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, –(A) + (B–C). Figure 9.2-6(c) shows the net (negative) change in economic welfare associated with the regulation as area D.

9.2.4 How Are Special Market Characteristics Addressed?

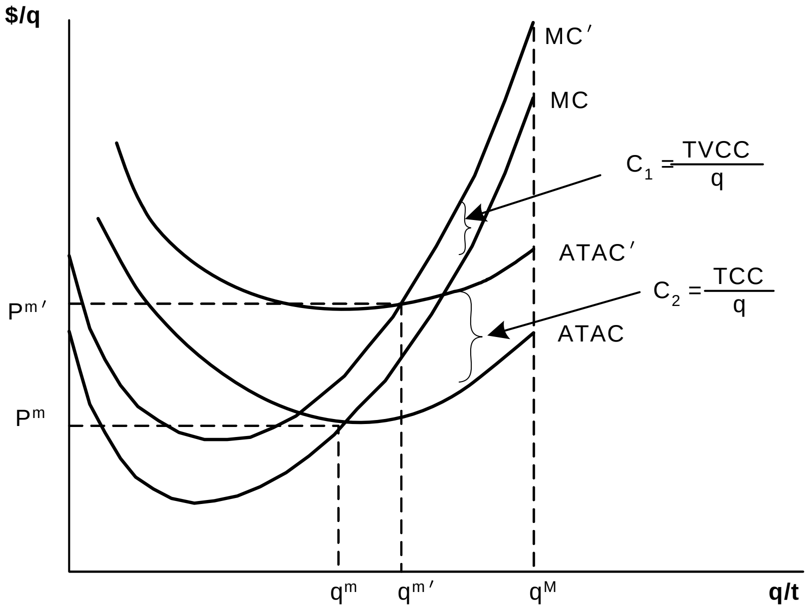
In addition to the general model features described in Section 9.2.2, there are several specific characteristics of the Small SI and Marine SI markets that need to be addressed in the EIM. These are the treatment of fixed and variable costs, fuel savings, programmatic flexibilities, and substitution, and distribution systems effects.

9.2.4.1 Fixed and Variable Costs in a Competitive Market

The estimated engineering compliance costs, consisting of fixed costs (R&D, capital/tooling, certification costs), variable costs, and operating costs provide an initial measure of total annual compliance costs without accounting for behavioral responses. The starting point for assessing the market impacts of a regulatory action is to incorporate the regulatory compliance costs into the production decision of the firm.

In general, shifting the supply curve by the total cost per unit implies that both capital and operating costs vary with output levels. At least in the case of capital, this raises some questions. In the long run, all inputs (and their costs) can be expected to vary with output. But a short(er)-run analysis typically holds some capital factors fixed. For instance, to the extent that a market supply function is tied to existing facilities, there is an element of fixed capital (or one-time R&D). As indicated above, the current market supply function might reflect these fixed factors with an upward slope. As shown in Figure 9.2-7, the marginal cost (MC) curve will only be affected, or shift upwards, by the per-unit variable compliance costs (c1=TVCC/q), while the average total cost (ATAC) curve will shift up by the per-unit total compliance costs (c2=TCC/q). Thus, the variable costs will directly affect the production decision (optimal output rate), and the fixed costs will affect the closure decision by establishing a new higher reservation price for the firm (i.e., Pm'). In other words, the fixed costs are important in determining whether the firm will stay in this line of business (i.e., produce anything at all), and the variable costs determine the level (quantity) of production.

Figure 9.2-7: Modeling Fixed Costs



(a) Upward-sloping supply function

Depending on the industry type, fixed costs associated with complying with a new regulation can generally be treated differently in an analysis of market impacts. In a competitive market, the industry supply curve is generally based on the market's marginal cost curve; fixed costs do not influence production decisions at the margin. Therefore, the market anlaysis for a competitive market is based on variable costs only.

The nature of the Small SI and Marine SI markets suggests the market supply curve shifts in the model should include fixed and variable compliance costs. This is because Small SI and Marine SI engine and equipment manufacturers produce a product that changes very little over time. These manufacturers may not engage in research and development to improve their products on a continuous basis (as opposed to highway vehicles or nonroad engines and equipment). In this case, the product changes that would be required to comply with the proposed standards would require these manufacturers to devote new funds and resources to product redesign and facilities changes. In this situation, Small SI and Marine SI engine and equipment manufacturers would be expected to increase their prices by the full amount of the compliance costs (both fixed and variable) to attempt to recover those costs. This is in contrast to the nonroad diesel engine and equipment markets: manufacturers in those markets generally allocate redesign resources each year to accommodate a changing market. To reflect these conditions, the supply shift in this EIM is based on both fixed and variable costs, even though the model assumes perfect competition. A sensitivity analysis was performed to investigate the impacts under the alternative scenario of shifting the supply curve by the variable costs only. The results of that analysis can be found in Appendix 9H.

9.2.4.2 Fuel Savings and Fuel Taxes

If all the costs of the regulation are not reflected in the supply shift, then the producer and consumer surplus changes reflected in Figure 9.2-6(c) will not capture the total social costs of the regulation. This will be the case, for example, if there are cost savings attributable to a program that are not readily apparent to consumers.

In this case, the proposed evaporative and exhaust controls are expected to result in fuel savings for users. Small SI engine and equipment manufacturers are expected to use fuel injection techniques to comply with the proposed standards for some of their two-cylinder Class II engines. These fuel injected engines are expected to have better fuel efficiency than carbureted engines. Marine SI manufacturers are expected to use 4-stroke and direction-injection 2-stroke technology for outboards and PWC. In addition, all sterndrive and inboard engines are expected to use fuel injection. These technologies are expected to result in reductions in fuel consumption.

These fuel savings are not included in the market analysis for this economic impact analysis. This is because all available evidence suggests that fuel savings do not affect consumer decisions with respect to the purchase of this equipment. Unlike motor vehicles or other consumer goods, neither Small SI nor Marine SI equipment is labeled with expected fuel consumption or expected annual operating costs. Therefore, there is no information available for the consumer to use to make this decision. Instead consumers base their purchase decision on other attributes of the product for which the manufacturer provides information. For lawn mowers this may be the horsepower of the engine, whether the machine has a bag or has a mulching feature, its blade size, etc. For PWC it may be how many people it can carry, its maximum speed, its horsepower, etc. In many cases, especially for Small SI equipment, the consumer may not even be aware of the fuel savings when operating the equipment, especially if he or she uses the same portable fuel storage container to fuel several different pieces of equipment.

These fuel savings are included in the social cost analysis. This is because they are savings that accrue to society. These savings are attributed to consumers of the relevant equipment. As explained in more detail in 9.3.5, the social cost analysis is based on the equivalent of the pre-tax price of gasoline in that analysis. Although the consumer will realize a savings equal to the pump price of gasoline (post-tax), part of that savings is offset by a tax loss to governmental agencies and is thus a loss to consumers of the services supported by those taxes. This tax revenue loss, considered a transfer payment in this analysis, does not affect the benefit-cost analysis results.

9.2.4.3 Flexibility Provisions

Consistent with the engineering cost estimates, the EIM does not include cost savings associated with compliance flexibility provisions or averaging, banking, and trading provisions. As a result, the results of this EIA can be viewed as somewhat conservative.

9.2.4.4 Substitution

Gasoline-powered SI engines convert the potential energy contained in the fuel into mechanical energy, which can then be used to do useful work, to provide locomotion, and/or to generate electricity. These machines are technologically similar compression-ignition engines powered by diesel fuel, and often compete in the same equipment and applications markets. Similarly, electric motors are capable of performing many of the same tasks as gasoline engines in small and inexpensive equipment.

The relationships modeled in the EIM do not include substitution away from Small SI and Marine SI engines and equipment to diesel or electric alternatives. This is appropriate because consumers are not likely to make these substitutions. Diesel engines' superior efficiency in energy conversion makes them more attractive for large engines, and for those with long required service lives, whether measured in operating hours or years of service. Gasoline-powered engines, on the other hand, have lower initial cost, and utilization in garden or recreational activities is not high enough for diesel fuel efficiency to overcome this gasoline advantage. On the SI marine side, the current population of recreational boats is overwhelmingly powered by gasoline engines, even in the large horsepower classes where diesel's superior efficiency would seem to provide significant cost advantages, and gasoline engines are the prevalent choice for garden equipment and residential generators. On the Small SI side, substitution to diesel is not a viable option for most residential consumers, either because diesel equipment does not exist (e.g., diesel string trimmers) or because there would be a large price premium that would discourage the use of diesel equipment (e.g., diesel lawnmowers and diesel recreational marine vessels). In addition, most households are not equipped to handle the additional fuel type and misfueling would carry a high cost. Finally, the lack of a large infrastructure system already in place like the one supporting the use of gasoline equipment for residential and recreational purposes, including refueling and maintenance, represents a large barrier to substitution from gasoline to diesel equipment. With regard to electric alternatives, the impact of substitution to electric for Small SI equipment (there are no comparable options for Marine SI) is also expected to be negligible. Gasoline is the power source of choice for small and inexpensive equipment due to its low initial cost. Gasoline equipment is also inherently portable, which make them more attractive to competing electric equipment that must be connected with a power grid or use batteries that require frequent recharging. Data that would allow investigation of the details of this clear consumer preference are not available, but it is reasonable to assume that increases in the cost of gasoline engines of the magnitude associated with this program would not cause widespread substitution to diesel or electric alternatives.

9.2.4.5 Distribution System Effects

The market interactions modeled in the EIM are those between producers and consumers of the specified engines and equipment that use those engines. The EIM does not consider sales distribution networks or how the regulated goods are sold to final consumers through wholesalers and/or retailers. This is appropriate because the proposed regulatory program does not impose additional costs on the distribution networks and those relationships are not expected to change as a result of the standards.

In the case of Small SI equipment, however, concerns have been raised about the potential for dominant retailers (big box stores such as Wal-Mart, Sears and K-Mart) to affect market equilibria and the ability of manufacturers to pass along cost increases associated with new emission control requirements. Specifically, some Small SI equipment manufacturers assert that Big Box stores impose a price structure that would force them to absorb the compliance costs associated with the proposed standards. They contend that this is a relatively new phenomenon for their market and that EPA should consider these effects in the economic impact analysis for this proposal.

Dominant retailers are a fairly well-understood sector of the consumer good distribution network, especially with regard to clothing and household goods. These stores reduce product prices by exerting important influences on relevant producers. Specifically, they discipline markets by encouraging manufacturers to compete on price, and force inefficient firms to cut costs or leave the market.

Dominant retailers may also prevent efficient producers from passing on increases in fixed costs to consumers, including R&D costs associated with engine or equipment redesign. So, for example, it may be the case that if a particular firm redesigns a lawnmower to produce more power a dominant retailer may not choose to change its pricing structure to account for that redesign. Nevertheless, the firm may still choose to incorporate the design change in the hope of capturing a greater share of the market and/or improve its name recognition.

It is unlikely, however, that a dominant retailer could prevent firms from passing on market-wide increases in marginal costs in response to a regulatory program. Profit maximizing manufacturers will continue to follow a marginal cost equals price pricing rule regardless of the distribution arrangements. A dominant retailer could not force the manufacturer to produce units where the marginal cost exceeds the price. If large retail distributors attempted to prevent efficient manufacturers from raising prices in response to the standards, manufacturers would likely respond to a retailer’s price pressure by reducing output. This would result in large excess demand in the equipment market which would ultimately have to be satisfied through some sort of arbitrage mechanism to a new higher equilibrium price.

An individual manufacturing company has little, if any, ability to pass on a price increase if it is the only entity affected by that price increase. In such a case, retailers would clearly have an incentive to purchase comparable engines or equipment that were not affected by the price increase, placing the affected firm at a competitive disadvantage and reducing its market share. However, in this case all engine manufacturers will face increased marginal costs of production associated with the regulatory program. Therefore, the program does not necessarily put one engine manufacturer at a competitive disadvantage, although manufacturers that can more easily accommodate the new requirements will likely see lower costs than those who cannot.

9.3 EIM Data Inputs and Model Solution

The EIM is a computer model comprised of a series of spreadsheet modules that simulate the supply and demand characteristics of the markets under consideration. The model equations, presented in Appendix D to this chapter, are based on the economic relationships described in Section 9.2. The EIM analysis consists of four basic steps:

- Define the initial equilibrium conditions of the markets under consideration (equilibrium prices and quantities and behavioral parameters; these yield equilibrium supply and demand curves).
- Introduce a policy "shock" into the model based on estimated compliance costs that shift the supply functions.
- Use a solution algorithm to estimate a new, with-regulation equilibrium price and quantity for all markets.
- Estimate the change in producer and consumer surplus in all markets included in the model.

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium reflects the new market prices where total market supply equals market demand.

The remainder of this section describes the data used to construct the EIM: initial equilibrium market conditions (equilibrium prices and quantities), compliance cost inputs, and model elasticity parameters. Also included is a brief discussion of the analytical expression used to estimate with-regulation market conditions.

9.3.1 Description of Product Markets

This EIM estimates the behavioral responses of the Small SI and Marine SI markets to the cost of complying with the proposed emission control program. Each of these markets is very briefly described below. More information can be found in the industry characterizations prepared for this proposal (Chapter 1 and RTI 2006).

9.3.1.1 Small SI Market

The Small SI market is the market for a variety of nonroad equipment powered by two-stroke or four-stroke spark-ignition engines rated up to 19 kW (25 hp). This economic impact assessment distinguishes between two Small SI market sectors: handheld and nonhandheld. The handheld (HH) sector consists generally of equipment that is carried by the operator and is operated multipositionally, although some equipment in this category may have two wheels. HH equipment includes string trimmers, edgers, leaf blowers, and chain saws. The nonhandheld (NHH) sector consists mostly of wheeled equipment such as lawn mowers, garden tractors, and wheeled trimmers, blowers, and edgers. Also included in the Small SI market are generators, compressors, and construction, agricultural, and small industrial equipment, as well as some recreational and utility vehicles and snowblowers.

The HH market can be characterized as an integrated market in which producers manufacture both the engine and the associated equipment. In the NHH market, in contrast, the engine and equipment manufacturers are typically separate entities. Engines produced by a manufacturer for use in its own equipment are called “captive” engines. Engines produced by manufacturers for sale on the open market to anyone who wants to buy them are called “merchant” engines. This distinction is important because compliance costs affect captive and merchant engines differently. Engine-related compliance costs for captive engines are absorbed into the equipment costs of integrated suppliers in their entirety. In contrast, nonintegrated suppliers who buy merchant engines absorb only part of the engine compliance costs into their equipment costs; the rest is borne by the engine manufacturer. Depending on the price sensitivity of demand in the engine market, the pass-through of engine compliance costs to the equipment manufacturer may be larger (more inelastic demand) or smaller (more elastic demand).

This analysis makes the simplifying assumption that virtually all Small SI equipment is sold to residential end-users for their personal use and a negligible number are sold to commercial entities for use as an input to the production of goods or services. This simplifying assumption allows us to disregard the impact of the compliance costs on the production of goods and services that would have Small SI equipment as an input. Any such impacts would be expected to be negligible given the relative share of Small SI equipment to any such production processes. This assumption is supported by data from the Outdoor Power Equipment and Engine Service Association (OPEESA), contained in Table 9.3-1, which indicates that only about 3 percent of the NHH products sold in 2003 and 2004 were sold to commercial users. The rest, 97 percent, were sold to residential users. While this data reflects only NHH equipment, a similar situation likely exists for HH equipment given the nature of that equipment (light-duty lawn and garden equipment or gensets). Recent EPA certification data also supports this simplifying assumption. According to model year 2005 data, about 5 percent of Class I and 7 percent of Class II engines were high hour useful life (commercial) categories, or a total of about 9 percent of Classes I and II combined. About 19 percent of HH engines were high useful life categories.

Table 9.3-1: Share of Residential and Commercial Small SI Shipments (Various years)

	2003	2004
Total Commercial Turf Products	297,085	234,475
Total Consumer NHH Products	8,598,901	8.188,614
Commercial Unit Volume NHH Share	3.3%	2.8%
HH products (assumed consumer)	12,600,440	11,949,557
Commercial share - all Small SI	1.4%	1.2%

Source: Outdoor Power Equipment & Engine Service Association, 2004.

The analysis also assumes that there is a one-to-one correspondence between engines and equipment (there is only one engine per equipment unit) and that there is no market for loose engines. These assumptions are reasonable given the nature of this equipment and because owners generally do not repower this equipment when the engine fails; instead, they repair the engine or replace the equipment. This assumption makes it possible to estimate the number of engines produced directly from the number of equipment.

9.3.1.1.1 Handheld Market

The HH engine market consists of Class III (< 20 cc), IV (20-50 cc) and V (>50 cc) engines. These engines are used in similar types of equipment, all of which are small and relatively lightweight. According to the industry profile prepared for this rule, the HH market is an integrated market in that about 90 percent of HH engines are “captive” engines, with the engine and equipment manufacturer being the same company (RTI, 2006). An integrated market means the EIM can use a one-market approach.

For the purpose of this analysis, all HH engines and equipment are grouped into one engine/equipment market. This is reasonable both because it is an integrated market and because the estimated compliance costs for the HH standards are expected to be similar for all types of HH engines and equipment regardless of size or application. The proposed standards for HH consist only of evaporative emission controls and tThe cost to comply with the standards are primarily related to fuel tank volume and fuel hose length, which do not vary significantly for most equipment.

9.3.1.1.2 Nonhandheld Market

The NHH engine market consists of Class I (<225 cc) and Class II (>225 cc) engines. There are three useful life categories for each and the costs for complying with the exhaust standards will vary by useful life category for each engine class. According to the industry profile prepared for this rule, the NHH market is not integrated in that about 95 percent of Class I and Class II NHH engines are merchant engines (RTI, 2006). The model thus explores the impacts on engine producers and equipment producers separately. This means it is necessary to use a two-market approach, with the engine and equipment markets sharing some of the compliance costs and consumers bearing the rest.

Snowblowers engines are treated differently under EPA’s proposed program. The proposed program would impose only evaporative controls on these engines. Because Class I manufacturers of snowblower engines make the whole engine as a set (i.e., including fuel tank and fuel lines), it was decided to place all of the compliance costs on the engine manufacturer. These manufacturers are expected to produce a separate snowblower engine to be used in this equipment. Class II engines are commonly sold without fuel tanks, and so the evaporative controls for Class II snowblowers are attributed to the equipment manufacturer.

The nine Small SI nonhandheld engine markets are summarized in Table 9.3-2.

Table 9.3-2: Small SI Nonhandheld Engine Categories

Class	Useful Life
Class I	125 hours
	250 hours
	500 hours
Class I - Snowblower	125 hours
	250 hours
	500 hours
Class II	250 hours
	500 hours
	1000 hours

The EIM includes eight types of NHH equipment, as described in Table 9.3-3. However, because not all engine/equipment combination are applicable, there are a total of 40 engine/equipment markets. Specifically, there are no Class II lawnmowers, there are no Class I tractors, and all equipment in the "other lawn and garden" category using Class I engines are in the UL125 grouping.

Table 9.3-3: Nonhandheld Equipment Categories

Equipment	Class I	Class II
Agriculture/construction/general industrial	Yes	Yes
Utility and recreational vehicles	Yes	Yes
Lawn mowers	Yes	No
Tractors	No	Yes
Lawn and garden, other	UL125 only	Yes
Gensets/welders	Yes	Yes
Pumps/compressors/pressure washers	Yes	Yes
Snowblowers	Yes	Yes

9.3.1.2 Marine SI market

The Marine SI market is the market for a variety of marine vessels powered by gasoline engines. These proposed Marine SI standards discussed here are for propulsion engines only. Auxiliary Marine SI engines <37 kW are included as Small SI engines for this rule. Larger auxiliary Marine SI engines were covered in the new standards for Large SI engines. Many of the auxiliary Marine SI engines are being designed with catalysts independent of the proposed standards, so the proposed standards will codify what is already happening in the industry and force new entrants in the market to employ the same types of emission controls. Given that the industry is already using catalysts, the estimated costs of complying are with the proposed standards are negligible. These engines typically use the same fuel tank as the propulsion engines so evaporative emission controls for these engines impose a nominal cost that is already covered in the vessel costs since the vessel costs include costs for hoses and tanks. The impact of treating marine Auxiliary Marine SI engines in this way are expected to be minimal because the number of vessels with installed auxiliary units is small and limited to sterndrive/inboard and outboard luxury vessels: about 23,000 out of a total of 378,500 vessels.

9.3.1.2.1 Marine SI Engine Markets

Unlike Small SI engines that can be used in a variety of different types of equipment, Marine SI engines are designed and manufactured for specific applications. Engines used in sterndrive or inboard vessels are different from those used in outboard applications, and are made by different manufacturers. Outboards and SD/I engines produced for luxury vessels are different from those produced for the general market. Personal watercraft, on the other hand, are generally an integrated system. Taking this into consideration, there are 15 engine markets included in this EIA, based on design and horsepower. These are described in Table 9.3-4.

Table 9.3-4: Marine SI Engine Markets

Engine Design	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp
PWC			XXX	XXX	XXX	
SD/I Recreation				XXX	XXX	XXX
SD/I Luxury					XXX	XXX
OB Recreational	XXX	XXX	XXX	XXX	XXX	
OB Luxury				XXX	XXX	

Similar to the Small SI market, most marine SI engines are used for recreational purposes. According to a 2000 study of the boat building industry, about 79 percent of Marine SI vessels are used for recreational purposes and only 7 percent for commercial purposes, with the remaining 14 percent for other purposes (CCA, 2000).[11] The propulsion system of choice for commercial marine vessels is diesel due to its greater reliability and lower fuel costs. The combustion characteristics of diesel engines also make them a better choice for vessels that are likely to spend large amounts of time at sea. While gasoline marine engines are used in applications such as lifeboats, patrol boats and small fishing vessels, their numbers are not large enough to warrant separate consideration in this Economic Impact Analysis.

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[11] This study looked at NAICS 336612 – establishments primarily engaged in building boats, defined as watercraft not built in shipyards and typically of the type suitable or intended for personal use; it is not clear what is meant by "other" in this study.

For the purposes of this analysis, all personal watercraft manufacturers are considered to be integrated manufacturers, and thus the engines are “captive.” This is reasonable because personal watercraft are similar to land-based recreational vehicles in that the engines are produced by the equipment manufacturer specifically for certain models.

The other two primary types of SI marine engines are outboards and sterndrives/inboards (SD/I). For these engines, we model a merchant relationship between the engine manufacturers and boat builders. This is reasonable because these engines are typically sold on the open market (outboards) or sold internally but through a market-type relationship between the engine and the equipment businesses (SD/I).

Outboard engines are typically produced by the engine manufacturer with little or no knowledge of what vessels the engines will be used on. Outboards are a self-contained assembly, with a power unit and drive unit, that can be fit to a wide range of boats. They may be used either with a portable fuel tank or connected to a fuel system installed on a vessel. In most cases, the engine manufacturer and boat builder are separate companies. However, it is becoming more common for engine manufacturing companies to purchase boat builders. Based on conversations with engine manufacturers and boat builders, we have received indications that this trend has not significantly changed the relationship between the engine business units and the boat building business units. The boat builders typically pay market price for the engines and there is little integration of design beyond a typical manufacturer/supplier relationship. It seems that engine manufacturers generally buy outboard vessel building companies to gain access to target markets rather than to develop an integrated design. Generally, the vessel is sold without the engine and the consumer chooses the engine at the point of sale. This means that the vessel builder may not be involved in the transaction and that the distribution of the compliance costs is between the engine builder and the end consumer rather than between the engine builder and the vessel builder.

The relationship between engine manufacturers and boat builders is similar for SD/I engines as for outboard engines. One difference is that there are only two large businesses and many small businesses producing SD/I engines. These small businesses typically do not produce boats or own companies that do. SD/I engines are often sold to buyer groups created by boat builders to gain volume discounts on engines. Because of this, SD/I engine manufacturers often do not know what boats their engines are being used in. In the case where a large SD/I manufacturer has purchased boat building companies, the relationship is similar to that for outboards. Nevertheless, the distribution of compliance costs would be between the engine manufacturer and the vessel builder, since the engine is integrated in the final vessel design.

9.3.1.2.2 Marine SI Equipment Markets

There are five types of marine vessel markets:

- SD/I recreational (runabouts, airboats, jetboats)
- SD/I luxury (yachts, cruisers offshore)
- OB recreational (runabouts, pontoons, fishing)

- OB luxury (yacht, cruiser, express fish)
- Personal watercraft

Of the 30 possible engine/vessel combinations, there are 15 combinations that are not applicable. For example, SD/I vessels use engines above 100 hp only. Personal watercraft use engines above 50 hp but do not use engines above 300 hp. This yields a total of 15 engine/vessel markets.

Table 9.3-5: Marine SI Vessel Types

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp
PWC			XXX	XXX	XXX	
SD/I Recreational				XXX	XXX	XXX
SD/I Luxury					XXX	XXX
OB Recreational	XXX	XXX	XXX	XXX	XXX	
OB Luxury				XXX	XXX	

Unlike Small SI equipment, there is not a one-to-one relationship between engines and equipment. Some vessels may have more than one propulsion engine. Table 9.3-6 shows the average number of engines per vessel assumed for the purposes of this analysis. In this table, OB engines per boat sale represents the average number of engines per outboard vessel in general. This average consists of three components: 1) some outboard vessels have more than one engine; 2) engines that are made as replacement engines; and 3) loose engines that are not sold with the boat, such as “kicker” engines which are used for low speed trolling.

Table 9.3-6: Average Number of Marine SI Engines per Vessel (2005)

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp	Average
PWC			1.00	1.00	1.00		1.00
SD/I Recreational				1.00	1.02	1.01	1.01
SD/I Luxury					1.25	1.52	1.39
OB Recreational	1.25	1.25	1.29	1.29	1.29		1.28
OB Luxury				2.50	2.50		2.50
OB Engine/boat sale							1.47

9.3.1.3 Market Linkages

In the EIM, the Small SI and Marine SI markets are not linked (there is no feedback mechanism between the Small SI and Marine SI market segments). This is appropriate because the affected equipment is not interchangeable and because there is very little overlap between the engine producers in each market. These two sectors represent different aspects of economic activity (lawn and garden care and power generation as opposed to recreational marine) and production and consumption of one product is not affected by the other. In other words, an increase in the price of lawnmowers is not expected to have an impact on the production and supply of personal watercraft, and vice versa. Production and consumption of each of these productions are the results of other factors that have little cross-over impacts (the need for residential garden upkeep or power generation; the desire for personal recreation).

9.3.2 Market Equilibrium Conditions

The starting point for the economic impact analysis is initial market equilibrium conditions (prices and quantities) that exist prior to the implementation of new standards. At pre-control market equilibrium conditions, consumers are willing to purchase the same amount of a product that producers are willing to produce at the market price.

9.3.2.1 Small SI Initial Equilibrium Quantities and Prices

9.3.2.1.1 Small SI Engine and Equipment Initial Equilibrium Quantities

The EIM uses the same engine sales quantities that are used in the Small SI cost analysis presented in Chapter 6. The sales numbers for 2005 are reproduced in Tables 9.3-7 and 9.3-8. They are based on engine and equipment sales are for 49 states (all states except California) for 2005. However, the sales numbers include construction and agriculture equipment sold in California, since that equipment is not covered by California's small engine program.

These engine sales numbers are taken from EPA's NONROAD 2005 emission inventory model. To breakout the sales data by equipment, industry information from Power Systems Research database-OELink was used to characterize the distribution of equipment by the eight different equipment categories noted earlier. In addition, the sales within each equipment category were apportioned to the different useful life categories based on the fraction of engines certified in each class determined from EPA certification data for model year 2005.

Because of the one-to-one correspondence between Small SI engines and equipment, the number of equipment is equal to the number of engines sold in a given year.

Table 9.3-7: Small SI Handheld Engine and Equipment Sales (2005)

Sales - All Handheld Engines, Equipment
8,153,106

Table 9.3-8: Small SI Nonhandheld Engine and Equipment Sales (2005)

Application	Class I			Class II			Total
	UL 125	UL 250	UL 500	UL 250	UL 500	UL 1000	
Agricultural/Construction/ General Industrial/ Material Handling Equip	71,682	7,675	5,287	71,380	15,503	17,585	189,112
Utility and Rec Vehicles	81,703	8,748	6,026	173,846	37,758	42,827	350,908
Lawn Mowers	5,895,682	631,264	434,859	NA	NA	NA	6,961,805
Tractors	NA	NA	NA	1,701,351	369,523	419,134	2,490,008
Lawn and Garden Other	647,256	NA	NA	127,915	27,782	31,512	834,465
Gensets/ Welders	271,391	29,058	20,017	605,169	131,439	149,086	1,206,160
Pumps/ Compressors/ Pressure Washers	579,773	62,078	42,763	253,971	55,161	62,576	1,056,322
Snowblowers	551,506	59,051	40,679	475,353	103,244	117,105	1,346,938
Total	8,098,993	797,874	549,631	3,408,985	740,410	839,816	14,435,709

9.3.2.1.2 Small SI Engine and Equipment Initial Equilibrium Prices

The initial equilibrium prices for Small SI engines and equipment are contained in Tables 9.3-9 and 9.3-10. The engine prices were prices estimated by EPA using prices compiled from various websites and obtained from manufacturers. The engine prices were averaged for each useful life category for each class. The equipment prices were gathered through a survey of retailers, government dealers, and equipment websites (Caffrey, 2006).

For the handheld market, although all costs are placed on the engine manufacturer, the engine and equipment manufacturers are integrated so only the equipment price is necessary for the analysis.

Table 9.3-9: Small SI Handheld Engine and Equipment Prices (2005$)

Equipment Price
$87

Table 9.3-10: Small SI Nonhandheld Engine and Equipment Equilibrium (2005$)

Application	Class I			Class II		
	UL 125	UL 250	UL 500	UL 250	UL 500	UL 1000
Agricultural/Construction/ General Industrial/ Material Handling Equip	$1,108	$1,621	$2,133	$1,825	$3,538	$5,251
Utility and Rec Vehicles	$570	$750	$931	$2,894	$3,981	$5,068
Lawn Mowers	$218	$420	$2,786			
Tractors				$1,937	$5,241	$6,841
Lawn and Garden Other	$245			$312	$969	$1,626
Gensets/ Welders	$999	$1,428	$1,856	$666	$1,414	$2,162
Pumps/ Compressors/ Pressure Washers	$96	$661	$1,225	$349	$1,485	$2,834
Snowblowers	$324	$480	$637	$665	$890	$1,115

9.3.2.2 Marine SI Initial Equilibrium Quantities and Prices

9.3.2.2.1 Marine SI Engine and Equipment InitialEquilibrium Quantities

The EIM uses the same engine sales quantities that are used in the Marine SI cost analysis presented in Chapter 6. The sales numbers for 2005 are reproduced in Tables 9.3-11 and 9.3-12. The engine sales data are derived for 2003 from certification databases for EPA and the California Air Resources Board and nationwide statistical data published by the National Marine Manufacturers Association (Samulski, 2004). These 2003 sales were adjusted to 2005 and future years using the growth rate described in 9.3.4.

Table 9.3-11: Marine SI Engine Sales (2005)

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp	Total
PWC			20,825	57,257	3,767		81,849
SD/I Recreational				15,069	35,668	25,975	76,712
SD/I Luxury					9,565	12,960	22,525
OB Recreational	38,529	52,858	79,083	46,229	42,680		259,380
OB Luxury				9,043	9,043		18,087
OB loose engines	32,667						32,667
Total	71,196	52,858	99,909	127,599	100,724	38,935	491,220

Table 9.3-12: Marine SI Vessel Sales (2005)

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp	Total
PWC			20,825	57,257	3,767		81,849
SD/I Recreational				15,069	34,894	25,645	75,608
SD/I Luxury					7,630	8,542	16,172
OB Recreational	30,823	42,287	61,182	35,765	33,019		203,076
OB Luxury				3,617	3,617		7,235
Total	30,823	42,287	82,007	111,708	82,928	34,186	383,940

9.3.2.2.2 Marine SI Engine and Vessel InitialEquilibrium Prices

The Marine SI engine and vessel initial equilibrium prices are contained in Tables 9.3-13 and 9.3-14. They are based on advertised prices in trade literatures and on the web and on statistical data collected by the National Marine Manufacturers Association (Samulski, 2004). For the estimated vessel prices, replacement engines are included but are discounted at 7 percent for outboard recreational and luxury outboard and sterndrive vessels. The discount is used to account for the assumption that replacement engines are purchased several years after the boat is purchased. For this analysis, the discount is based on the average useful engine life estimates in the NONROAD2005 model. The original price data was 2003 data; these were adjusted by applying the Product Price Index Series published by the U.S. Bureau of Labor Statistics.[12]

Table 9.3-13: Marine SI Engine Prices (2005$)

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp
PWC			N/A	N/A	N/A	
SD/I Recreational				$7,577	$12,604	$18,715
SD/I Luxury					$16,508	$31,959
OB Recreational	$2,606	$5,693	$9,114	$13,481	$20,786	
OB Luxury				$26,001	$40,074	
OB loose engines	$2,491					

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[12] For Marine SI engines, the PPI for Gasoline Engines (except aircraft, automobile, highway truck, bus, and tank; PCU3336183336181) was used; the ratio for this index is 110.1/105.7 = 1.042. For marine vessel, the PPI for Boat Building (PCU 336612336612) was used; the ratio for this index is 206.7/194.2 = 1.064.

Table 9.3-14: Marine SI Vessel Prices* (2005$)

Vessel	<25 hp	25-50 hp	51-100 hp	101-175 hp	176-300 hp	>301 hp
PWC			$7,566	$9,982	$11,960	
SD/I Recreational				$16,549	$32,356	$46,432
SD/I Luxury					$58,024	$205,658
OB Recreational	$3,658	$10,884	$21,561	$32,467	$49,420	
OB Luxury				$65,097	$104,562	

*Includes replacement engines discounted at 7% for outboard recreational and luxury outboard in sterndrive/inboard vessels.

9.3.3 Compliance Costs

The social costs of the proposed standards are estimated by shocking the initial market equilibrium conditions by the amount of the compliance costs. The compliance costs used in this analysis are the engineering compliance costs described in Chapters 6 of this RIA and are summarized in this section.

The fixed cost portion of the engineering costs incorporate a 7 percent cost of capital recovered over the first five years of the exhaust standards even though the costs actually occur prior to the beginning of the program. The period of recovery is 2011 through 2015 for Class I Small SI engines and 2012 through 2016 for Class II Small SI engines. Marine engine fixed costs are recovered over the period 2009 through 2013 for engines and 2011 through 2016 for vessels, PWC, and outboards <25 hp. The other marine vessels have a small amount of fixed costs associated with the evaporative controls.

9.3.3.1 Small SI Market Compliance Costs

The Small SI engine and equipment compliance costs are summarized in Tables 9.3-15 and 9.3-16. There is one set of compliance costs for HH engines, since there is only one market. There are nine sets of engine compliance costs for NHH engines, one for each engine market. These costs begin in 2009 for HH and 2008 for NHH; the costs changes over time reflecting the phase-in of the different standards.

There are no equipment compliance cost estimates for HH or for Class I NHH equipment. Since the HH market is integrated, all costs are applied to engines. For NHH Class I equipment, the engine manufacturers typically produce a complete engine and fuel system package. Therefore, the proposed program is not expected to impose any additional costs on the equipment manufacturers. Costs are provided for NHH Class II equipment, reflecting the need for evaporative and emission controls. An average cost for all Class II equipment was applied in this analysis to each of the equipment categories.

Table 9.3-15: Compliance Costs per Engine - Small SI (2005$)

Class	Useful Life	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017+
Handheld												
All Engines		Variable	$0.00	$0.00	$0.81	$0.81	$0.81	$0.81	$0.81	$0.69	$0.69	$0.69
		Fixed	$0.00	$0.00	$0.01	$0.01	$0.01	$0.01	$0.01	$0.00	$0.00	$0.00
		Total	$0.00	$0.00	$0.82	$0.82	$0.82	$0.82	$0.82	$0.69	$0.69	$0.69
Nonhandheld												
1	125	Variable	$0.33	$0.33	$0.33	$0.33	$13.30	$13.17	$13.19	$13.19	$13.19	$11.95
		Fixed	$0.02	$0.02	$0.02	$0.02	$1.53	$1.49	$1.47	$1.46	$1.44	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$14.83	$14.66	$14.66	$14.64	$14.63	$12.14
1	250	Variable	$0.33	$0.33	$0.33	$0.33	$15.64	$15.51	$15.53	$15.53	$15.53	$14.21
		Fixed	$0.02	$0.02	$0.02	$0.02	$4.91	$4.81	$4.74	$4.67	$4.60	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$20.55	$20.32	$20.26	$20.19	$20.13	$14.40
1	500	Variable	$0.33	$0.33	$0.33	$0.33	$19.46	$19.33	$19.35	$19.35	$19.35	$17.73
		Fixed	$0.02	$0.02	$0.02	$0.02	$7.03	$6.89	$6.79	$6.68	$6.59	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$26.49	$26.22	$26.13	$26.03	$25.93	$17.92
1	125 Snow-blower	Variable	$0.33	$0.33	$0.33	$0.33	$2.69	$2.56	$2.58	$2.58	$2.58	$2.10
		Fixed	$0.02	$0.02	$0.02	$0.02	$0.47	$0.45	$0.45	$0.45	$0.45	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$3.16	$3.01	$3.03	$3.03	$3.03	$2.29
1	250 Snow-blower	Variable	$0.33	$0.33	$0.33	$0.33	$2.69	$2.56	$2.58	$2.58	$2.58	$2.10
		Fixed	$0.02	$0.02	$0.02	$0.02	$0.47	$0.45	$0.45	$0.45	$0.45	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$3.16	$3.01	$3.03	$3.03	$3.03	$2.29
1	500 Snow-blower	Variable	$0.33	$0.33	$0.33	$0.33	$2.69	$2.56	$2.58	$2.58	$2.58	$2.10
		Fixed	$0.02	$0.02	$0.02	$0.02	$0.47	$0.45	$0.45	$0.45	$0.45	$0.19
		Total	$0.35	$0.35	$0.35	$0.35	$3.16	$3.01	$3.03	$3.03	$3.03	$2.29
2	250	Variable	$0.00	$0.00	$0.00	$32.74	$32.74	$32.74	$32.74	$32.74	$27.06	$27.06
		Fixed	$0.00	$0.00	$0.00	$3.63	$3.56	$3.50	$3.44	$3.39	$0.00	$0.00
		Total	$0.00	$0.00	$0.00	$36.37	$36.30	$36.24	$36.18	$36.13	$27.06	$27.06
2	500	Variable	$0.00	$0.00	$0.00	$25.87	$25.87	$25.87	$25.87	$25.87	$21.63	$21.63
		Fixed	$0.00	$0.00	$0.00	$6.13	$6.02	$5.92	$5.82	$5.73	$0.00	$0.00
		Total	$0.00	$0.00	$0.00	$32.00	$31.89	$31.79	$31.69	$31.60	$21.63	$21.63
2	1,000	Variable	$0.00	$0.00	$0.00	$58.53	$58.53	$58.53	$58.53	$58.53	$45.00	$45.00
		Fixed	$0.00	$0.00	$0.00	$16.00	$15.73	$15.46	$15.20	$14.96	$0.00	$0.00
		Total	$0.00	$0.00	$0.00	$74.53	$73.99	$73.73	$73.73	$73.49	$45.00	$45.00

Table 9.3-16: Compliance Costs per Equipment - Small SI (2005$)

Class	Useful Life	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017+
Handheld												
All Engines		Variable	No equipment costs for HH; all costs are allocated to engine manufacturer									
		Fixed										
		Total										
Nonhandheld												
1	125	Variable	No equipment costs for NHH Class I; all costs are allocated to engine manufacturer									
		Fixed										
		Total										
2	250	Variable	$1.09	$1.09	$1.09	$6.44	$6.44	$6.31	$6.31	$6.31	$5.40	$5.40
		Fixed	$0.04	$0.04	$0.04	$5.11	$5.05	$4.94	$4.87	$4.81	$0.68	$0.68
		Total	$1.13	$1.13	$1.13	$11.55	$11.48	$11.24	$11.18	$11.12	$6.08	$6.08
2	500	Variable	$1.09	$1.09	$1.09	$6.44	$6.44	$6.31	$6.31	$6.31	$5.40	$5.40
		Fixed	$0.04	$0.04	$0.04	$19.03	$18.73	$18.38	$18.10	$17.83	$0.68	$0.68
		Total	$1.13	$1.13	$1.13	$25.47	$25.16	$24.69	$24.41	$24.13	$6.08	$6.08
2	1000	Variable	$1.09	$1.09	$1.09	$6.44	$6.44	$6.31	$6.31	$6.31	$5.40	$5.40
		Fixed	$0.04	$0.04	$0.04	$16.93	$16.66	$16.35	$16.10	$15.86	$0.68	$0.68
		Total	$1.13	$1.13	$1.13	$23.36	$23.10	$22.66	$22.41	$22.16	$6.08	$6.08

9.3.3.2 Marine SI Market Compliance Costs

The Marine SI engine and equipment compliance costs are summarized in Tables 9.3-17 and 9.3-18. Cost estimates are given for each of the 15 engine/equipment combinations, plus cost estimates for loose OB engines. The engine costs begin in 2009 and decrease in 2014 when the fixed costs are fully amortized. In addition, we apply a one time learning curve correction to the variable cost in the sixth year. The engine compliance costs remain the same for 2014 and later years. The equipment costs are more complicated due to the phase in of the different standards. They begin in 2009, increase until about 2012, and then decrease in 2018. Equipment compliance costs remain the same for 2018 and later years.

Table 9.3-17: Compliance Costs per Engine - Marine SI (2005$)

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
PWC	50-100	Variable		$870	$870	$870	$870	$870	$696	$696	$696	$696	$696	$696
		Fixed		$29	$29	$29	$29	$29	---	---	---	---	---	---
		Total		$899	$899	$899	$899	$899	$696	$696	$696	$696	$696	$696
PWC	100-175	Variable		$85	$85	$85	$85	$85	$68	$68	$68	$68	$68	$68
		Fixed		$13	$13	$13	$13	$13	---	---	---	---	---	---
		Total		$98	$98	$98	$98	$98	$68	$68	$68	$68	$68	$68
PWC	175-300	Variable		$1,290	$1,290	$1,290	$1,290	$1,290	$1,032	$1,032	$1,032	$1,032	$1,032	$1,032
		Fixed		$45	$45	$45	$45	$45	---	---	---	---	---	---
		Total		$1,335	$1,335	$1,335	$1,335	$1,335	$1,032	$1,032	$1,032	$1,032	$1,032	$1,032
SD/I Recreational	100-175	Variable		$421	$421	$421	$421	$421	$337	$337	$337	$337	$337	$337
		Fixed		$19	$19	$19	$19	$19	---	---	---	---	---	---
		Total		$440	$440	$440	$440	$440	$337	$337	$337	$337	$337	$337
SD/I Recreational	175-300	Variable		$292	$292	$292	$292	$292	$234	$234	$234	$234	$234	$234
		Fixed		$20	$20	$20	$20	$20	---	---	---	---	---	---
		Total		$312	$312	$312	$312	$312	$234	$234	$234	$234	$234	$234
SD/I Recreational	300 +	Variable		$349	$349	$349	$349	$349	$279	$279	$279	$279	$279	$279
		Fixed		$28	$28	$28	$28	$28	---	---	---	---	---	---
		Total		$377	$377	$377	$377	$377	$279	$279	$279	$279	$279	$279
SD/I Luxury	175-300	Variable		$292	$292	$292	$292	$292	$234	$234	$234	$234	$234	$234
		Fixed		$20	$20	$20	$20	$20	---	---	---	---	---	---
		Total		$312	$312	$312	$312	$312	$234	$234	$234	$234	$234	$234
SD/I Luxury	300 +	Variable		$349	$349	$349	$349	$349	$279	$279	$279	$279	$279	$279
		Fixed		$28	$28	$28	$28	$28	---	---	---	---	---	---
		Total		$377	$377	$377	$377	$377	$279	$279	$279	$279	$279	$279
OB Recreational	< 25	Variable		$69	$69	$69	$69	$69	$55	$55	$55	$55	$55	$55

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
		Fixed		$5	$5	$5	$5	$5	---	---	---	---	---	---
		Total		$74	$74	$74	$74	$74	$55	$55	$55	$55	$55	$55
OB Recreational	25-50	Variable		$216	$216	$216	$216	$216	$173	$173	$173	$173	$173	$173
		Fixed		$6	$6	$6	$6	$6	---	---	---	---	---	---
		Total		$222	$222	$222	$222	$222	$173	$173	$173	$173	$173	$173
OB Recreational	50-100	Variable		$203	$203	$203	$203	$203	$162	$162	$162	$162	$162	$162
		Fixed		$8	$8	$8	$8	$8	---	---	---	---	---	---
		Total		$211	$211	$211	$211	$211	$162	$162	$162	$162	$162	$162
OB Recreational	100-175	Variable		$338	$338	$338	$338	$338	$270	$270	$270	$270	$270	$270
		Fixed		$15	$15	$15	$15	$15	---	---	---	---	---	---
		Total		$353	$353	$353	$353	$353	$270	$270	$270	$270	$270	$270
OB Recreational	175-300	Variable		$690	$690	$690	$690	$690	$552	$552	$552	$552	$552	$552
		Fixed		$27	$27	$27	$27	$27	---	---	---	---	---	---
		Total		$717	$717	$717	$717	$717	$552	$552	$552	$552	$552	$552
OB Luxury	100-175	Variable		$338	$338	$338	$338	$338	$270	$270	$270	$270	$270	$270
		Fixed		$15	$15	$15	$15	$15	---	---	---	---	---	---
		Total		$353	$353	$353	$353	$353	$270	$270	$270	$270	$270	$270
OB Luxury	175-300	Variable		$690	$690	$690	$690	$690	$552	$552	$552	$552	$552	$552
		Fixed		$27	$27	$27	$27	$27						
		Total		$717	$717	$717	$717	$717	$552	$552	$552	$552	$552	$552
OB Loose Engines	< 25	Variable		$69	$69	$69	$69	$69	$55	$55	$55	$55	$55	$55
		Fixed		$5	$5	$5	$5	$5						
		Total		$74	$74	$74	$74	$74	$55	$55	$55	$55	$55	$55

Table 9.3-18: Compliance Costs per Equipment- Marine SI (2005$)

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
PWC	50-100	Variable		$1.6	$1.6	$3.8	$3.8	$3.8	$3.8	$3.8	$3.8	$3.8	$3.8	$3.8
		Fixed		$0.4	$0.4	$12.1	$12.1	$12.1	$12.1	$12.1	$12.1	$5.9	$5.9	$5.9
		Total		$1.9	$1.9	$15.9	$15.9	$15.9	$15.9	$15.9	$15.9	$9.7	$9.7	$9.7
PWC	100-175	Variable		$1.9	$1.9	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7
		Fixed		$0.4	$0.4	$13.3	$13.3	$13.3	$13.3	$13.3	$13.3	$6.5	$6.5	$6.5
		Total		$2.3	$2.3	$18.0	$18.0	$18.0	$18.0	$18.0	$18.0	$11.2	$11.2	$11.2
PWC	175-300	Variable		$1.9	$1.9	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7	$4.7
		Fixed		$0.4	$0.4	$13.3	$13.3	$13.3	$13.3	$13.3	$13.3	$6.5	$6.5	$6.5
		Total		$2.3	$2.3	$18.0	$18.0	$18.0	$18.0	$18.0	$18.0	$11.2	$11.2	$11.2
SD/I Recreational	100-175	Variable		$3.8	$31.4	$31.4	$67.2	$67.2	$67.2	$67.2	$61.7	$61.7	$56.3	$56.3
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.1			
		Total		$4.4	$31.9	$31.9	$67.8	$67.8	$67.8	$67.8	$61.8	$61.7	$56.3	$56.3
SD/I Recreational	175-300	Variable		$4.5	$42.8	$42.8	$92.3	$92.3	$92.3	$92.3	$84.7	$84.7	$78.9	$78.9
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.1	$0.1			
		Total		$5.0	$43.3	$43.3	$93.0	$93.0	$93.0	$92.4	$84.8	$84.7	$78.9	$78.9
SD/I Recreational	300 +	Variable		$5.2	$70.7	$70.7	$155.6	$155.6	$155.6	$155.6	$142.5	$142.5	$135.6	$135.6
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.1	$0.1	---	---	---
		Total		$5.7	$71.2	$71.2	$156.3	$156.3	$156.3	$155.7	$142.6	$142.5	$135.6	$135.6
SD/I Luxury	175-300	Variable		$9.0	$85.5	$85.5	$184.7	$184.7	$184.7	$184.7	$169.4	$169.4	$157.8	$157.8
		Fixed		$0.5	$0.5	$0.5	$0.8	$0.8	$0.8	$0.2	$0.2	---	---	---
		Total		$9.6	$86.0	$86.0	$185.4	$185.4	$185.4	$184.9	$169.6	$169.4	$157.8	$157.8
SD/I Luxury	300 +	Variable		$10.3	$141.4	$141.4	$311.2	$311.2	$311.2	$311.2	$285.0	$285.0	$271.3	$271.3
		Fixed		$0.5	$0.5	$0.5	$0.8	$0.8	$0.8	$0.2	$0.2	---	---	---
		Total		$10.9	$141.9	$141.9	$312.0	$312.0	$312.0	$311.5	$285.3	$285.0	$271.3	$271.3

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
OB Recreational	< 25	Variable		$3.1	$4.4	$5.4	$5.4	$5.4	$5.4	$5.4	$5.1	$5.1	$5.1	$6.1
		Fixed		$0.2	$0.2	$6.7	$6.7	$6.7	$6.7	$6.7	$3.2	$3.2	$3.2	$6.5
		Total		$3.3	$4.6	$12.0	$12.0	$12.0	$12.0	$12.0	$8.3	$8.3	$8.3	$12.6
OB Recreational	25-50	Variable		$4.4	$17.3	$17.3	$30.9	$30.9	$30.9	$30.9	$28.3	$28.3	$23.6	$23.6
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.1	$0.1	---	---
		Total		$5.0	$17.8	$17.8	$31.6	$31.6	$31.6	$31.6	$28.5	$28.5	$23.6	$23.6
OB Recreational	50-100	Variable		$6.5	$26.7	$26.7	$47.7	$47.7	$47.7	$47.7	$43.6	$43.6	$38.6	$38.6
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.1	$0.1	---	---
		Total		$7.0	$27.3	$27.3	$48.3	$48.3	$48.3	$48.3	$43.7	$43.7	$38.6	$38.6
OB Recreational	100-175	Variable		$7.7	$40.6	$40.6	$73.8	$73.8	$73.8	$73.8	$67.3	$67.3	$61.7	$61.7
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.1	$0.1	---	---
		Total		$8.3	$41.1	$41.1	$74.5	$74.5	$74.5	$74.5	$67.4	$67.4	$61.7	$61.7
OB Recreational	175-300	Variable		$9.0	$57.9	$57.9	$107.0	$107.0	$107.0	$107.0	$97.2	$97.2	$91.0	$91.0
		Fixed		$0.5	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.1	$0.1	---	---
		Total		$9.6	$58.4	$85.4	$107.6	$107.6	$107.6	$107.6	$97.3	$97.3	$91.0	$91.0
OB Luxury	100-175	Variable		$15.5	$81.1	$81.1	$147.6	$147.6	$147.6	$147.6	$134.5	$134.5	$123.4	$123.4
		Fixed		$0.5	$0.5	$0.5	$0.8	$0.8	$0.8	$0.8	$0.2	$0.2	---	---
		Total		$16.0	$81.6	$81.6	$148.4	$148.4	$148.4	$148.4	$134.7	$134.7	$123.4	$123.4
OB Luxury	175-300	Variable		$18.1	$115.8	$115.8	$213.9	$213.9	$213.9	$213.9	$14.4	$14.4	$182.0	$182.0
		Fixed		$0.5	$0.5	$0.5	$0.8	$0.8	$0.8	$0.8	$0.2	$0.2	---	---
		Total		$18.6	$116.4	$116.4	$214.7	$214.7	$214.7	$214.7	$194.6	$194.6	$182.0	$182.0
OB Loose Engines	< 25	Variable		$3.0	$4.0	$5.0	$5.0	$5.0	$5.0	$5.0	$5.0	$5.0	$5.0	$6.0
		Fixed		$6.0	$0.0	$7.0	$7.0	$7.0	$7.0	$6.0	$6.0	$3.0	$3.0	$6.0
		Total		$3.0	$5.0	$12.0	$12.0	$12.0	$12.0	$12.0	$12.0	$8.0	$8.0	$13.0

9.3.4 Growth Rates

The growth rates used in this analysis for future Small SI and Marine SI engines and equipment sales are from EPA's Nonroad 2005 model and are the same the same as those use for the cost analysis (EPA 2004b). Because the growth rates are linear, the annual growth rate decreases over time. For Small SI, the growth rate is approximately 2 percent per year beginning in 2008 to decreases to approximately 1.5 percent for 2020 and later years. The growth rate for Marine SI is about 0.8 percent per year in the early years and 0.6 percent in later years.

9.3.5 Fuel Savings

As noted in Section 9.2.4.2, there are fuel savings attributable to the proposed emission control program, reflecting the reduction in evaporative emissions and the use of more fuel-efficient engine technology to meet the proposed engine exhaust standards. As explained in that section, these savings are included in the economic welfare analysis as a separate line item. Consumers of Small SI and Marine SI engines and equipment will realize an increase in their welfare equivalent to the amount of gallons of gasoline saved multiplied by the retail price of the gasoline (post-tax price). In the engineering cost analysis the fuel savings are estimated in this manner. However, in the context of the social welfare analysis, some of this increase in consumer welfare is offset by lost tax revenues to local, state, and federal governments. These welfare losses must be accounted for as well. Therefore, the net change in social welfare is the difference between the increase in consumer welfare and the lost tax revenues. This is equivalent to using the pre-tax price of gasoline to estimate the fuel savings for the social welfare analysis.

The amount of gallons of gasoline fuel saved is composed of two parts. First, upgrades in engine technology is expected to reduce fuel consumption rates. These fuel consumption reductions were calculated using the NONROAD2005 model. In addition, fuel savings due to evaporative emission control is estimated based on the VOC reductions attributable to these controls. Tons of annual VOC reductions are translated to gallons of gasoline saved using a fuel density of 6 lbs per gallon (for lighter hydrocarbons which evaporate first).

Because the gallons of gasoline saved are based on estimated national reductions and were not estimated by PADD, we estimated a national average retail gasoline price (RTI, Memorandum on Calculation Motor Gasoline Prices in Small SI rule EIA, 2006). This estimate is the sum of the weighted average of pre-tax gasoline prices by PADD and the weighted average gasoline tax by PADD, using data from the 2005 Petroleum Marketing Annual (DoE 2005, Table 31). The results of this analysis are shown in Tables 13.3-19 and 13.3-20.

Table 9.3-19: Estimated National Average Fuel Prices (2005$)

PADD	Weight	Pre-tax Price/Gallon	Average State Taxes	Federal Tax	Post-Tax Price/Gallon
PADD 1	0.40	$1.819	$0.207	$0.184	$2.210
PADD 2	0.31	$1.792	$0.209	$0.184	$2.185
PADD 3	0.18	$1.787	$0.194	$0.184	$2.165
PADD 4	0.04	$1.848	$0.225	$0.184	$2.257
PADD 5 (excluding CA)	0.07	$1.938	$0.198	$0.184	$2.320
Total		$1.814			$2.204

Source: *2005 Petroleum Marketing Annual* (Table 31). U.S. Department of Energy, Energy Information Administration (DoE 2005). *Memorandum on Calculation Motor Gasoline Prices in Small SI Rule EIA*, RTI, 2006.

From 2009 until 2016 the estimated consumer savings associated with reduced gasoline consumption from the gas can controls increases sharply, from $16.7 million to $244 million. After 2016 the savings continue to accrue, but at a reduced rate as the engines and equipment population turns over and fuel savings are due to the continuing benefits of using compliant engines and equipment. Similarly, the tax revenue losses are expected to be increased from $3 million in 2009 to $43 million in 2016.

Table 13.3-20: Estimated Fuel Savings and Tax Revenue Impacts (2005$)

Year	Small SI Gallons	Marine SI Gallons	Total Gallons	Consumer Fuel Savings (Million$)	Tax Revenue Impacts (Million$)	Net Fuel Savings (Millions$)
2008	1,710,034	0	1,710,034	$3.8	$0.7	$3.1
2009	3,430,377	4,143,348	7,573,726	$16.7	$3.0	$13.7
2010	5,447,927	8,561,114	14,009,041	$30.9	$5.5	$25.4
2011	22,646,301	13,117,609	35,763,910	$78.8	$13.9	$64.9
2012	38,820,204	18,222,489	57,042,693	$125.7	$22.2	$103.5
2013	51,968,776	23,304,500	75,273,275	$165.9	$29.3	$136.5
2014	60,526,996	28,367,111	88,894,107	$195.9	$34.7	$161.2
2015	67,159,572	33,371,341	100,530,913	$221.5	$39.2	$182.3
2016	72,453,313	38,326,645	110,779,958	$244.1	$43.2	$200.9
2017	75,973,455	43,218,105	119,191,560	$262.6	$46.5	$216.2
2018	78,721,263	48,034,529	126,755,792	$279.3	$49.4	$229.9
2019	81,051,936	52,441,003	133,492,939	$294.2	$52.0	$242.1
2020	83,107,200	56,436,144	139,543,344	$307.5	$54.4	$253.1
2021	84,875,051	60,288,468	145,163,518	$319.9	$56.6	$263.3
2022	86,484,675	63,989,930	150,474,605	$331.6	$58.7	$272.9
2023	87,990,954	67,173,629	155,164,583	$341.9	$60.5	$281.4
2024	89,466,431	70,031,410	159,497,841	$351.5	$62.2	$289.3
2025	90,924,555	72,627,522	163,552,076	$360.4	$63.8	$296.6
2026	92,374,877	74,999,472	167,374,349	$368.8	$65.2	$303.6
2027	93,815,016	77,157,506	170,972,522	$376.7	$66.6	$310.1
2028	95,245,161	79,117,289	174,362,449	$384.2	$68.0	$316.3
2029	96,666,097	80,838,412	177,504,508	$391.1	$69.2	$321.9
2030	98,077,275	82,349,823	180,427,098	$397.6	$70.3	$327.3
2031	99,481,730	83,737,102	183,218,832	$403.7	$71.4	$332.3
2032	100,883,561	84,965,626	185,849,187	$409.5	$72.4	$337.1
2033	102,282,368	86,094,905	188,377,272	$415.1	$73.4	$341.7
2034	103,678,793	87,140,798	190,819,590	$420.5	$74.4	$346.1
2035	105,073,460	88,101,996	193,175,456	$425.7	$75.3	$350.4
2036	106,463,214	88,990,652	195,453,866	$430.7	$76.2	$354.5
2037	107,848,254	89,818,189	197,666,443	$435.6	$77.1	$358.5
2038	109,231,748	90,613,170	199,844,918	$440.4	$77.9	$362.5

9.3.6 Supply and Demand Elasticity Estimates

The estimated market impacts and economic welfare costs of this emission control program are a function of the ways in which producers and consumers of the Small SI and Marine SI engines and equipment affected by the standards change their behavior in response to the costs incurred in complying with the standards. These behavioral responses are incorporated in the EIM through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves), which measure the price sensitivity of consumers and producers.

Because we were unable to find published supply and demand elasticities for the Small SI and Marine SI markets, we estimated these parameters using the procedures described in Appendix 9E. These methods are well-documented and are consistent with generally accepted econometric practice. It should be noted that these elasticities reflect intermediate-run behavioral changes. In the long run, supply and demand are expected to be more elastic.

The estimated supply and demand elasticities were based on best data we could find. For supply elasticities, we used the industry-level data published by the National Bureau of Economic Research (NBER)-Center for Economic Studies (Bartlesman, Becker, and Gray, 2000). For demand elasticities, in addition to data from the NBER, we used the Current Industrial Reports (CIR) series from the U.S. Census Bureau to produce an annual summary of the production of motors and generators and a summary of production of several types of lawn and garden equipment; both of these reports include the number of units manufactured and the value of production (U.S. Census Bureau, 1998; 2000). For walk-behind lawnmowers, we used several data series reported in a study by Air Improvement Resource, Inc., and National Economic Research Associates (AIR/NERA, 2003). The U.S. Census Bureau publishes historical data on household income and housing starts (U.S. Census Bureau, 2002; 2004), and we collected price, wage, and material cost indexes from the Bureau of Labor Statistics (BLS, 2004a,b,c,d,e). In cases where a price index was not available, we used the most recent implicit gross domestic product (GDP) price deflator reported by the U.S. Bureau of Economic Analysis (BEA, 2004).[13] It should be noted that the aggregate data we used to estimate elasticities include data on other markets as well as the Small SI or Marine SI markets. If we had been able to obtain market-specific data for Small SI or Marine SI only, the estimated price elasticities may have been different.

Tables 9.3-21 and 9.3-22 provide a summary of the demand and supply elasticities used to estimate the economic impact of the proposed rule.

The estimated supply elasticities for all of the equipment and engine markets are elastic, ranging from 2.3 for all recreational marine except PWC, to 3.3 for generators, 3.4 for PWCs and all Small SI applications except generators, and 3.8 for engines. This means that quantities supplied are expected to be fairly sensitive to price changes (e.g., a 1 percent change in price yields a 3.3 percent change in quantity of generators produced).

On the demand side, the Marine SI equipment market estimated demand elasticity is elastic, at -2.0. This is consistent with the discretionary nature of purchases of recreational marine vessels (consumers can easily decide to spend their recreational budget on other alternatives).

The estimated demand elasticity for handheld equipment is elastic, at -1.9. This suggests that consumers are more sensitive to price changes for handheld equipment than for other Small SI equipment. In other words, they are more likely to change their purchase decision for a small change in the price of a string trimmer, perhaps opting for trimmer shears or deciding to forego trimming altogether.

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[13] All values are expressed in 1987$. Note the GDP deflators have been updated since the original estimation of supply elasticities for the Clean Air Nonroad Diesel rule. As a result, the elasticity estimation method is the same; however, the coefficients may vary slightly.

The estimated demand elasticity for lawnmowers is very inelastic at -0.2. This suggests that consumers of this equipment are not very sensitive to price changes. Most of this equipment is sold to individual homeowners, who are often required by local authorities to keep their lawns trimmed. Household ownership of a gasoline lawnmower is often their least expensive option. Lawncare services are more expensive since the price for these services includes labor and other factors of production. Purchasing other equipment may also not be attractive, since electric and diesel mowers are generally more expensive and often less convenient. Finally, the option of using landscape alternatives (e.g., prairie, wildflower, or rock gardens) may not be attractive for home homeowners who may also use their yards for recreational purposes. For all these reasons, the price sensitivity of homeowners to lawnmower prices would be expected to be inelastic.

All the other demand elasticities, for gensets, welders, compressors, and agriculture/ construction equipment, are about unit elastic, at -1.0 meaning a 1 percent change in price is expected to result in a 1 percent change in demand.

The demand elasticities for the engine markets are internally derived as part of the process of running the model. This is an important feature of the EIM, which allows it to link the engine and equipment components of each model and simulate how compliance costs can be expected to ripple through the affected market. In actual markets, for example, the quantity of lawnmowers produced in a particular period depends on the price of engines (the Small SI engine market) and the demand for equipment by residential consumers. Similarly, the number of engines produced depends on the demand for engines (the lawnmower market), which depends on consumer demand for equipment. Changes in conditions in one of these markets will affect the others. By designing the model to derive the engine demand elasticities, the EIM simulates these connections between supply and demand among the product markets and replicates the economic interactions between producers and consumers.

Because the elasticity estimates are a key input to the model, a sensitivity analysis for supply and demand elasticity parameters was performed as part of this analysis in considering the uncertainty involved in the estimated elasticities. The results are presented in Appendix 9H.

Table 9.3-21: Summary of Market Supply Elasticities Used in EIM

Market	Estimate	Source	Method	Input Data Source
Engine Markets				
Small SI and Marine SI	3.8	EPA econometric estimate	Cobb-Douglas production function	Bartlesman et al (2000); 1958-1996; SIC 3519
Marine Equipment Markets				
PWC	3.4	EPA econometric estimate	Cobb-Douglas production function	Bartlesman et al (2000); 1958-1996; SIC 3799
All other vessel types	2.3	EPA econometric estimate	Cobb-Douglas production function	Bartlesman et al (2000); 1958-1996; SIC 3732
Small SI Equipment Markets				
Gensets/welders	3.3	EPA econometric estimate	Cobb-Douglas production function	Bartlesman et al (2000); 1958-1996; SIC 3621
All other Small SI equipment (handheld and nonhandheld)	3.4	EPA econometric estimate	Cobb-Douglas production function	Bartlesman et al (2000); 1958-1996; SIC 3524

Table 9.3-22: Summary of Market Demand Elasticities Used in EIM

Market	Estimate	Source	Method	Input Data Source
Engine Markets Small SI and Marine SI	Derived Demand			
Marine Equipment Markets				
All vessel types	-2.0	EPA econometric estimate	Simultaneous equation (3SLS)	Bartlesman et al (2000); 1958-1996; SIC 3732
Small SI Equipment Markets				
HANDHELD: All	-1.9	EPA econometric estimate	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980-1997
NONHANDHELD				
Lawn mowers	-0.2	EPA econometric estimate	Simultaneous equation (3SLS)	AIR/NERA (2003); 1973-2002
Other lawn and garden	-0.9	EPA econometric estimate	Simultaneous equation (2SLS)	Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980-1997
Gensets/welders - Class I	-1.4	EPA econometric estimate	Simultaneous equation (2SLS)	Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980-1997
Gensets/welders - Class II	-1.1	EPA econometric estimate	Simultaneous equation (2SLS)	Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980-1997
All other nonhandheld	-1.0	EPA econometric estimate	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980-1997

9.3.7 Economic Impact Model Structure

9.3.7.1 Computing Baseline and With-Regulation Equilibrium Conditions

The economic impact analysis is conducted using the data and the supply and demand framework described above. The price and quantity data, along with the supply and demand elasticities, are used to identify the market supply and demand curves. The regulatory costs are then used to shift the supply curve, and the resulting new equilibrium determines the market impacts and distribution of social impacts.

Figure 9.3-1 illustrates the economic impact modeling structure. Point A represents the initial baseline equilibrium price and quantity (corresponding to the prices and quantities presented in section 9.3.2). The slope of the supply and demand curves passing through the baseline point A are determined by applying the appropriate supply and demand elasticities presented in section 9.3.6. These slopes reflect the responsiveness of producers and consumers when prices change and determine how much of the compliance costs producers are able to pass along to consumers in the with-regulation equilibrium.

The compliance costs associated with the regulation (presented in Section 9.3.3) enter the model expressed as per-unit costs and result in an upward shift in the supply curve from S_0 to S_1 in Figure 9.3-1. Note that the demand curve does not shift because consumer preferences and income are not affected by the regulation.

With the addition of the compliance costs, if prices were not allowed to adjust demanders would still want to consume the quantity at point A, but suppliers would only be willing to supply the quantity at point B (i.e., demand exceeds supply at the baseline price, P). The model then solves for the new equilibrium price (P*) where the quantity demanded equals the quantity supplied. The movement from the baseline equilibrium point A to with-regulation equilibrium point C determines the market impacts (changes in price and quantity) as well as the distribution of social costs. Appendix 9D describes the set of supply and demand equations included in the model. Given the number of equations included in the model, the solution algorithm described below is used to identify the new with-regulation set of equilibrium prices and quantities (Point C).

The analysis illustrated in Figure 9.3-1 is repeated for each year included in the period of analysis. For future years, a projected time series of prices and quantities are developed and used as the baseline (point A) from which market changes are evaluated. The engineering cost analysis provides quantities for future years using historical annual growth rates. In contrast, there is much more uncertainty surrounding future prices for these markets. As a result, we use a constant 2005 observed prices for the relevant markets during the period of analysis.

9.3.7.2 Solution Algorithm

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium is the result of a series of iterations in which price is adjusted and producers and consumers respond, until a set of stable market prices arises where total market supply equals market demand. Market price adjustment takes place based on a price-revision rule, described below, that adjusts price upward (downward) by a given percentage in response to excess demand (excess supply).

The EIM model uses a similar type of algorithm for determining with-regulation equilibria and the process can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.

2. Recalculate the market supply in each market. Excess demand currently exists.

3. Determine the new prices via a price revision rule. We use a rule similar to the factor price revision rule described by Kimbell and Harrison (1986). P_i is the market price at iteration I, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z \tag{10.1}$$

4. Recalculate market supply with new prices,

5. Compute market demand in each market.

6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one). When the ratio is appropriately close to one, the market-clearing condition of supply equals demand is satisfied.

9.3.7.3 Estimating Impacts

Using the static partial equilibrium analysis, the EIM model loops through each year calculating new market equilibriums based on the projected baseline economic conditions and compliance cost estimates that shift the supply curves in the model. The model calculates price and quantity changes and uses these measures to estimate the social costs of the rule and partition the impact between producers and consumers.

9.4 Methods for Describing Uncertainty

Every economic impact analysis examining the market and social welfare impacts of a regulatory program is limited to some extent by limitations in model capabilities, deficiencies in the economic literatures with respect to estimated values of key variables necessary to configure the model, and data gaps. In this EIA, there are three main potential sources of uncertainty: (1) uncertainty resulting from the way the EIM is designed, particularly from the use of a partial equilibrium model; (2) uncertainty resulting from the values for key model parameters, particularly the price elasticity of supply and demand; and (3) uncertainty resulting from the values for key model inputs, particularly baseline equilibrium price and quantities. Sources of uncertainty that have a bearing on the results of the EIA for the proposed program are listed and described in more detail in Table 9.4-1.

The values used for the price elasticities of supply and demand are critical parameters in the EIM. The values of these parameters have an impact on both the estimated change in price and quantity produced expected as a result of compliance with the proposed standards and on how the burden of the social costs will be shared among producer and consumer groups. In selecting the values to use in the EIM it is important that they reflect the behavioral responses of the industries under analysis.

The first source of values for elasticities of supply and demand is the published economic literature. These estimates are peer reviewed and generally constitute reasonable estimates for the industries in question. In this analysis, because we were unable to find published supply and demand elasticities for the Small SI and Marine SI markets, we estimated these parameters econometrically using the procedures described in Appendix 9E.

The estimates of supply elasticities reflect a production function approach using data at the aggregate industry level. This method was chosen because of limitations with the available data: we were not able to obtain firm-level or plant-level production data for companies that operate in the affected sectors. However, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To address these concerns, EPA intends to investigate estimates for the price elasticity of supply for the affected industries for which published estimates are not available, using alternative methods and data inputs. This research program will use the cross-sectional data model at either the firm-level or plant level from the U.S. Census Bureau to estimate these elasticities. We plan to use the results of this research provided the results are robust and that they are available in time for the analysis for the final rule.

Table 9 .4-1 Primary Sources of Uncertainty in the Economic Impact Analysis

Source of Uncertainty	Description	Potential Impact
UNCERTAINTIES ASSOCIATED WITH ECONOMIC IMPACT MODEL STRUCTURE		
Partial equilibrium model	The EIM domain is limited to the economic sectors directly affected by the emission control program; impacts on secondary markets are not accounted for. However, such impacts are not expected to be large since directly affected products and services (small SI equipment and marine SI vessels) are mostly used by households and only a very small portion of these engines and equipment are used as production inputs to other industry (e.g., agriculture, manufacturing, construction). In addition, Small SI engines and equipment would not be a large share of total production costs for final goods and services in those commercial markets.	Results understate social costs; magnitude of impact is uncertain.
National level model	The EIM considers only national-level impacts; regional impacts are not modeled. This is appropriate because Small SI engine and equipment or Marine SI engine and vessel markets are national markets. While there may be some regional differences these are likely to be small due to the competitive nature of the manufacture industry.	Impacts uncertain
Supply side assumptions	On the supply side, industries are assumed to be mature and behave linearly within the range of analysis; no substitution between production inputs. This is appropriate because per unit compliance costs are not large enough to prompt a major change in product design or assembly.	Impacts uncertain
Demand side assumption	On the demand side, end consumer's preferences or consumption patterns are assumed to be constant and behave linearly within the range of analysis. This is appropriate because all other factors in the demand function will not be changed by the proposed rule.	Impacts uncertain
Constant price assumption	Prices are assumed to be constant across the period of analysis. This is a reasonable assumption since it is not possible to predict changes in these prices over time (see Appendix G).	Impacts uncertain
Period of analysis	Each period of analysis is assumed to be independent of previous period and producers are assumed to not engage in long-term planning to smooth the compliance costs over a longer period of time. Because the new exhaust standards will not go into effect for several years after the program is finalized, producers may in fact take the full program into account in production plans to minimize their costs.	Estimated price changes may be too high for early periods, too low for later periods; magnitude of impact is uncertain

Market shock	In the EIM, the market is shocked by the full compliance costs, including variable and fixed costs. This is appropriate because producers in these industries may not engage in R&D on a continuous basis and thus the product changes that would be required to comply with the proposed standards would require manufacturers to devote new funds and resources to product redesign. A sensitivity analysis performed that excludes fixed costs in supply shift.	Results may overstate distribution of social costs to some producers, understate market impacts; magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH PRICE ELASTICITY ESTIMATION		
	Uncertainty resulting from the functional form used in the estimation, the data used (aggregate or firm-level), the time period involved, sample size.	Impacts on distribution of social costs among stakeholders (e.g., higher supply elasticity would result in less social costs for manufacturers and more social costs for consumers) Impacts on market analysis (change in price, change in quantity produced) Magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH DATA INPUTS		
Submarket groupings	Submarket data is assumed to be representative and capture the range of affected equipment. However, the product groupings in NAICS or SIC 4-digit categories may include other engines or equipment that may not have the same production or consumption characteristics; these groupings not behave the same way as the directly-affected industries.	Impacts on social welfare and market analyses uncertain
Baseline equilibrium prices	Estimated baseline equilibrium prices are assumed to be representative and capture the range of affected equipment, and reflect actual transaction prices. However, the actual prices paid by consumers may be different. Also, the mix of products included in price analysis may not be representative of the population.	Impacts on market analysis uncertain
Baseline equilibrium quantities	Estimated baseline equilibrium quantities and future quantities assumed to be representative; these are the same as the cost analysis.	Impacts on market analysis uncertain

To explore the effects of key sources of uncertainty, we performed a sensitivity analysis in which we examine the results of using alternative values for the price elasticity of supply and demand (using the upper and lower bound of at 95 percent confidence interval around the point estimate for each elasticity estimate), alternative methods to shock to the market equilibrium (using variable costs only) and alternative baseline equilibrium prices for lawnmowers and tractors. The results of these analyses are contained in Appendix 9H. A summary of the results are presented in Table 9.4-2.

Table 9.4-2. Results of Sensitivity Analysis

Parameter	Year	Change in Value	Impact
Price Elasticity of Supply	2013	More elastic (upper bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 0.2 additional increase in price increase compared to primary analysis; less than 0.2 additional increase in quantity decrease compared to primary analysis) More elasticity price elasticity of supply associated with increase in social cost burden for users of Small SI and Marine SI engines and equipment (shift of about 1.4 percent of burden of compliance costs from producers to consumers in Marine SI market; shift of about 2.0 percent of burden of compliance costs from producers to consumers in Small SI market)
	2013	Less Elastic (lower bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 0.1 additional increase in price increase compared to primary analysis; less than 0.2 percent additional increase in quantity decrease compared to primary analysis) Higher value associated with increase in social cost burden for producers of Small SI and Marine SI engines and equipment (shift of about 1.3 percent of burden of compliance costs from consumers to producers in Marine SI market; shift of about 1.9 percent of burden of compliance costs from consumers to producers in Small SI market)
Price Elasticity of Demand	2013	More Elastic (upper bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 1.0 percent additional increase in price increase compared to primary analysis; less than 1.5 additional increase in quantity decrease, compared to primary analysis) More elastic price elasticity of demand associated with increase in social cost burden for producers of Small SI and Marine SI engines and equipment (shift of about 11 percent of burden of compliance costs from consumers to producers in Marine SI market; shift of about 10 percent of burden of compliance costs from consumers to producers in Small SI market)

	2013	Less Elastic (lower bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 2.0 percent additional increase in price increase compared to primary analysis; less than 2.5 additional increase in quantity decrease, compared to primary analysis) Less elastic price elasticity of demand associated with increase in social cost burden for users of Small SI and Marine SI engines and equipment (shift of about 30.5 percent of burden of compliance costs from producers to consumers in Marine SI market; shift of about 14.5 percent of burden of compliance costs from producers to consumers in Small SI market)
Market Supply Shift	2013	Include only variable costs	Smaller projected price increases and quantity decreases (less than 1.5 percent additional increase in price compared to primary analysis; less than 1.0 percent additional increase in quantity decrease, compared to primary analysis) Engine and equipment manufacturers expected to bear larger share of total compliance costs (shift of about 3.1 percent of burden of compliance costs from consumers to producers in Marine SI market; shift of about 16.2 percent of burden of compliance costs from consumers to producers in Small SI market)
Alternative Baseline Equilibrium Price - Lawnmowers and Tractors	2013	Lower baseline equilibrium price	Larger percent increase in price and percent decrease in quantity, although absolute changes are smaller (about 2 percent additional price increase for both sectors compared to primary analysis; about 0.4 percent additional quantity decrease for lawn mowers and about 1.9 percent additional quantity decrease for tractors compared to primary analysis) Social welfare impacts unchanged.

Chapter 9 References

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Appendix 9A: Impacts on Small SI Markets

This appendix provides the time series of impacts from 2008 through 2038 for the following Small SI engines and equipment markets; a complete set of results for all markets can be found in the docket for this rule (Li, 2007). Results are presented for equipment in the Class I UL125 and Class II UL250 categories because those are the categories with the highest sales.

- Class I engines
- Class II engines
- Agriculture/construcion/general industrial, UL125 and UL250
- Utility and recreational vehicles, UL125 and UL250
- Lawn mowers, UL125
- Tractors, UL250
- Lawn and garden other, UL125 and UL250
- Gensets/welders, UL125 and 250
- Pumps/compressors, pressure washers, UL125 and UL250
- Snowblowers, UL125 and UL250

Table 9A-1 through Table 9A-17 provide the time series of impacts for each engine class market and each selected equipment market, respectively, includes the following:

- average engine or equipment price
- average engineering costs (variable and fixed) per engine or equipment
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs associated with each engine or equipment market
- changes in producer surplus associated with each engine or equipment market

All prices and costs are presented in 2005 dollars and real engine or equipment prices are assumed to be constant during the period of analysis. Net present values were estimated using social discount rates of 3 percent and 7 percent over the period of analysis.

Table 9A-1: Impact on Small SI Engine Market
Class I (Average Price per Engine = $130)[a]

	Small SI Engine (Class I)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.3%	0.0%	$0.0	–$0.2
2009	$0	$0	0.3%	0.0%	$3.6	–$0.2
2010	$0	$0	0.3%	0.0%	$3.7	–$0.2
2011	$0	$0	0.3%	0.0%	$3.7	–$0.2
2012	$15	$14	10.9%	–2.0%	$161.9	–$7.3
2013	$15	$14	10.7%	–2.0%	$162.8	–$7.4
2014	$15	$14	10.7%	–2.0%	$165.4	–$7.5
2015	$15	$14	10.7%	–2.0%	$167.8	–$7.6
2016	$15	$14	10.7%	–2.0%	$170.2	–$7.7
2017	$12	$11	8.6%	–1.6%	$139.0	–$6.3
2018	$12	$11	8.6%	–1.6%	$141.2	–$6.4
2019	$12	$11	8.6%	–1.6%	$143.4	–$6.5
2020	$12	$11	8.6%	–1.6%	$145.6	–$6.6
2021	$12	$11	8.6%	–1.6%	$147.7	–$6.7
2022	$12	$11	8.6%	–1.6%	$149.9	–$6.8
2023	$12	$11	8.6%	–1.6%	$152.1	–$6.9
2024	$12	$11	8.6%	–1.6%	$154.3	–$7.0
2025	$12	$11	8.6%	–1.6%	$156.5	–$7.1
2026	$12	$11	8.6%	–1.6%	$158.7	–$7.2
2027	$12	$11	8.6%	–1.6%	$160.9	–$7.3
2028	$12	$11	8.6%	–1.6%	$163.1	–$7.4
2029	$12	$11	8.6%	–1.6%	$165.3	–$7.5
2030	$12	$11	8.6%	–1.6%	$167.5	–$7.6
2031	$12	$11	8.6%	–1.6%	$169.7	–$7.7
2032	$12	$11	8.6%	–1.6%	$171.9	–$7.8
2033	$12	$11	8.6%	–1.6%	$174.1	–$7.9
2034	$12	$11	8.6%	–1.6%	$176.3	–$7.9
2035	$12	$11	8.6%	–1.6%	$178.5	–$8.1
2036	$12	$11	8.6%	–1.6%	$180.7	–$8.2
2037	$12	$11	8.6%	–1.6%	$182.9	–$8.3
2038	$12	$11	8.6%	–1.6%	$185.2	–$8.4
NPV (3%)					$2,630.8	–$119.5
NPV (7%)					$1,466.2	–$66.7

[a] Figures are in 2005 dollars.

Table 9A-2. Impact on Small SI Engine Market
Class II (Average Price per Engine = $290)[a]

	Small SI Engine (Class II)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers Surplus (million $)
2008	$0	$0	0.0%	–0.1%	$0.0	–$0.2
2009	$0	$0	0.0%	–0.1%	$0.0	–$0.2
2010	$0	$0	0.0%	–0.1%	$0.0	–$0.2
2011	$42	$40	14.0%	–3.1%	$202.2	–$10.8
2012	$42	$40	13.9%	–3.1%	$205.2	–$10.9
2013	$42	$40	13.9%	–3.1%	$208.3	–$11.0
2014	$42	$40	13.9%	–3.0%	$211.3	–$11.2
2015	$42	$40	13.8%	–3.0%	$214.3	–$11.3
2016	$29	$28	10.1%	–2.0%	$152.7	–$7.3
2017	$29	$28	10.1%	–2.0%	$155.1	–$7.4
2018	$29	$28	10.1%	–2.0%	$157.6	–$7.5
2019	$29	$28	10.1%	–2.0%	$160.1	–$7.6
2020	$29	$28	10.1%	–2.0%	$162.5	–$7.8
2021	$29	$28	10.1%	–2.0%	$165.0	–$7.9
2022	$29	$28	10.1%	–2.0%	$167.4	–$8.0
2023	$29	$28	10.1%	–2.0%	$169.9	–$8.1
2024	$29	$28	10.1%	–2.0%	$172.4	–$8.2
2025	$29	$28	10.1%	–2.0%	$174.8	–$8.3
2026	$29	$28	10.1%	–2.0%	$177.3	–$8.5
2027	$29	$28	10.1%	–2.0%	$179.8	–$8.6
2028	$29	$28	10.1%	–2.0%	$182.3	–$8.7
2029	$29	$28	10.1%	–2.0%	$184.7	–$8.8
2030	$29	$28	10.1%	–2.0%	$187.2	–$8.9
2031	$29	$28	10.1%	–2.0%	$189.7	–$9.1
2032	$29	$28	10.1%	–2.0%	$192.2	–$9.2
2033	$29	$28	10.1%	–2.0%	$194.7	–$9.3
2034	$29	$28	10.1%	–2.0%	$197.1	–$9.4
2035	$29	$28	10.1%	–2.0%	$199.6	–$9.5
2036	$29	$28	10.1%	–2.0%	$202.1	–$9.7
2037	$29	$28	10.1%	–2.0%	$204.6	–$9.8
2038	$29	$28	10.1%	–2.0%	$207.0	–$9.9
NPV (3%)					$3,164.8	–$156.3
NPV (7%)					$1,828.9	–$91.5

[a] Figures are in 2005 dollars.

Table 9A-3: Impact on Small SI Equipment Market
Handheld (Average Price per Equipment = $87)[a,b]

	Small SI Equipment (Handheld)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$0	$0	0.0%	0.0%	$0.0	$0.0
2010	$1	$1	0.6%	–1.1%	$7.3	–$2.6
2011	$1	$1	0.6%	–1.1%	$7.4	–$2.6
2012	$1	$1	0.6%	–1.1%	$7.5	–$2.7
2013	$1	$1	0.6%	–1.1%	$7.7	–$2.7
2014	$1	$1	0.6%	–1.1%	$7.8	–$2.8
2015	$1	$0	0.5%	–1.0%	$6.7	–$2.4
2016	$1	$0	0.5%	–1.0%	$6.8	–$2.4
2017	$1	$0	0.5%	–1.0%	$6.9	–$2.5
2018	$1	$0	0.5%	–1.0%	$7.0	–$2.5
2019	$1	$0	0.5%	–1.0%	$7.1	–$2.6
2020	$1	$0	0.5%	–1.0%	$7.2	–$2.6
2021	$1	$0	0.5%	–1.0%	$7.4	–$2.6
2022	$1	$0	0.5%	–1.0%	$7.5	–$2.7
2023	$1	$0	0.5%	–1.0%	$7.6	–$2.7
2024	$1	$0	0.5%	–1.0%	$7.7	–$2.7
2025	$1	$0	0.5%	–1.0%	$7.8	–$2.8
2026	$1	$0	0.5%	–1.0%	$7.9	–$2.8
2027	$1	$0	0.5%	–1.0%	$8.0	–$2.9
2028	$1	$0	0.5%	–1.0%	$8.1	–$2.9
2029	$1	$0	0.5%	–1.0%	$8.2	–$2.9
2030	$1	$0	0.5%	–1.0%	$8.3	–$3.0
2031	$1	$0	0.5%	–1.0%	$8.4	–$3.0
2032	$1	$0	0.5%	–1.0%	$8.5	–$3.1
2033	$1	$0	0.5%	–1.0%	$8.7	–$3.1
2034	$1	$0	0.5%	–1.0%	$8.8	–$3.1
2035	$1	$0	0.5%	–1.0%	$8.9	–$3.2
2036	$1	$0	0.5%	–1.0%	$9.0	–$3.2
2037	$1	$0	0.5%	–1.0%	$9.1	–$3.2
2038	$1	$0	0.5%	–1.0%	$9.2	–$3.3
NPV (3%)					$139.9	–$49.9
NPV (7%)					$81.3	–$29.0

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-4: Impact on Small SI Equipment Market: Class I Ag/Constr./Gen. Ind/ Material Handling Equipment UL 125 (Average Price per Equipment = $1,108)[a,b]

	Class 1 Agricultural/Construction/General Industrial/ Material Handling Equipment UL 125					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$0	$0	0.0%	0.0%	$0.0	$0.0
2010	$0	$0	0.0%	0.0%	$0.0	$0.0
2011	$0	$0	0.0%	0.0%	$0.0	$0.0
2012	$0	$12	1.1%	–1.1%	$0.0	–$0.3
2013	$0	$12	1.1%	–1.1%	$0.0	–$0.3
2014	$0	$12	1.1%	–1.1%	$0.0	–$0.3
2015	$0	$12	1.1%	–1.1%	$0.0	–$0.3
2016	$0	$12	1.1%	–1.1%	$0.0	–$0.3
2017	$0	$9	0.8%	–0.8%	$0.0	–$0.2
2018	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2019	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2020	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2021	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2022	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2023	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2024	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2025	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2026	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2027	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2028	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2029	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2030	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2031	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2032	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2033	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2034	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2035	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2036	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2037	$0	$9	0.8%	–0.8%	$0.0	–$0.3
2038	$0	$9	0.8%	–0.8%	$0.0	–$0.3
NPV (3%)					$0.0	–$4.8
NPV (7%)					$0.0	–$2.7

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-5: Impact on Small SI Equipment Market: Class I Utility and Recreational Vehicles UL 125 (Average Price per Equipment = $570)[a,b]

	Small SI Equipment (Class I Utility and Recreational Vehicles UL 125)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$0	$0	0.0%	0.0%	$0.0	$0.0
2010	$0	$0	0.0%	0.0%	$0.0	$0.0
2011	$0	$0	0.0%	0.0%	$0.0	$0.0
2012	$0	$12	2.1%	–2.1%	$0.0	–$0.3
2013	$0	$12	2.0%	–2.0%	$0.0	–$0.3
2014	$0	$12	2.0%	–2.0%	$0.0	–$0.3
2015	$0	$12	2.0%	–2.0%	$0.0	–$0.3
2016	$0	$12	2.0%	–2.0%	$0.0	–$0.3
2017	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2018	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2019	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2020	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2021	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2022	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2023	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2024	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2025	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2026	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2027	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2028	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2029	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2030	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2031	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2032	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2033	$0	$9	1.6%	–1.6%	$0.0	–$0.3
2034	$0	$9	1.6%	–1.6%	$0.0	–$0.4
2035	$0	$9	1.6%	–1.6%	$0.0	–$0.4
2036	$0	$9	1.6%	–1.6%	$0.0	–$0.4
2037	$0	$9	1.6%	–1.6%	$0.0	–$0.4
2038	$0	$9	1.6%	–1.6%	$0.0	–$0.4
NPV (3%)					$0.0	–$5.1
NPV (7%)					$0.0	–$2.8

[a] Figures are in 2005 dollars.
[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-6: Impact on Small SI Equipment Market: Class I Lawn Mowers UL 125 (Average Price per Equipment = $218)[a,b]

Year	Small SI Equipment (Class I Lawn Mowers UL 125) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.1%	0.0%	$0.0	–$0.1
2009	$0	$0	0.1%	0.0%	$0.0	–$0.1
2010	$0	$0	0.1%	0.0%	$0.0	–$0.1
2011	$0	$0	0.1%	0.0%	$0.0	–$0.1
2012	$0	$14	6.6%	–1.3%	$0.0	–$5.4
2013	$0	$14	6.6%	–1.2%	$0.0	–$5.4
2014	$0	$14	6.6%	–1.2%	$0.0	–$5.5
2015	$0	$14	6.6%	–1.2%	$0.0	–$5.6
2016	$0	$14	6.5%	–1.2%	$0.0	–$5.7
2017	$0	$11	5.2%	–1.0%	$0.0	–$4.6
2018	$0	$11	5.2%	–1.0%	$0.0	–$4.7
2019	$0	$11	5.2%	–1.0%	$0.0	–$4.8
2020	$0	$11	5.2%	–1.0%	$0.0	–$4.8
2021	$0	$11	5.2%	–1.0%	$0.0	–$4.9
2022	$0	$11	5.2%	–1.0%	$0.0	–$5.0
2023	$0	$11	5.2%	–1.0%	$0.0	–$5.1
2024	$0	$11	5.2%	–1.0%	$0.0	–$5.1
2025	$0	$11	5.2%	–1.0%	$0.0	–$5.2
2026	$0	$11	5.2%	–1.0%	$0.0	–$5.3
2027	$0	$11	5.2%	–1.0%	$0.0	–$5.4
2028	$0	$11	5.2%	–1.0%	$0.0	–$5.4
2029	$0	$11	5.2%	–1.0%	$0.0	–$5.5
2030	$0	$11	5.2%	–1.0%	$0.0	–$5.6
2031	$0	$11	5.2%	–1.0%	$0.0	–$5.6
2032	$0	$11	5.2%	–1.0%	$0.0	–$5.7
2033	$0	$11	5.2%	–1.0%	$0.0	–$5.8
2034	$0	$11	5.2%	–1.0%	$0.0	–$5.9
2035	$0	$11	5.2%	–1.0%	$0.0	–$5.9
2036	$0	$11	5.2%	–1.0%	$0.0	–$6.0
2037	$0	$11	5.2%	–1.0%	$0.0	–$6.1
2038	$0	$11	5.2%	–1.0%	$0.0	–$6.2
NPV (3%)					$0.0	–$87.6
NPV (7%)					$0.0	–$48.8

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-7: Impact on Small SI Equipment Market: Class I Other Lawn and Garden Equipment UL 125 (Average Price per Equipment = $245)[a,b]

	Small SI Equipment (Class I Other Lawn and Garden Equipment UL 125)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2009	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2010	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2011	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2012	$0	$12	4.9%	–4.4%	$0.0	–$2.3
2013	$0	$12	4.9%	–4.4%	$0.0	–$2.3
2014	$0	$12	4.9%	–4.4%	$0.0	–$2.4
2015	$0	$12	4.9%	–4.4%	$0.0	–$2.4
2016	$0	$12	4.9%	–4.4%	$0.0	–$2.4
2017	$0	$10	3.9%	–3.5%	$0.0	–$2.0
2018	$0	$10	3.9%	–3.5%	$0.0	–$2.0
2019	$0	$10	3.9%	–3.5%	$0.0	–$2.0
2020	$0	$10	3.9%	–3.5%	$0.0	–$2.1
2021	$0	$10	3.9%	–3.5%	$0.0	–$2.1
2022	$0	$10	3.9%	–3.5%	$0.0	–$2.1
2023	$0	$10	3.9%	–3.5%	$0.0	–$2.2
2024	$0	$10	3.9%	–3.5%	$0.0	–$2.2
2025	$0	$10	3.9%	–3.5%	$0.0	–$2.2
2026	$0	$10	3.9%	–3.5%	$0.0	–$2.3
2027	$0	$10	3.9%	–3.5%	$0.0	–$2.3
2028	$0	$10	3.9%	–3.5%	$0.0	–$2.3
2029	$0	$10	3.9%	–3.5%	$0.0	–$2.4
2030	$0	$10	3.9%	–3.5%	$0.0	–$2.4
2031	$0	$10	3.9%	–3.5%	$0.0	–$2.4
2032	$0	$10	3.9%	–3.5%	$0.0	–$2.5
2033	$0	$10	3.9%	–3.5%	$0.0	–$2.5
2034	$0	$10	3.9%	–3.5%	$0.0	–$2.5
2035	$0	$10	3.9%	–3.5%	$0.0	–$2.5
2036	$0	$10	3.9%	–3.5%	$0.0	–$2.6
2037	$0	$10	3.9%	–3.5%	$0.0	–$2.6
2038	$0	$10	3.9%	–3.5%	$0.0	–$2.6
NPV (3%)					$0.0	–$37.7
NPV (7%)					$0.0	–$21.1

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-8: Impact on Small SI Equipment Market: Class I Gensets/Welders UL 125 (Average Price per Equipment = $999)[a,b]

Year	Small SI Equipment (Class I Gensets/Welders UL 125) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$0	$0	0.0%	0.0%	$0.0	$0.0
2010	$0	$0	0.0%	0.0%	$0.0	$0.0
2011	$0	$0	0.0%	0.0%	$0.0	$0.0
2012	$0	$11	1.1%	–1.5%	$0.0	–$1.4
2013	$0	$11	1.1%	–1.5%	$0.0	–$1.4
2014	$0	$11	1.1%	–1.5%	$0.0	–$1.4
2015	$0	$11	1.1%	–1.5%	$0.0	–$1.4
2016	$0	$11	1.1%	–1.5%	$0.0	–$1.4
2017	$0	$9	0.9%	–1.2%	$0.0	–$1.2
2018	$0	$9	0.9%	–1.2%	$0.0	–$1.2
2019	$0	$9	0.9%	–1.2%	$0.0	–$1.2
2020	$0	$9	0.9%	–1.2%	$0.0	–$1.2
2021	$0	$9	0.9%	–1.2%	$0.0	–$1.2
2022	$0	$9	0.9%	–1.2%	$0.0	–$1.3
2023	$0	$9	0.9%	–1.2%	$0.0	–$1.3
2024	$0	$9	0.9%	–1.2%	$0.0	–$1.3
2025	$0	$9	0.9%	–1.2%	$0.0	–$1.3
2026	$0	$9	0.9%	–1.2%	$0.0	–$1.3
2027	$0	$9	0.9%	–1.2%	$0.0	–$1.4
2028	$0	$9	0.9%	–1.2%	$0.0	–$1.4
2029	$0	$9	0.9%	–1.2%	$0.0	–$1.4
2030	$0	$9	0.9%	–1.2%	$0.0	–$1.4
2031	$0	$9	0.9%	–1.2%	$0.0	–$1.4
2032	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2033	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2034	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2035	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2036	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2037	$0	$9	0.9%	–1.2%	$0.0	–$1.5
2038	$0	$9	0.9%	–1.2%	$0.0	–$1.6
NPV (3%)					$0.0	–$22.1
NPV (7%)					$0.0	–$12.3

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-9: Impact on Small SI Equipment Market: Class I Pumps/Compressors/Pressure Washers UL 125 (Average Price per Equipment = $96)[a,b]

	Small SI Equipment (Class I Pumps/Compressors/Pressure Washers UL 125)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.3%	–0.3%	$0.0	–$0.1
2009	$0	$0	0.3%	–0.3%	$0.0	–$0.1
2010	$0	$0	0.3%	–0.3%	$0.0	–$0.1
2011	$0	$0	0.3%	–0.3%	$0.0	–$0.1
2012	$0	$12	12.3%	–12.3%	$0.0	–$2.2
2013	$0	$12	12.2%	–12.2%	$0.0	–$2.2
2014	$0	$12	12.2%	–12.2%	$0.0	–$2.2
2015	$0	$12	12.1%	–12.1%	$0.0	–$2.2
2016	$0	$12	12.1%	–12.1%	$0.0	–$2.3
2017	$0	$9	9.7%	–9.7%	$0.0	–$1.9
2018	$0	$9	9.7%	–9.7%	$0.0	–$1.9
2019	$0	$9	9.7%	–9.7%	$0.0	–$1.9
2020	$0	$9	9.7%	–9.7%	$0.0	–$2.0
2021	$0	$9	9.7%	–9.7%	$0.0	–$2.0
2022	$0	$9	9.7%	–9.7%	$0.0	–$2.0
2023	$0	$9	9.7%	–9.7%	$0.0	–$2.0
2024	$0	$9	9.7%	–9.7%	$0.0	–$2.1
2025	$0	$9	9.7%	–9.7%	$0.0	–$2.1
2026	$0	$9	9.7%	–9.7%	$0.0	–$2.1
2027	$0	$9	9.7%	–9.7%	$0.0	–$2.2
2028	$0	$9	9.7%	–9.7%	$0.0	–$2.2
2029	$0	$9	9.7%	–9.7%	$0.0	–$2.2
2030	$0	$9	9.7%	–9.7%	$0.0	–$2.3
2031	$0	$9	9.7%	–9.7%	$0.0	–$2.3
2032	$0	$9	9.7%	–9.7%	$0.0	–$2.3
2033	$0	$9	9.7%	–9.7%	$0.0	–$2.3
2034	$0	$9	9.7%	–9.7%	$0.0	–$2.4
2035	$0	$9	9.7%	–9.7%	$0.0	–$2.4
2036	$0	$9	9.7%	–9.7%	$0.0	–$2.4
2037	$0	$9	9.7%	–9.7%	$0.0	–$2.5
2038	$0	$9	9.7%	–9.7%	$0.0	–$2.5
NPV (3%)					$0.0	–$35.6
NPV (7%)					$0.0	–$19.9

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-10: Impact on Small SI Equipment Market: Class I Snowblowers UL 125 (Average Price per Equipment = $324)[a,b]

	Small SI Equipment (Class I Snowblowers UL 125)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$0	0.1%	–0.1%	$0.0	$0.0
2009	$0	$0	0.1%	–0.1%	$0.0	$0.0
2010	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2011	$0	$0	0.1%	–0.1%	$0.0	–$0.1
2012	$0	$2	0.7%	–0.7%	$0.0	–$0.4
2013	$0	$2	0.7%	–0.7%	$0.0	–$0.4
2014	$0	$2	0.7%	–0.7%	$0.0	–$0.4
2015	$0	$2	0.7%	–0.7%	$0.0	–$0.4
2016	$0	$2	0.7%	–0.7%	$0.0	–$0.4
2017	$0	$2	0.5%	–0.5%	$0.0	–$0.3
2018	$0	$2	0.5%	–0.5%	$0.0	–$0.3
2019	$0	$2	0.5%	–0.5%	$0.0	–$0.3
2020	$0	$2	0.5%	–0.5%	$0.0	–$0.3
2021	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2022	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2023	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2024	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2025	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2026	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2027	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2028	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2029	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2030	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2031	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2032	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2033	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2034	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2035	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2036	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2037	$0	$2	0.5%	–0.5%	$0.0	–$0.4
2038	$0	$2	0.5%	–0.5%	$0.0	–$0.4
NPV (3%)					$0.0	–$6.4
NPV (7%)					$0.0	–$3.6

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-11: Impact on Small SI Equipment Market: Class II Agri/Constr./G. Ind/ Material Handling Equipment UL 250 (Average Price per Equipment = $1,825)[a,b]

	Small SI Equipment (Class II Agricultural/Construction /General Industrial/ Material Handling Equipment UL 250)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$1	0.0%	0.0%	$0.0	$0.0
2009	$1	$1	0.0%	0.0%	$0.1	$0.0
2010	$1	$1	0.0%	0.0%	$0.1	$0.0
2011	$12	$35	1.9%	–1.9%	$0.9	–$0.8
2012	$11	$35	1.9%	–1.9%	$0.9	–$0.8
2013	$11	$35	1.9%	–1.9%	$0.9	–$0.9
2014	$11	$35	1.9%	–1.9%	$0.9	–$0.9
2015	$11	$35	1.9%	–1.9%	$0.9	–$0.9
2016	$6	$25	1.3%	–1.3%	$0.5	–$0.6
2017	$6	$25	1.3%	–1.3%	$0.5	–$0.6
2018	$6	$25	1.3%	–1.3%	$0.5	–$0.6
2019	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2020	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2021	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2022	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2023	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2024	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2025	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2026	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2027	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2028	$6	$25	1.3%	–1.3%	$0.6	–$0.7
2029	$6	$25	1.3%	–1.3%	$0.6	–$0.8
2030	$6	$25	1.3%	–1.3%	$0.6	–$0.8
2031	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2032	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2033	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2034	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2035	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2036	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2037	$6	$25	1.3%	–1.3%	$0.7	–$0.8
2038	$6	$25	1.3%	–1.3%	$0.7	–$0.8
NPV (3%)					$11.9	–$12.9
NPV (7%)					$7.1	–$7.6

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-12: Impact on Small SI Equipment Market: Class II Utility and Recreational Vehicle UL 250 (Average Price per Equipment = $2,894)[a,b]

Year	Small SI Equipment (Class II Utility and Recreational Vehicle UL 250) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$1	0.0%	0.0%	$0.0	–$0.1
2009	$1	$1	0.0%	0.0%	$0.2	–$0.1
2010	$1	$1	0.0%	0.0%	$0.2	–$0.1
2011	$12	$35	1.2%	–1.2%	$2.2	–$2.0
2012	$11	$35	1.2%	–1.2%	$2.3	–$2.0
2013	$11	$35	1.2%	–1.2%	$2.3	–$2.1
2014	$11	$35	1.2%	–1.2%	$2.3	–$2.1
2015	$11	$35	1.2%	–1.2%	$2.3	–$2.1
2016	$6	$25	0.8%	–0.8%	$1.3	–$1.5
2017	$6	$25	0.8%	–0.8%	$1.3	–$1.5
2018	$6	$25	0.8%	–0.8%	$1.3	–$1.6
2019	$6	$25	0.8%	–0.8%	$1.3	–$1.6
2020	$6	$25	0.8%	–0.8%	$1.4	–$1.6
2021	$6	$25	0.8%	–0.8%	$1.4	–$1.6
2022	$6	$25	0.8%	–0.8%	$1.4	–$1.7
2023	$6	$25	0.8%	–0.8%	$1.4	–$1.7
2024	$6	$25	0.8%	–0.8%	$1.5	–$1.7
2025	$6	$25	0.8%	–0.8%	$1.5	–$1.7
2026	$6	$25	0.8%	–0.8%	$1.5	–$1.8
2027	$6	$25	0.8%	–0.8%	$1.5	–$1.8
2028	$6	$25	0.8%	–0.8%	$1.5	–$1.8
2029	$6	$25	0.8%	–0.8%	$1.6	–$1.8
2030	$6	$25	0.8%	–0.8%	$1.6	–$1.9
2031	$6	$25	0.8%	–0.8%	$1.6	–$1.9
2032	$6	$25	0.8%	–0.8%	$1.6	–$1.9
2033	$6	$25	0.8%	–0.8%	$1.6	–$1.9
2034	$6	$25	0.8%	–0.8%	$1.7	–$2.0
2035	$6	$25	0.8%	–0.8%	$1.7	–$2.0
2036	$6	$25	0.8%	–0.8%	$1.7	–$2.0
2037	$6	$25	0.8%	–0.8%	$1.7	–$2.0
2038	$6	$25	0.8%	–0.8%	$1.7	–$2.1
NPV (3%)					$29.2	–$31.7
NPV (7%)					$17.5	–$18.4

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-13: Impact on Small SI Equipment Market: Class II Tractors UL 250 (Average Price per Equipment = $1,937)[a,b]

	Small SI Equipment (Class II Tractors UL 250)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$1	0.0%	0.0%	$0.0	–$0.4
2009	$1	$1	0.0%	0.0%	$2.1	–$0.5
2010	$1	$1	0.0%	0.0%	$2.1	–$0.5
2011	$12	$35	1.8%	–1.8%	$22.0	–$19.7
2012	$11	$35	1.8%	–1.8%	$22.2	–$19.9
2013	$11	$35	1.8%	–1.8%	$22.1	–$20.2
2014	$11	$35	1.8%	–1.8%	$22.4	–$20.5
2015	$11	$35	1.8%	–1.8%	$22.6	–$20.7
2016	$6	$25	1.3%	–1.3%	$12.6	–$14.8
2017	$6	$25	1.3%	–1.3%	$12.8	–$15.1
2018	$6	$25	1.3%	–1.3%	$13.0	–$15.3
2019	$6	$25	1.3%	–1.3%	$13.2	–$15.5
2020	$6	$25	1.3%	–1.3%	$13.4	–$15.8
2021	$6	$25	1.3%	–1.3%	$13.6	–$16.0
2022	$6	$25	1.3%	–1.3%	$13.8	–$16.3
2023	$6	$25	1.3%	–1.3%	$14.0	–$16.5
2024	$6	$25	1.3%	–1.3%	$14.2	–$16.7
2025	$6	$25	1.3%	–1.3%	$14.4	–$17.0
2026	$6	$25	1.3%	–1.3%	$14.6	–$17.2
2027	$6	$25	1.3%	–1.3%	$14.8	–$17.5
2028	$6	$25	1.3%	–1.3%	$15.0	–$17.7
2029	$6	$25	1.3%	–1.3%	$15.2	–$17.9
2030	$6	$25	1.3%	–1.3%	$15.4	–$18.2
2031	$6	$25	1.3%	–1.3%	$15.6	–$18.4
2032	$6	$25	1.3%	–1.3%	$15.8	–$18.7
2033	$6	$25	1.3%	–1.3%	$16.0	–$18.9
2034	$6	$25	1.3%	–1.3%	$16.2	–$19.1
2035	$6	$25	1.3%	–1.3%	$16.4	–$19.4
2036	$6	$25	1.3%	–1.3%	$16.6	–$19.6
2037	$6	$25	1.3%	–1.3%	$16.8	–$19.9
2038	$6	$25	1.3%	–1.3%	$17.0	–$20.1
NPV (3%)					$285.9	–$308.5
NPV (7%)					$171.3	–$178.8

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-14: Impact on Small SI Equipment Market: Class II Other Lawn and Garden Equipment UL 250(Average Price per Equipment = $312)[a,b]

	Small SI Equipment (Class II Other Lawn and Garden Equipment UL 250)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$1	0.3%	–0.2%	$0.0	$0.0
2009	$1	$1	0.3%	–0.2%	$0.2	$0.0
2010	$1	$1	0.3%	–0.2%	$0.2	$0.0
2011	$12	$36	11.6%	–10.5%	$1.7	–$1.3
2012	$11	$36	11.6%	–10.4%	$1.7	–$1.3
2013	$11	$36	11.5%	–10.4%	$1.7	–$1.3
2014	$11	$36	11.5%	–10.3%	$1.7	–$1.4
2015	$11	$36	11.5%	–10.3%	$1.7	–$1.4
2016	$6	$25	8.0%	–7.2%	$0.9	–$1.0
2017	$6	$25	8.0%	–7.2%	$1.0	–$1.0
2018	$6	$25	8.0%	–7.2%	$1.0	–$1.0
2019	$6	$25	8.0%	–7.2%	$1.0	–$1.0
2020	$6	$25	8.0%	–7.2%	$1.0	–$1.1
2021	$6	$25	8.0%	–7.2%	$1.0	–$1.1
2022	$6	$25	8.0%	–7.2%	$1.0	–$1.1
2023	$6	$25	8.0%	–7.2%	$1.1	–$1.1
2024	$6	$25	8.0%	–7.2%	$1.1	–$1.1
2025	$6	$25	8.0%	–7.2%	$1.1	–$1.1
2026	$6	$25	8.0%	–7.2%	$1.1	–$1.2
2027	$6	$25	8.0%	–7.2%	$1.1	–$1.2
2028	$6	$25	8.0%	–7.2%	$1.1	–$1.2
2029	$6	$25	8.0%	–7.2%	$1.1	–$1.2
2030	$6	$25	8.0%	–7.2%	$1.2	–$1.2
2031	$6	$25	8.0%	–7.2%	$1.2	–$1.2
2032	$6	$25	8.0%	–7.2%	$1.2	–$1.3
2033	$6	$25	8.0%	–7.2%	$1.2	–$1.3
2034	$6	$25	8.0%	–7.2%	$1.2	–$1.3
2035	$6	$25	8.0%	–7.2%	$1.2	–$1.3
2036	$6	$25	8.0%	–7.2%	$1.3	–$1.3
2037	$6	$25	8.0%	–7.2%	$1.3	–$1.3
2038	$6	$25	8.0%	–7.2%	$1.3	–$1.4
NPV (3%)					$21.7	–$20.6
NPV (7%)					$13.1	–$11.9

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-15: Impact on Small SI Equipment Market: Class II Gensets/Welders UL 250 (Average Price per Equipment = $666)[a,b]

	Small SI Equipment (Class II Gensets/Welders UL 250)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$1	0.1%	–0.1%	$0.0	–$0.2
2009	$1	$1	0.1%	–0.1%	$0.7	–$0.2
2010	$1	$1	0.1%	–0.1%	$0.8	–$0.2
2011	$12	$34	5.2%	–5.7%	$7.8	–$7.5
2012	$11	$34	5.2%	–5.7%	$7.9	–$7.7
2013	$11	$34	5.1%	–5.6%	$7.9	–$7.7
2014	$11	$34	5.1%	–5.6%	$8.0	–$7.9
2015	$11	$34	5.1%	–5.6%	$8.0	–$8.0
2016	$6	$24	3.6%	–3.9%	$4.5	–$5.7
2017	$6	$24	3.6%	–3.9%	$4.5	–$5.8
2018	$6	$24	3.6%	–3.9%	$4.6	–$5.9
2019	$6	$24	3.6%	–3.9%	$4.7	–$6.0
2020	$6	$24	3.6%	–3.9%	$4.8	–$6.1
2021	$6	$24	3.6%	–3.9%	$4.8	–$6.2
2022	$6	$24	3.6%	–3.9%	$4.9	–$6.3
2023	$6	$24	3.6%	–3.9%	$5.0	–$6.4
2024	$6	$24	3.6%	–3.9%	$5.0	–$6.5
2025	$6	$24	3.6%	–3.9%	$5.1	–$6.6
2026	$6	$24	3.6%	–3.9%	$5.2	–$6.6
2027	$6	$24	3.6%	–3.9%	$5.3	–$6.7
2028	$6	$24	3.6%	–3.9%	$5.3	–$6.8
2029	$6	$24	3.6%	–3.9%	$5.4	–$6.9
2030	$6	$24	3.6%	–3.9%	$5.5	–$7.0
2031	$6	$24	3.6%	–3.9%	$5.6	–$7.1
2032	$6	$24	3.6%	–3.9%	$5.6	–$7.2
2033	$6	$24	3.6%	–3.9%	$5.7	–$7.3
2034	$6	$24	3.6%	–3.9%	$5.8	–$7.4
2035	$6	$24	3.6%	–3.9%	$5.8	–$7.5
2036	$6	$24	3.6%	–3.9%	$5.9	–$7.6
2037	$6	$24	3.6%	–3.9%	$6.0	–$7.7
2038	$6	$24	3.6%	–3.9%	$6.1	–$7.8
NPV (3%)					$101.7	–$119.0
NPV (7%)					$60.9	–$68.9

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-16: Impact on Small SI Equipment Market: Class II Pumps/Compressors/ Pressure Washers UL 250 (Average Price per Equipment = $349)[a,b]

	Small SI Equipment (Class II Pumps/Compressors/Pressure Washers UL 250)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$1	0.2%	–0.2%	$0.0	–$0.1
2009	$1	$1	0.2%	–0.2%	$0.3	–$0.1
2010	$1	$1	0.2%	–0.2%	$0.3	–$0.1
2011	$12	$35	10.2%	–10.2%	$3.3	–$2.8
2012	$11	$35	10.1%	–10.1%	$3.3	–$2.9
2013	$11	$35	10.1%	–10.1%	$3.3	–$2.9
2014	$11	$35	10.0%	–10.0%	$3.3	–$2.9
2015	$11	$35	10.0%	–10.0%	$3.4	–$3.0
2016	$6	$25	7.0%	–7.0%	$1.9	–$2.2
2017	$6	$25	7.0%	–7.0%	$1.9	–$2.2
2018	$6	$25	7.0%	–7.0%	$1.9	–$2.2
2019	$6	$25	7.0%	–7.0%	$2.0	–$2.3
2020	$6	$25	7.0%	–7.0%	$2.0	–$2.3
2021	$6	$25	7.0%	–7.0%	$2.0	–$2.3
2022	$6	$25	7.0%	–7.0%	$2.1	–$2.4
2023	$6	$25	7.0%	–7.0%	$2.1	–$2.4
2024	$6	$25	7.0%	–7.0%	$2.1	–$2.4
2025	$6	$25	7.0%	–7.0%	$2.1	–$2.5
2026	$6	$25	7.0%	–7.0%	$2.2	–$2.5
2027	$6	$25	7.0%	–7.0%	$2.2	–$2.5
2028	$6	$25	7.0%	–7.0%	$2.2	–$2.6
2029	$6	$25	7.0%	–7.0%	$2.3	–$2.6
2030	$6	$25	7.0%	–7.0%	$2.3	–$2.6
2031	$6	$25	7.0%	–7.0%	$2.3	–$2.7
2032	$6	$25	7.0%	–7.0%	$2.4	–$2.7
2033	$6	$25	7.0%	–7.0%	$2.4	–$2.7
2034	$6	$25	7.0%	–7.0%	$2.4	–$2.8
2035	$6	$25	7.0%	–7.0%	$2.5	–$2.8
2036	$6	$25	7.0%	–7.0%	$2.5	–$2.8
2037	$6	$25	7.0%	–7.0%	$2.5	–$2.9
2038	$6	$25	7.0%	–7.0%	$2.5	–$2.9
NPV (3%)					$42.6	–$44.8
NPV (7%)					$25.5	–$26.0

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9A-17: Impact on Small SI Equipment Market: Class II Snowblowers UL 250 (Average Price per Equipment = $665)[a,b]

	Small SI Equipment (Class II Snowblowers UL 250)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$1	0.1%	–0.1%	$0.0	–$0.1
2009	$1	$1	0.1%	–0.1%	$0.6	–$0.1
2010	$1	$1	0.1%	–0.1%	$0.6	–$0.1
2011	$7	$5	0.8%	–0.8%	$3.7	–$0.8
2012	$7	$5	0.8%	–0.8%	$3.7	–$0.8
2013	$7	$5	0.8%	–0.8%	$3.7	–$0.8
2014	$7	$5	0.8%	–0.8%	$3.7	–$0.9
2015	$7	$5	0.8%	–0.8%	$3.8	–$0.9
2016	$5	$4	0.6%	–0.6%	$3.0	–$0.7
2017	$5	$4	0.6%	–0.6%	$3.1	–$0.7
2018	$5	$4	0.6%	–0.6%	$3.1	–$0.7
2019	$5	$4	0.6%	–0.6%	$3.2	–$0.7
2020	$5	$4	0.6%	–0.6%	$3.2	–$0.7
2021	$5	$4	0.6%	–0.6%	$3.3	–$0.7
2022	$5	$4	0.6%	–0.6%	$3.3	–$0.8
2023	$5	$4	0.6%	–0.6%	$3.4	–$0.8
2024	$5	$4	0.6%	–0.6%	$3.4	–$0.8
2025	$5	$4	0.6%	–0.6%	$3.5	–$0.8
2026	$5	$4	0.6%	–0.6%	$3.5	–$0.8
2027	$5	$4	0.6%	–0.6%	$3.6	–$0.8
2028	$5	$4	0.6%	–0.6%	$3.6	–$0.8
2029	$5	$4	0.6%	–0.6%	$3.7	–$0.8
2030	$5	$4	0.6%	–0.6%	$3.7	–$0.8
2031	$5	$4	0.6%	–0.6%	$3.8	–$0.9
2032	$5	$4	0.6%	–0.6%	$3.8	–$0.9
2033	$5	$4	0.6%	–0.6%	$3.9	–$0.9
2034	$5	$4	0.6%	–0.6%	$3.9	–$0.9
2035	$5	$4	0.6%	–0.6%	$4.0	–$0.9
2036	$5	$4	0.6%	–0.6%	$4.0	–$0.9
2037	$5	$4	0.6%	–0.6%	$4.0	–$0.9
2038	$5	$4	0.6%	–0.6%	$4.1	–$0.9
NPV (3%)					$62.2	–$14.1
NPV (7%)					$35.9	–$8.2

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Appendix 9B: Impacts on Marine SI Markets

This appendix provides the time series of impacts from 2008 through 2038 for the following Small SI engines and equipment markets; a complete set of results for all markets can be found in the docket for this rule (Li, 2007). For engine markets, Results are presented for the aggregated categories by power. For the vessel markets, results are presented for the categories with the highest sales.

- Marine SI engines: <25 hp; 26-50 hp; 51-100 hp; 101-175 hp; 176-300 hp; >300 hp
- SD/I, 175-300 hp and >300 hp
- OB recreational, 50-100 hp
- OB luxury, 175-300 hp
- PWC 100-175 hp

Table 9B-1 through Table 9A-11 provide the time series of impacts for each engine class market and each selected equipment market, respectively, includes the following:

- average engine or equipment price
- average engineering costs (variable and fixed) per engine or equipment
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs associated with each engine or equipment market
- changes in producer surplus associated with each engine or equipment market

All prices and costs are presented in 2005 dollars and real engine or equipment prices are assumed to be constant during the period of analysis. Net present values were estimated using social discount rates of 3 percent and 7 percent over the period of analysis.

Table 9B-1: Impact on Marine SI Engine Market:
<25hp (Average Price per Engine = $2,500)[a]

	Marine SI Engine (<25hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$74	$50	2.0%	–3.6%	$5.4	–$1.7
2010	$74	$49	1.9%	–3.6%	$5.4	–$1.8
2011	$74	$47	1.9%	–3.9%	$5.5	–$1.9
2012	$74	$47	1.9%	–3.9%	$5.5	–$1.9
2013	$74	$47	1.9%	–3.9%	$5.6	–$2.0
2014	$55	$35	1.4%	–3.1%	$4.2	–$1.5
2015	$55	$35	1.4%	–3.1%	$4.2	–$1.5
2016	$55	$35	1.4%	–3.0%	$4.3	–$1.6
2017	$55	$36	1.4%	–2.9%	$4.3	–$1.5
2018	$55	$36	1.4%	–2.9%	$4.3	–$1.5
2019	$55	$36	1.4%	–2.9%	$4.3	–$1.5
2020	$55	$36	1.4%	–2.9%	$4.4	–$1.5
2021	$55	$36	1.4%	–2.9%	$4.4	–$1.5
2022	$55	$36	1.4%	–2.9%	$4.4	–$1.5
2023	$55	$36	1.4%	–2.9%	$4.5	–$1.6
2024	$55	$34	1.4%	–3.1%	$4.5	–$1.7
2025	$55	$34	1.4%	–3.1%	$4.5	–$1.7
2026	$55	$34	1.4%	–3.1%	$4.6	–$1.7
2027	$55	$34	1.4%	–3.1%	$4.6	–$1.7
2028	$55	$34	1.4%	–3.1%	$4.6	–$1.7
2029	$55	$34	1.4%	–3.1%	$4.6	–$1.7
2030	$55	$34	1.4%	–3.1%	$4.7	–$1.7
2031	$55	$34	1.4%	–3.1%	$4.7	–$1.7
2032	$55	$34	1.4%	–3.1%	$4.7	–$1.8
2033	$55	$34	1.4%	–3.1%	$4.8	–$1.8
2034	$55	$34	1.4%	–3.1%	$4.8	–$1.8
2035	$55	$34	1.4%	–3.1%	$4.8	–$1.8
2036	$55	$34	1.4%	–3.1%	$4.8	–$1.8
2037	$55	$34	1.4%	–3.1%	$4.9	–$1.8
2038	$55	$34	1.4%	–3.1%	$4.9	–$1.8
NPV (3%)					$90.1	–$32.0
NPV (7%)					$55.6	–$19.6

[a] Figures are in 2005 dollars.

Table 9B-2: Impact on Marine SI Engine Market:
26–50hp (Average Price per Engine = $5,700)[a]

	Marine SI Engine (26–50hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$222	$187	3.3%	–2.3%	$12.1	–$1.9
2010	$222	$185	3.3%	–2.4%	$12.2	–$2.0
2011	$222	$185	3.3%	–2.4%	$12.2	–$2.0
2012	$222	$183	3.2%	–2.6%	$12.3	–$2.1
2013	$222	$183	3.2%	–2.6%	$12.4	–$2.1
2014	$173	$142	2.5%	–2.1%	$9.8	–$1.7
2015	$173	$142	2.5%	–2.0%	$9.8	–$1.7
2016	$173	$142	2.5%	–2.0%	$9.9	–$1.7
2017	$173	$142	2.5%	–2.0%	$10.0	–$1.7
2018	$173	$143	2.5%	–2.0%	$10.0	–$1.7
2019	$173	$143	2.5%	–2.0%	$10.1	–$1.7
2020	$173	$143	2.5%	–2.0%	$10.2	–$1.7
2021	$173	$143	2.5%	–2.0%	$10.2	–$1.8
2022	$173	$143	2.5%	–2.0%	$10.3	–$1.8
2023	$173	$143	2.5%	–2.0%	$10.4	–$1.8
2024	$173	$143	2.5%	–2.0%	$10.4	–$1.8
2025	$173	$143	2.5%	–2.0%	$10.5	–$1.8
2026	$173	$143	2.5%	–2.0%	$10.6	–$1.8
2027	$173	$143	2.5%	–2.0%	$10.6	–$1.8
2028	$173	$143	2.5%	–2.0%	$10.7	–$1.8
2029	$173	$143	2.5%	–2.0%	$10.8	–$1.8
2030	$173	$143	2.5%	–2.0%	$10.9	–$1.9
2031	$173	$143	2.5%	–2.0%	$10.9	–$1.9
2032	$173	$143	2.5%	–2.0%	$11.0	–$1.9
2033	$173	$143	2.5%	–2.0%	$11.1	–$1.9
2034	$173	$143	2.5%	–2.0%	$11.1	–$1.9
2035	$173	$143	2.5%	–2.0%	$11.2	–$1.9
2036	$173	$143	2.5%	–2.0%	$11.3	–$1.9
2037	$173	$143	2.5%	–2.0%	$11.3	–$1.9
2038	$173	$143	2.5%	–2.0%	$11.4	–$2.0
NPV (3%)					$207.2	–$35.1
NPV (7%)					$127.2	–$21.5

[a] Figures are in 2005 dollars.

Table 9B-3: Impact on Marine SI Engine Market: 51–100hp (Average Price per Engine = $9,100)[a]

	Marine SI Engine (51–100hp)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$211	$182	2.0%	–1.2%	$17.2	–$2.3
2010	$211	$180	2.0%	–1.3%	$17.3	–$2.5
2011	$211	$180	2.0%	–1.3%	$17.4	–$2.5
2012	$211	$178	1.9%	–1.4%	$17.5	–$2.7
2013	$211	$178	1.9%	–1.4%	$17.7	–$2.8
2014	$162	$136	1.5%	–1.1%	$13.7	–$2.2
2015	$162	$136	1.5%	–1.1%	$13.8	–$2.3
2016	$162	$136	1.5%	–1.1%	$13.9	–$2.2
2017	$162	$136	1.5%	–1.1%	$14.0	–$2.2
2018	$162	$137	1.5%	–1.1%	$14.1	–$2.2
2019	$162	$137	1.5%	–1.1%	$14.2	–$2.2
2020	$162	$137	1.5%	–1.1%	$14.3	–$2.2
2021	$162	$137	1.5%	–1.1%	$14.4	–$2.3
2022	$162	$137	1.5%	–1.1%	$14.5	–$2.3
2023	$162	$137	1.5%	–1.1%	$14.6	–$2.3
2024	$162	$137	1.5%	–1.1%	$14.7	–$2.3
2025	$162	$137	1.5%	–1.1%	$14.8	–$2.3
2026	$162	$137	1.5%	–1.1%	$14.9	–$2.3
2027	$162	$137	1.5%	–1.1%	$15.0	–$2.4
2028	$162	$137	1.5%	–1.1%	$15.1	–$2.4
2029	$162	$137	1.5%	–1.1%	$15.2	–$2.4
2030	$162	$137	1.5%	–1.1%	$15.3	–$2.4
2031	$162	$137	1.5%	–1.1%	$15.4	–$2.4
2032	$162	$137	1.5%	–1.1%	$15.5	–$2.4
2033	$162	$137	1.5%	–1.1%	$15.6	–$2.4
2034	$162	$137	1.5%	–1.1%	$15.7	–$2.5
2035	$162	$137	1.5%	–1.1%	$15.7	–$2.5
2036	$162	$137	1.5%	–1.1%	$15.8	–$2.5
2037	$162	$137	1.5%	–1.1%	$15.9	–$2.5
2038	$162	$137	1.5%	–1.1%	$16.0	–$2.5
NPV (3%)					$292.3	–$46.4
NPV (7%)					$179.7	–$29.5

[a] Figures are in 2005 dollars.

Table 9B-4: Impact on Marine SI Engine Market:
101–175hp (Average Price per Engine =$11,800)[a]

	Marine SI Engine (101–175hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$371	$319	2.7%	–1.6%	$27.0	–$3.7
2010	$371	$315	2.7%	–1.7%	$27.2	–$4.0
2011	$371	$315	2.7%	–1.7%	$27.4	–$4.1
2012	$371	$312	2.7%	–1.8%	$27.6	–$4.4
2013	$371	$312	2.7%	–1.8%	$27.8	–$4.4
2014	$284	$237	2.0%	–1.4%	$21.4	–$3.5
2015	$284	$237	2.0%	–1.4%	$21.6	–$3.6
2016	$284	$238	2.0%	–1.4%	$21.7	–$3.5
2017	$284	$238	2.0%	–1.4%	$21.9	–$3.6
2018	$284	$238	2.0%	–1.4%	$22.0	–$3.5
2019	$284	$238	2.0%	–1.4%	$22.2	–$3.6
2020	$284	$238	2.0%	–1.4%	$22.3	–$3.6
2021	$284	$238	2.0%	–1.4%	$22.5	–$3.6
2022	$284	$238	2.0%	–1.4%	$22.6	–$3.6
2023	$284	$238	2.0%	–1.4%	$22.8	–$3.7
2024	$284	$238	2.0%	–1.4%	$22.9	–$3.7
2025	$284	$238	2.0%	–1.4%	$23.1	–$3.7
2026	$284	$238	2.0%	–1.4%	$23.2	–$3.7
2027	$284	$238	2.0%	–1.4%	$23.4	–$3.8
2028	$284	$238	2.0%	–1.4%	$23.5	–$3.8
2029	$284	$238	2.0%	–1.4%	$23.7	–$3.8
2030	$284	$238	2.0%	–1.4%	$23.8	–$3.8
2031	$284	$238	2.0%	–1.4%	$24.0	–$3.8
2032	$284	$238	2.0%	–1.4%	$24.2	–$3.9
2033	$284	$238	2.0%	–1.4%	$24.3	–$3.9
2034	$284	$238	2.0%	–1.4%	$24.5	–$3.9
2035	$284	$238	2.0%	–1.4%	$24.6	–$3.9
2036	$284	$238	2.0%	–1.4%	$24.8	–$4.0
2037	$284	$238	2.0%	–1.4%	$24.9	–$4.0
2038	$284	$238	2.0%	–1.4%	$25.1	–$4.0
NPV (3%)					$457.3	–$72.3
NPV (7%)					$281.4	–$44.2

[a] Figures are in 2005 dollars.

Table 9B-5: Impact on Marine SI Engine Market: 176–300hp (Average Price per Engine =$19,000)[a]

	Marine SI Engine (176–300hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$527	$456	2.4%	–1.3%	$52.7	–$7.1
2010	$527	$451	2.4%	–1.4%	$53.0	–$7.6
2011	$527	$451	2.4%	–1.4%	$53.4	–$7.7
2012	$527	$445	2.4%	–1.5%	$53.8	–$8.3
2013	$527	$445	2.4%	–1.5%	$54.2	–$8.3
2014	$402	$337	1.8%	–1.2%	$41.7	–$6.7
2015	$402	$338	1.8%	–1.2%	$42.0	–$6.8
2016	$402	$339	1.8%	–1.2%	$42.3	–$6.7
2017	$402	$339	1.8%	–1.2%	$42.6	–$6.7
2018	$402	$339	1.8%	–1.2%	$42.9	–$6.7
2019	$402	$339	1.8%	–1.2%	$43.2	–$6.8
2020	$402	$339	1.8%	–1.2%	$43.5	–$6.8
2021	$402	$339	1.8%	–1.2%	$43.8	–$6.9
2022	$402	$339	1.8%	–1.2%	$44.1	–$6.9
2023	$402	$339	1.8%	–1.2%	$44.3	–$6.9
2024	$402	$339	1.8%	–1.2%	$44.6	–$7.0
2025	$402	$339	1.8%	–1.2%	$44.9	–$7.0
2026	$402	$339	1.8%	–1.2%	$45.2	–$7.1
2027	$402	$339	1.8%	–1.2%	$45.5	–$7.1
2028	$402	$339	1.8%	–1.2%	$45.8	–$7.2
2029	$402	$339	1.8%	–1.2%	$46.1	–$7.2
2030	$402	$339	1.8%	–1.2%	$46.4	–$7.3
2031	$402	$339	1.8%	–1.2%	$46.7	–$7.3
2032	$402	$339	1.8%	–1.2%	$47.0	–$7.4
2033	$402	$339	1.8%	–1.2%	$47.3	–$7.4
2034	$402	$339	1.8%	–1.2%	$47.6	–$7.4
2035	$402	$339	1.8%	–1.2%	$47.9	–$7.5
2036	$402	$339	1.8%	–1.2%	$48.2	–$7.6
2037	$402	$339	1.8%	–1.2%	$48.5	–$7.6
2038	$402	$339	1.8%	–1.2%	$48.8	–$7.6
NPV (3%)					$890.6	–$137.3
NPV (7%)					$548.1	–$83.8

[a] Figures are in 2005 dollars.

Table 9B-6: Impact on Marine SI Engine Market: 300+ hp (Average Price per Engine = $18,000)[a]

	Marine SI Engine (300+ hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Engine Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$377	$343	1.6%	–0.6%	$11.9	–$1.4
2010	$377	$337	1.5%	–0.7%	$12.0	–$1.6
2011	$377	$337	1.5%	–0.7%	$12.1	–$1.7
2012	$377	$328	1.5%	–0.9%	$12.2	–$2.0
2013	$377	$328	1.5%	–0.9%	$12.3	–$2.0
2014	$279	$239	1.1%	–0.7%	$9.2	–$1.7
2015	$279	$239	1.1%	–0.7%	$9.3	–$1.7
2016	$279	$241	1.1%	–0.7%	$9.3	–$1.6
2017	$279	$241	1.1%	–0.7%	$9.4	–$1.6
2018	$279	$241	1.1%	–0.7%	$9.5	–$1.6
2019	$279	$241	1.1%	–0.7%	$9.5	–$1.6
2020	$279	$241	1.1%	–0.7%	$9.6	–$1.6
2021	$279	$241	1.1%	–0.7%	$9.7	–$1.6
2022	$279	$241	1.1%	–0.7%	$9.7	–$1.7
2023	$279	$241	1.1%	–0.7%	$9.8	–$1.7
2024	$279	$241	1.1%	–0.7%	$9.9	–$1.7
2025	$279	$241	1.1%	–0.7%	$9.9	–$1.7
2026	$279	$241	1.1%	–0.7%	$10.0	–$1.7
2027	$279	$241	1.1%	–0.7%	$10.1	–$1.7
2028	$279	$241	1.1%	–0.7%	$10.1	–$1.7
2029	$279	$241	1.1%	–0.7%	$10.2	–$1.7
2030	$279	$241	1.1%	–0.7%	$10.3	–$1.8
2031	$279	$241	1.1%	–0.7%	$10.3	–$1.8
2032	$279	$241	1.1%	–0.7%	$10.4	–$1.8
2033	$279	$241	1.1%	–0.7%	$10.4	–$1.8
2034	$279	$241	1.1%	–0.7%	$10.5	–$1.8
2035	$279	$241	1.1%	–0.7%	$10.6	–$1.8
2036	$279	$241	1.1%	–0.7%	$10.6	–$1.8
2037	$279	$241	1.1%	–0.7%	$10.7	–$1.8
2038	$279	$241	1.1%	–0.7%	$10.8	–$1.8
NPV (3%)					$198.0	–$32.5
NPV (7%)					$122.2	–$19.7

[a] Figures are in 2005 dollars.

Table 9B-7: Impact on Marine Vessels Market:
SD/I Recreational 175–300 hp (Average Price per Equipment = $32,367)[a,b]

	Marine Vessel (SD/I Recreational 175–300 hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$5	$156	0.5%	–1.0%	$0.2	–$4.9
2010	$43	$174	0.5%	–1.1%	$1.6	–$5.5
2011	$43	$174	0.5%	–1.1%	$1.6	–$5.5
2012	$93	$198	0.6%	–1.2%	$3.4	–$6.3
2013	$93	$198	0.6%	–1.2%	$3.4	–$6.3
2014	$93	$160	0.5%	–1.0%	$3.5	–$5.1
2015	$92	$159	0.5%	–1.0%	$3.5	–$5.2
2016	$85	$156	0.5%	–1.0%	$3.2	–$5.1
2017	$85	$156	0.5%	–1.0%	$3.2	–$5.1
2018	$79	$153	0.5%	–0.9%	$3.0	–$5.1
2019	$79	$153	0.5%	–0.9%	$3.0	–$5.1
2020	$79	$153	0.5%	–0.9%	$3.1	–$5.1
2021	$79	$153	0.5%	–0.9%	$3.1	–$5.2
2022	$79	$153	0.5%	–0.9%	$3.1	–$5.2
2023	$79	$153	0.5%	–0.9%	$3.1	–$5.2
2024	$79	$153	0.5%	–0.9%	$3.1	–$5.3
2025	$79	$153	0.5%	–0.9%	$3.2	–$5.3
2026	$79	$153	0.5%	–0.9%	$3.2	–$5.3
2027	$79	$153	0.5%	–0.9%	$3.2	–$5.4
2028	$79	$153	0.5%	–0.9%	$3.2	–$5.4
2029	$79	$153	0.5%	–0.9%	$3.3	–$5.5
2030	$79	$153	0.5%	–0.9%	$3.3	–$5.5
2031	$79	$153	0.5%	–0.9%	$3.3	–$5.5
2032	$79	$153	0.5%	–0.9%	$3.3	–$5.6
2033	$79	$153	0.5%	–0.9%	$3.3	–$5.6
2034	$79	$153	0.5%	–0.9%	$3.4	–$5.6
2035	$79	$153	0.5%	–0.9%	$3.4	–$5.7
2036	$79	$153	0.5%	–0.9%	$3.4	–$5.7
2037	$79	$153	0.5%	–0.9%	$3.4	–$5.7
2038	$79	$153	0.5%	–0.9%	$3.4	–$5.8
NPV (3%)					$56.1	–$102.9
NPV (7%)					$32.5	–$62.6

[a] Figures are in 2005 dollars.
[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9B-8: Impact on Marine Vessels Market:
SD/I Luxury 300+ hp (Average Price per Equipment = $205,729)[a,b]

	Marine Vessel (SD/I Luxury 300+ hp)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$11	$292	0.1%	–0.3%	$0.1	–$2.2
2010	$142	$358	0.2%	–0.3%	$1.3	–$2.8
2011	$142	$358	0.2%	–0.3%	$1.3	–$2.8
2012	$312	$443	0.2%	–0.4%	$2.8	–$3.5
2013	$312	$443	0.2%	–0.4%	$2.8	–$3.5
2014	$312	$369	0.2%	–0.4%	$2.8	–$2.9
2015	$311	$369	0.2%	–0.4%	$2.9	–$2.9
2016	$285	$356	0.2%	–0.3%	$2.6	–$2.9
2017	$285	$356	0.2%	–0.3%	$2.7	–$2.9
2018	$271	$349	0.2%	–0.3%	$2.5	–$2.8
2019	$271	$349	0.2%	–0.3%	$2.6	–$2.9
2020	$271	$349	0.2%	–0.3%	$2.6	–$2.9
2021	$271	$349	0.2%	–0.3%	$2.6	–$2.9
2022	$271	$349	0.2%	–0.3%	$2.6	–$2.9
2023	$271	$349	0.2%	–0.3%	$2.6	–$2.9
2024	$271	$349	0.2%	–0.3%	$2.6	–$3.0
2025	$271	$349	0.2%	–0.3%	$2.7	–$3.0
2026	$271	$349	0.2%	–0.3%	$2.7	–$3.0
2027	$271	$349	0.2%	–0.3%	$2.7	–$3.0
2028	$271	$349	0.2%	–0.3%	$2.7	–$3.0
2029	$271	$349	0.2%	–0.3%	$2.7	–$3.1
2030	$271	$349	0.2%	–0.3%	$2.8	–$3.1
2031	$271	$349	0.2%	–0.3%	$2.8	–$3.1
2032	$271	$349	0.2%	–0.3%	$2.8	–$3.1
2033	$271	$349	0.2%	–0.3%	$2.8	–$3.1
2034	$271	$349	0.2%	–0.3%	$2.8	–$3.2
2035	$271	$349	0.2%	–0.3%	$2.8	–$3.2
2036	$271	$349	0.2%	–0.3%	$2.9	–$3.2
2037	$271	$349	0.2%	–0.3%	$2.9	–$3.2
2038	$271	$349	0.2%	–0.3%	$2.9	–$3.2
NPV (3%)					$46.7	–$56.7
NPV (7%)					$27.0	–$34.2

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9B-9: Impact on Marine Vessels Market:
OB Recreational 50–100 hp (Average Price per Equipment = $21,569)[a,b]

	Marine Vessel (OB Recreational 50–100 hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$7	$130	0.6%	–1.2%	$0.4	–$0.2
2010	$27	$139	0.6%	–1.3%	$1.7	–$0.8
2011	$27	$139	0.6%	–1.3%	$1.7	–$0.8
2012	$48	$149	0.7%	–1.4%	$3.1	–$1.4
2013	$48	$149	0.7%	–1.4%	$3.1	–$1.5
2014	$48	$120	0.6%	–1.1%	$3.2	–$1.5
2015	$48	$119	0.6%	–1.1%	$3.1	–$1.5
2016	$44	$118	0.5%	–1.1%	$2.9	–$1.3
2017	$44	$118	0.5%	–1.1%	$2.9	–$1.4
2018	$39	$115	0.5%	–1.1%	$2.6	–$1.2
2019	$39	$115	0.5%	–1.1%	$2.6	–$1.2
2020	$39	$115	0.5%	–1.1%	$2.6	–$1.2
2021	$39	$115	0.5%	–1.1%	$2.6	–$1.2
2022	$39	$115	0.5%	–1.1%	$2.7	–$1.2
2023	$39	$115	0.5%	–1.1%	$2.7	–$1.2
2024	$39	$115	0.5%	–1.1%	$2.7	–$1.3
2025	$39	$115	0.5%	–1.1%	$2.7	–$1.3
2026	$39	$115	0.5%	–1.1%	$2.7	–$1.3
2027	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2028	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2029	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2030	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2031	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2032	$39	$115	0.5%	–1.1%	$2.8	–$1.3
2033	$39	$115	0.5%	–1.1%	$2.9	–$1.3
2034	$39	$115	0.5%	–1.1%	$2.9	–$1.3
2035	$39	$115	0.5%	–1.1%	$2.9	–$1.3
2036	$39	$115	0.5%	–1.1%	$2.9	–$1.4
2037	$39	$115	0.5%	–1.1%	$2.9	–$1.4
2038	$39	$115	0.5%	–1.1%	$2.9	–$1.4
NPV (3%)					$49.7	–$23.2
NPV (7%)					$29.2	–$13.6

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9B-10: Impact on Marine Vessels Market: OB Luxury 175–300 hp (Average Price per Equipment = $104,598)[a,b]

	Marine Vessel (OB Luxury 175–300 hp)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$19	$763	0.7%	–1.5%	$0.1	–$2.5
2010	$116	$804	0.8%	–1.5%	$0.4	–$2.6
2011	$116	$804	0.8%	–1.5%	$0.4	–$2.6
2012	$215	$845	0.8%	–1.6%	$0.8	–$2.8
2013	$215	$845	0.8%	–1.6%	$0.8	–$2.8
2014	$215	$672	0.6%	–1.3%	$0.8	–$2.2
2015	$214	$672	0.6%	–1.3%	$0.8	–$2.3
2016	$195	$663	0.6%	–1.3%	$0.8	–$2.2
2017	$195	$663	0.6%	–1.3%	$0.8	–$2.3
2018	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2019	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2020	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2021	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2022	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2023	$182	$658	0.6%	–1.3%	$0.7	–$2.3
2024	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2025	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2026	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2027	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2028	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2029	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2030	$182	$658	0.6%	–1.3%	$0.8	–$2.4
2031	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2032	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2033	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2034	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2035	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2036	$182	$658	0.6%	–1.3%	$0.8	–$2.5
2037	$182	$658	0.6%	–1.3%	$0.8	–$2.6
2038	$182	$658	0.6%	–1.3%	$0.8	–$2.6
NPV (3%)					$13.4	–$46.4
NPV (7%)					$7.8	–$28.4

[a] Figures are in 2005 dollars.

[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Table 9B-11: Impact on Marine Vessels Market:
PWC 100–175 hp (Average Price per Equipment = $9,986)[a,b]

	Marine Vessel (PWC 100–175 hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (million $)**	**Change in Equipment Manufacturers Surplus (million $)**
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$98	$63	0.6%	–1.3%	$5.8	–$2.2
2010	$98	$63	0.6%	–1.3%	$5.8	–$2.2
2011	$98	$73	0.7%	–1.5%	$5.9	–$2.6
2012	$98	$73	0.7%	–1.5%	$5.9	–$2.6
2013	$98	$73	0.7%	–1.5%	$6.0	–$2.6
2014	$68	$54	0.5%	–1.1%	$4.2	–$1.9
2015	$68	$54	0.5%	–1.1%	$4.2	–$1.9
2016	$68	$54	0.5%	–1.1%	$4.2	–$2.0
2017	$68	$50	0.5%	–1.0%	$4.2	–$1.8
2018	$68	$50	0.5%	–1.0%	$4.3	–$1.8
2019	$68	$50	0.5%	–1.0%	$4.3	–$1.9
2020	$68	$50	0.5%	–1.0%	$4.3	–$1.9
2021	$68	$50	0.5%	–1.0%	$4.4	–$1.9
2022	$68	$50	0.5%	–1.0%	$4.4	–$1.9
2023	$68	$50	0.5%	–1.0%	$4.4	–$1.9
2024	$68	$50	0.5%	–1.0%	$4.4	–$1.9
2025	$68	$50	0.5%	–1.0%	$4.5	–$1.9
2026	$68	$50	0.5%	–1.0%	$4.5	–$1.9
2027	$68	$50	0.5%	–1.0%	$4.5	–$2.0
2028	$68	$50	0.5%	–1.0%	$4.6	–$2.0
2029	$68	$50	0.5%	–1.0%	$4.6	–$2.0
2030	$68	$50	0.5%	–1.0%	$4.6	–$2.0
2031	$68	$50	0.5%	–1.0%	$4.7	–$2.0
2032	$68	$50	0.5%	–1.0%	$4.7	–$2.0
2033	$68	$50	0.5%	–1.0%	$4.7	–$2.0
2034	$68	$50	0.5%	–1.0%	$4.7	–$2.0
2035	$68	$50	0.5%	–1.0%	$4.8	–$2.1
2036	$68	$50	0.5%	–1.0%	$4.8	–$2.1
2037	$68	$50	0.5%	–1.0%	$4.8	–$2.1
2038	$68	$50	0.5%	–1.0%	$4.9	–$2.1
NPV (3%)					$91.2	–$39.2
NPV (7%)					$56.8	–$24.3

[a] Figures are in 2005 dollars.
[b] Average price per equipment for the market is a weighted average of the price of equipment by hp.

Appendix 9C: Time Series Projections of Social Cost

This appendix provides a time series of the rule’s projected social costs for each year through 2038. Costs are presented in 2005 dollars. In addition, this appendix includes the net present values by stakeholder using social discount rates of 3 percent and 7 percent over the period of analysis. As a result, it illustrates how the choice of discount rate determines the present value of the total social costs of the program.

Table 9C: Time Series Projection of Social Costs: 2008 to 2038 (Million $)[a]

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Consumer Surplus Change, Total	**–$7.5**	**–$118.2**	**–$128.5**	**–$331.6**	**–$477.2**	**–$481.1**	**–$460.7**	**–$465.4**	**–$389.4**	**–$365.1**	**–$369.1**
Marine SI											
End users (households)	$0.0	–$110.6	–$116.1	–$117.8	–$124.2	–$125.1	–$99.6	–$100.3	–$100.0	–$100.3	–$100.2
Small SI											
End users (households)	–$7.5	–$7.6	–$12.4	–$213.7	–$353.0	–$356.0	–$361.0	–$365.1	–$289.5	–$264.8	–$269.0
Producer Surplus Change, Total	**–$2.0**	**–$50.6**	**–$59.5**	**–$131.8**	**–$160.9**	**–$162.3**	**–$152.5**	**–$153.6**	**–$125.7**	**–$122.4**	**–$122.9**
Marine SI	$0.0	–$48.5	–$54.8	–$56.0	–$63.3	–$63.8	–$52.6	–$52.9	–$52.0	–$52.0	–$51.3
Engine manufacturers	$0.0	–$18.1	–$19.5	–$19.8	–$21.4	–$21.5	–$17.4	–$17.5	–$17.3	–$17.4	–$17.3
Equipment manufacturers	$0.0	–$30.4	–$35.3	–$36.2	–$41.9	–$42.2	–$35.2	–$35.4	–$34.7	–$34.6	–$34.0
Small SI	–$2.0	–$2.1	–$4.7	–$75.8	–$97.6	–$98.5	–$99.9	–$100.8	–$73.7	–$70.4	–$71.5
Engine manufacturers	–$0.4	–$0.4	–$0.4	–$10.9	–$18.2	–$18.4	–$18.6	–$18.9	–$15.0	–$13.7	–$13.9
Equipment manufacturers	–$1.7	–$1.7	–$4.3	–$64.8	–$79.4	–$80.2	–$81.3	–$81.9	–$58.8	–$56.8	–$57.7
Fuel Savings	**$3.1**	**$13.7**	**$25.4**	**$64.9**	**$103.5**	**$136.5**	**$161.2**	**$182.3**	**$200.9**	**$216.2**	**$229.9**
Consumer savings	$3.8	$16.7	$30.9	$78.8	$125.7	$165.9	$195.9	$221.5	$244.1	$262.6	$279.3
Fuel	$3.1	$13.7	$25.4	$64.9	$103.5	$136.5	$161.2	$182.3	$200.9	$216.2	$229.9
Tax	$0.7	$3.0	$5.5	$13.9	$22.2	$29.3	$34.7	$39.2	$43.2	$46.5	$49.4
Government revenue	–$0.7	–$3.0	–$5.5	–$13.9	–$22.2	–$29.3	–$34.7	–$39.2	–$43.2	–$46.5	–$49.4
Total Surplus Change	**–$6.4**	**–$155.1**	**–$162.6**	**–$398.5**	**–$534.7**	**–$506.9**	**–$451.9**	**–$436.7**	**–$314.2**	**–$271.3**	**–$262.1**

(continued)

Table 9C: Time Series Projection of Social Costs (Million $) (continued)

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Consumer Surplus Change, Total	–$374.1	–$378.9	–$383.8	–$388.6	–$393.5	–$398.4	–$403.3	–$408.2	–$413.1	–$418.0	–$422.9
Marine SI											
End users (households)	–$100.9	–$101.6	–$102.3	–$102.9	–$103.6	–$104.4	–$105.1	–$105.8	–$106.5	–$107.1	–$107.8
Small SI											
End users (households)	–$273.2	–$277.4	–$281.5	–$285.7	–$289.9	–$294.1	–$298.3	–$302.5	–$306.7	–$310.9	–$315.1
Producer Surplus Change, Total	–$124.3	–$125.8	–$127.3	–$128.7	–$130.2	–$131.9	–$133.3	–$134.8	–$136.3	–$137.8	–$139.3
Marine SI	–$51.7	–$52.0	–$52.4	–$52.7	–$53.1	–$53.7	–$54.0	–$54.4	–$54.7	–$55.1	–$55.4
Engine manufacturers	–$17.4	–$17.5	–$17.6	–$17.8	–$17.9	–$18.1	–$18.2	–$18.3	–$18.5	–$18.6	–$18.7
Equipment manufacturers	–$34.3	–$34.5	–$34.7	–$35.0	–$35.2	–$35.6	–$35.8	–$36.0	–$36.3	–$36.5	–$36.7
Small SI	–$72.7	–$73.8	–$74.9	–$76.0	–$77.1	–$78.2	–$79.3	–$80.5	–$81.6	–$82.7	–$83.8
Engine manufacturers	–$14.1	–$14.3	–$14.5	–$14.8	–$15.0	–$15.2	–$15.4	–$15.6	–$15.8	–$16.1	–$16.3
Equipment manufacturers	–$58.6	–$59.5	–$60.4	–$61.2	–$62.1	–$63.0	–$63.9	–$64.8	–$65.7	–$66.7	–$67.6
Fuel Savings	$242.1	$253.1	$263.3	$272.9	$281.4	$289.3	$296.6	$303.6	$310.1	$316.3	$321.9
Consumer savings	$294.2	$307.5	$319.9	$331.6	$341.9	$351.5	$360.4	$368.8	$376.7	$384.2	$391.1
Fuel	$242.1	$253.1	$263.3	$272.9	$281.4	$289.3	$296.6	$303.6	$310.1	$316.3	$321.9
Tax	$52.0	$54.4	$56.6	$58.7	$60.5	$62.2	$63.8	$65.2	$66.6	$68.0	$69.2
Government revenue	–$52.0	–$54.4	–$56.6	–$58.7	–$60.5	–$62.2	–$63.8	–$65.2	–$66.6	–$68.0	–$69.2
Total Surplus Change	–$256.2	–$251.6	–$247.7	–$244.4	–$242.2	–$241.0	–$240.0	–$239.5	–$239.3	–$239.5	–$240.2

(continued)

Table 9C: Time Series Projection of Social Costs (million $) (continued)

	2030	2031	2032	2033	2034	2035	2036	2037	2038	NPV (3%)	NPV (7%)
Consumer Surplus Change, Total	–$427.8	–$432.7	–$437.6	–$442.6	–$447.5	–$452.4	–$457.3	–$462.2	–$467.1	–$7,392.2	–$4,322.0
Marine SI											
End users (households)	–$108.5	–$109.2	–$109.9	–$110.6	–$111.3	–$112.0	–$112.7	–$113.4	–$114.1	–$2,058.8	–$1,259.9
Small SI											
End users (households)	–$319.3	–$323.5	–$327.7	–$332.0	–$336.2	–$340.4	–$344.6	–$348.8	–$353.0	–$5,333.4	–$3,062.1
Producer Surplus Change, Total	–$140.7	–$142.2	–$143.7	–$145.2	–$146.6	–$148.1	–$149.6	–$151.1	–$152.5	–$2,490.0	–$1,472.0
Marine SI	–$55.8	–$56.1	–$56.5	–$56.9	–$57.2	–$57.6	–$57.9	–$58.3	–$58.6	–$1,043.2	–$633.9
Engine manufacturers	–$18.8	–$18.9	–$19.1	–$19.2	–$19.3	–$19.4	–$19.5	–$19.7	–$19.8	–$354.4	–$216.2
Equipment manufacturers	–$37.0	–$37.2	–$37.4	–$37.7	–$37.9	–$38.2	–$38.4	–$38.6	–$38.9	–$688.8	–$417.6
Small SI	–$84.9	–$86.1	–$87.2	–$88.3	–$89.4	–$90.6	–$91.7	–$92.8	–$93.9	–$1,446.9	–$838.2
Engine manufacturers	–$16.5	–$16.7	–$16.9	–$17.1	–$17.4	–$17.6	–$17.8	–$18.0	–$18.2	–$275.0	–$157.8
Equipment manufacturers	–$68.5	–$69.4	–$70.3	–$71.2	–$72.1	–$73.0	–$73.9	–$74.8	–$75.7	–$1,171.8	–$680.4
Fuel Savings	$327.3	$332.3	$337.1	$341.7	$346.1	$350.4	$354.5	$358.5	$362.5	$4,356.1	$2,291.5
Consumer savings	$397.6	$403.7	$409.5	$415.1	$420.5	$425.7	$430.7	$435.6	$440.4	$5,292.3	$2,784.0
Fuel	$327.3	$332.3	$337.1	$341.7	$346.1	$350.4	$354.5	$358.5	$362.5	$4,356.1	$2,291.5
Tax	$70.3	$71.4	$72.4	$73.4	$74.4	$75.3	$76.2	$77.1	$77.9	$936.2	$492.5
Government revenue	–$70.3	–$71.4	–$72.4	–$73.4	–$74.4	–$75.3	–$76.2	–$77.1	–$77.9	–$936.2	–$492.5
Total Surplus Change	–$241.3	–$242.6	–$244.2	–$246.0	–$248.0	–$250.1	–$252.3	–$254.7	–$257.1	–$5,526.1	–$3,502.6

[a] Figures are in 2005 dollars.

Appendix 9D: Overview of Model Equations and Calculation

To develop the economic impact model, we use set of nonlinear supply and demand equations for the affected markets and transform them into a set of linear supply and demand equations. These resulting equations describe stakeholder production and consumption responses to policy-induced cost and price changes in each market. They also are used to specify the conditions for a new with-policy equilibrium. We describe these equations in more detail below.

9D.1 Economic Model Equations

Supply Equations

First, we consider the formal definition of the elasticity of supply with respect to changes in own price:

$$\varepsilon_s \equiv \frac{dQ_s / Q_s}{dp / p}. \tag{9D.1}$$

Next, we can use "hat" notation to transform Eq. (C.1) to proportional changes and rearrange terms:

$$\hat{Q}_s = \varepsilon_s \hat{p} \tag{9D.1a}$$

where

$\hat{Q}_s$ = percentage change in the quantity of market supply,

ε_s = market elasticity of supply, and

$\hat{p}$ = percentage change in market price.

As Fullerton and Metcalfe (2002) note, this approach takes the elasticity definition and turns it into a linear *behavioral* equation for each market.

To introduce the direct impact of the regulatory program, we assume the direct per-unit compliance cost (c) leads to a proportional shift in the marginal cost of production. Under the assumption of perfect competition (price equals marginal cost), we can approximate this shift at the initial equilibrium point as follows:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o}. \tag{9D.2}$$

The with-regulation supply response to price and cost changes can now be written as:

$$\hat{Q}_s = \varepsilon_s (\hat{p} - \hat{MC}) \tag{9D.3}$$

For equipment producers, the supply response should also simultaneously accounts for changes in equilibrium input prices (engines). To do this, we modify Eq. (9D.2) as follows:

$$\hat{MC} = \frac{c + \alpha(\Delta p_{engine})}{MC_o} = \frac{c + \alpha(\Delta p_{engine})}{p_o} \tag{9D.3a}$$

where Δp_{engine} is the equilibrium change in the engine price and α is the ratio of engines used per unit of equipment. For example, if one piece of equipment uses only one engine, then $\alpha = 1$. This equation can accommodate other engine to equipment ratios by multiplying Δp_{eng} by the appropriate engine-to-equipment ratio (α).

Demand Equations

Similar to supply, we can characterize equipment demand responses to price changes as:

$$\hat{Q}_d = \eta_d \hat{p} \tag{9D.4}$$

where

$\hat{Q}_d$ = percentage change in the quantity of market demand,

η^d = market elasticity of demand, and

$\hat{p}$ = percentage change in market price.

In contrast to equipment demand, the demand for engines is a derived demand and is related to equipment supply decisions. In order to maintain a constant engine-to-equipment ratio, the demand for engines is specified as:

$$\hat{Q}_d engines = \hat{Q}_s equipment \tag{9D.5}$$

Market Equilibrium Conditions

In response to the exogenous increase in equipment and engine production costs, stakeholder responses are completely characterized by represented in Eq. (9D.3)(equipment and engine supply), Eq. (9D.4) (equipment demand), and Eq. (9D.5)(engine demand). Next, we specify the relationship that must hold for markets to “clear”, that is, supply in each market equals demand. Given the equations specified above, the new equilibrium satisfies the condition that for each market, the proportional change in supply equals the proportional change in demand:

$$\hat{Q}_d = \hat{Q}_s \tag{9D.6}$$

9D.2 Computing With-Regulation Equilibrium Conditions

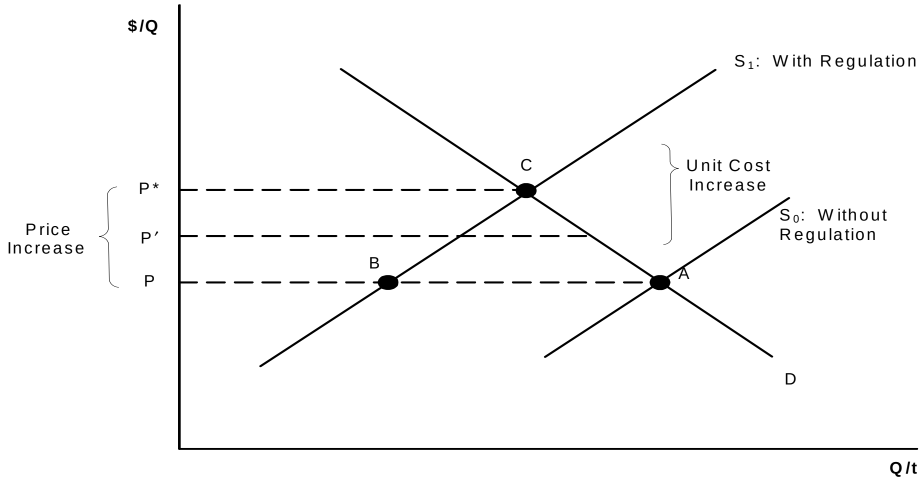
The choice of efficient model solution algorithms depends on several factors such as the number of markets included in the economic model, complexity of interactions between consumers and producers within these markets, and the software used to construct the model. To find the new market equilibrium prices and quantities, we used a solution algorithm that has proven very useful in "searching" for the equilibrium prices and quantities for partial equilibrium spreadsheet simulations with complicated relationships. We describe this approach in more detail below.

9D.2.1 Conceptual Description of RTI's Spreadsheet Model Solution Algorithm: PE_Walrasian_Auctioneer©2005

The French economist Léon Walras proposed one early model of market price adjustment by using the following thought experiment. Suppose there is a hypothetical agent that facilitates market adjustment by playing the role of an "auctioneer." He announces prices, collects information about supply and demand responses (without transactions actually taking place), and continues this process until market equilibrium is achieved.

For example, consider the with-regulation supply and demand conditions at the without-regulation equilibrium price (P) (see Figure 9D-1a). The auctioneer determines that the quantity demanded (A) exceeds the quantity supplied (B) at this price and calls out a new (higher) price (P′) based on the amount of excess demand. Consumers and producers make new consumption and production choices at this new price (i.e., they move along their respective demand and supply functions), and the auctioneer checks again to see if excess demand or supply exists. This process continues until P = P* (point C in Figure 9D-1a) is reached (i.e., excess demand is zero in the market). A similar analysis takes place when excess supply exists. The auctioneer calls out lower prices when the price is higher than the equilibrium price.

Figure 9D-1a. Computing with Regulation Equilibrium



The model uses a similar type of algorithm for determining with-regulation equilibria, and the process can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.
2. Recalculate the market supply in each market. Excess demand currently exists.
3. Determine the new prices via a price revision rule. We used a rule similar to the factor price revision rule described by Kimbell and Harrison (1986). P_i is the market price at iteration i, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and the speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s}\right)^z \tag{9D.7}$$

4. Recalculate market supply with new prices.
5. Compute market demand in each market.
6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one). When the ratio is appropriately close to one, the market-clearing condition of supply equals demand is satisfied.

9D.2.2 Consumer and Producer Welfare Calculations

The change in consumer surplus in the affected markets can be estimated using the following linear approximation method:

$$\Delta CS = -\, Q_1 \bullet \Delta p + 0.5 \bullet \Delta Q \bullet \Delta p. \tag{9D.8}$$

As shown, higher market prices and reduced consumption lead to welfare losses for consumers. A geometric representation of this calculation is illustrated in Figure 9D-1b.

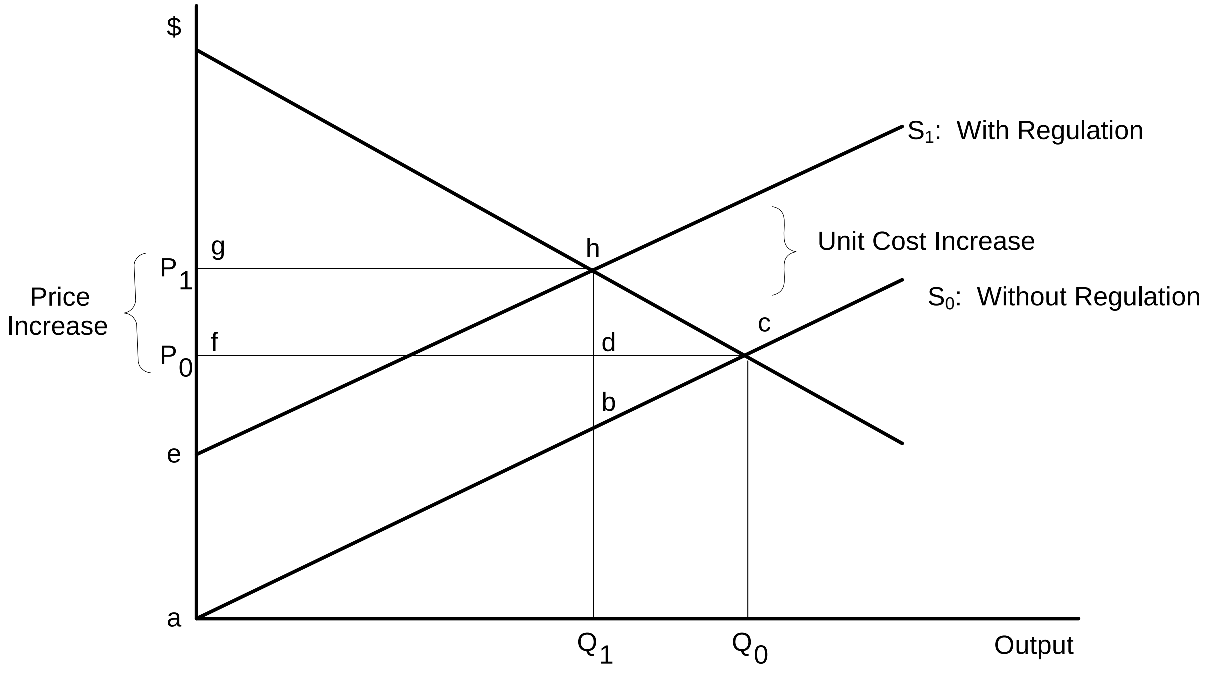
For affected supply, the change in producer surplus can be estimated with the following equation:

$$\Delta PS = Q_1 \bullet (\Delta p - c) - 0.5 \bullet \Delta Q \bullet (\Delta p - c). \tag{9D.9}$$

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change (Δp – c) is negative. However, these losses are mitigated, to some degree, as a result of higher market prices. A geometric representation of this calculation is illustrated in Figure 9D-1b.

Δ consumer surplus =–[fghd + dhc]
Δ producer surplus =[fghd – aehb] – bdc
Δ total surplus =–[aehb + dhc + bdc]

Figure 9D-1b. Welfare Calculations



Appendix 9E: Elasticity Parameters for Economic Impact Modeling

The Economic Impact Model (EIM) relies on elasticity parameters to estimate the behavioral response of consumers and producers to the regulation and its associated social costs. To operationalize the market model, supply and demand elasticities are needed to represent the behavioral adjustments that are likely to be made by market participants. The following parameters are needed:

- supply and demand elasticities for Marine SI equipment markets
- supply and demand elasticities for Small SI equipment markets
- supply elasticities for Marine SI engine markets
- supply elasticities for Small SI engine markets

Note that demand elasticities for the Marine SI and Small SI engine markets are not estimated because they are derived internally in the model. They are a function of changes in output levels in the equipment markets.

Tables 9E-1 and 9E-2 contain the demand and supply elasticities used to estimate the economic impact of the rule. Two methods were used to obtain the supply and demand elasticities used in the EIM. First, the professional literature was surveyed to identify elasticity estimates used in published studies. Second, when literature estimates were not available for specific markets, established econometric techniques were used to estimate supply and demand elasticity parameters directly. Since very few studies have been identified to quantify elasticities for Small SI and Marine SI markets in the literature survey, the supply and demand elasticities for all of the equipment and engine markets were estimated econometrically.

This appendix describes the methods used to estimate demand and supply elasticities for Marine SI and Small SI engines and equipment markets and presents the data sources and the regression results obtained from applying those methods.

Finally, it should be noted that these elasticities reflect intermediate run behavioral changes. In the long run, supply and demand are expected to be more elastic since more substitutes may become available.

Table 9E-1: Summary of Market Supply Elasticities Used in the Market Model

Markets	Estimate	Source	Method	Input Data Summary
Recreational Marine				
All vessel types except PWC	2.3	EPA econometric estimate Table 9E-4	Cobb-Douglas production function	Bartlesman et al. (2000); 1958–1996; SIC 3732
PWC	3.4	EPA econometric estimate Table 9E-5	Cobb-Douglas production function	Bartlesman et al. (2000); 1958–1996; SIC 3799
Small SI				
All lawn and garden equipment	3.4	EPA econometric estimate Table 9E-6	Cobb-Douglas production function	Bartlesman et al. (2000); 1958–1996; SIC 3524
Generators	3.3	EPA econometric estimate Table 9E-7	Cobb-Douglas production function	Bartlesman et al. (2000); 1966–1996; SIC 3621
All Engines Categories	3.8	EPA econometric estimate Table 9E-3	Cobb-Douglas production function	Bartlesman et al. (2000); 1958–1996; SIC 3519

Table 9E-2: Summary of Market Demand Elasticities Used in the Market Model

Market	Estimate	Source	Method	Primary Input Data Summary
Equipment				
All recreational marine (including PWC)	−2.0	EPA econometric estimate Table 9E-8	Simultaneous equation (3SLS)	Bartlesman et al. (2000); 1958–1996; SIC 3732
Lawnmowers	−0.2	EPA econometric estimate Table 9E-9, Column 2	Simultaneous equation (3SLS)	AIR/NERA (2003); 1973–2002
Lawn and garden tractors	–1.0	EPA econometric estimate Table 9E-9, Column 5	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980–1997
Pumps/compressors/ pressure washers, snowblowers	–1.0[a]	EPA econometric estimate Table 9E-9, Column 5	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980–1997
Agriculture, construction, general industrial	–1.0[a]	EPA econometric estimate Table 9E-9, Column 5	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980–1997
Other lawn and garden	–0.9[b]	EPA econometric estimate Table 9E-9, Column 3	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected previous years; 1980–1997
All handheld lawn and garden equipment	–1.9	EPA econometric estimate Table 9E-9, Column 4	Simultaneous equation (2SLS)	U.S. Census Bureau, Current Industrial Reports, MA333A 2000 and selected years; 1980–1997
Gensets/welders Class 1	–1.4	EPA econometric estimate Table 9E-10, Column 2	Simultaneous equation (3SLS)	U.S. Census Bureau, Current Industrial Reports, MA335H 2000 and selected years; 1980–1997
Gensets/welders Class 2	–1.1	EPA econometric estimate Table 9E-10, Column 3	Simultaneous equation (3SLS)	U.S. Census Bureau, Current Industrial Reports, MA335H 2000 and selected years; 1980–1997
All Engines		Derived demand	NA	

[a] Uses econometric estimate for lawn and garden tractors.

[b] Uses econometric estimate for commercial mowers.

9E.1 Supply Elasticities

We use a two-steps approach to estimate the price elasticity of supply. In the first step, we estimate an industry production function by using the regression model. In the second step, we calculate the supply elasticity by the parameters estimated in the estimated production function. This section discusses the regression model used to estimate the industry production function, data sources used for the regression, and estimated results for supply elasticities. The economics theory on the relationship between the supply elasticity and the production function is discussed in Appendix 9F.

In economics, the production function is defined as the relationship between inputs and outputs of the production process. In this case, we assume that Small SI and Marine SI industry follows the Cobb-Douglas production function, and is specified as

$$Q_t = A\,(K_t)^{\alpha_K}\,(L_t)^{\alpha_L}\,(M_t)^{\alpha_M}\,t^{\lambda} \tag{9E.1}$$

where

Q_t = output in year t,
K_t = real capital consumed in production in year t,
L_t = quantity of labor used in year t,
M_t = material inputs in year t, and
t = a time trend variable to reflect technology changes.

This equation can be written in linear form by taking the natural logarithms of each side of the equation. The parameters of this model, α_K, α_L, α_M, can then be estimated using linear regression techniques:

$$\ln Q_t = \ln A + \alpha_K \ln K_t + \alpha_L \ln L_t + \alpha_M \ln M_t + \lambda \ln t \tag{E9.2}$$

Under the assumptions of a competitive market and perfect competition, the elasticity of supply with respect to the price of the final product can be expressed in terms of the parameters of the production function:[14]

$$\text{Supply Elasticity} = (\alpha_L + \alpha_M\,) / (1 - \alpha_L - \alpha_M). \tag{9E.3}$$

To maintain the desired properties of the Cobb-Douglas production function, the analyst must place restrictions on the estimated coefficients. For example, if $\alpha_L + \alpha_M = 1$, then the supply elasticity will be undefined. Alternatively, if $\alpha_L + \alpha_M > 1$, this yields a negative supply elasticity. Thus, a common assumption is that $\alpha_K + \alpha_L + \alpha_M = 1$. This implies constant returns to scale, which is consistent with most empirical studies.

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[14] Appendix 9F provides the derivation of this result.

9E.1.1 Data Sets

The National Bureau of Economic Research-Center for Economic Studies (Bartlesman, Becker, and Gray, 2000) publishes industry-level data used for the analysis. In cases where a price index was not available, we used the most recent implicit gross domestic product (GDP) price deflator reported by the U.S. Bureau of Economic Analysis (BEA, 2004).[15] The following variables were used:

- value of shipments (NBER-CES),
- price index of value shipments (NBER-CES),
- production worker wages (NBER-CES),
- GDP deflator (BEA)
- cost of materials (NBER-CES),
- price index for materials (NBER-CES), and
- value added (NBER-CES).

To provide a measure of capital consumed, a capital variable was calculated as follows:

Capital = (Value added – Production worker wages)/GDP deflator

9E.1.2 Results of Supply Elasticity Estimation

We used an autoregressive error model to estimate Eq. (9E.2). SAS procedure PROC AUTOREG computes a linear regression corrected for serial correlation. We assume the error term is AR(2). This approach is identical to the one used successfully for the Nonroad CI Engines and Equipment EIA completed in 2003 (EPA, 2004), with some of the data series updated with the most recent data. Using this model, reasonable estimates were obtained for Small SI products. Durbin-Watson statistics were calculated to check for autocorrelation and Goldfeld-Quandt tests to check for heteroskedasticity. As shown in Tables 9E-3 through 9E-7, supply elasticity estimates for Small SI products range from 2.3 (Boat Building) to 3.8 (Engines).

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[15] All values are expressed in $1987. Note the GDP deflators have been updated since RTI's estimation of supply elasticities for the nonroad rule. As a result, the elasticity estimation method is the same; however, the coefficient estimates may vary slightly.

Table 9E-3: Gasoline Engines: SIC 3519 Internal Combustion Engines, Not Elsewhere Classified: 1958 to 1996

Number of Observations = 39
Total R-square = 0.9978
Durbin-Watson = 1.80 (1% critical values = 1.085, 1.517)
Goldfeld-Quandt F = 3.10 (p-value = 0.018); DF=14
Supply Elasticity = 3.8

Variable	Estimated Coefficients	t-statistic	p value
intercept	0.962	24.21	<0.0001
ln K	0.207	4.73	<0.0001
ln L	0.207	5.60	<0.0001
ln M	0.587	13.04	<0.0001
ln t	0.022	2.37	0.0238

Table 9E-4: Gasoline-Powered Boats: SIC 3732 Boat Building and Repairing: 1958 to 1996

Number of Observations = 39
Total R-square = 0.9976
Durbin-Watson = 1.89 (1% critical values = 1.085, 1.517)
Goldfeld-Quandt F = 1.76 (p-value = 0.141); DF=14
Supply Elasticity = 2.3

Variable	Estimated Coefficients	t-statistic	p-value
intercept	1.144	25.42	<0.0001
ln K	0.303	5.73	<0.0001
ln L	0.328	7.28	<0.0001
ln M	0.369	7.34	<0.0001
ln t	0.022	1.56	0.1295

Table 9E-5: PWCs, ATVs, Snowmobiles: SIC 3799 Transportation Equipment, Not Elsewhere Classified: 1958 to 1996
Number of Observations = 39
Total R-square = 0.9978
Durbin-Watson = 1.758 (1% critical values = 1.085, 1.517)
Goldfeld-Quandt F = 2.99 (p-value = 0.025); DF=14
Supply Elasticity = 3.4

Variable	**Estimated Coefficients**	**t-statistic**	**p value**
intercept	0.786	19.4	<0.0001
ln K	0.229	10.4	<0.0001
ln L	0.127	4.57	<0.0001
ln M	0.644	20.2	<0.0001
ln t	0.028	2.90	0.0065

Table 9E-6: Small Handheld/Nonhandheld: SIC 3524 Lawn and Garden Tractors and Home Lawn and Garden Equipment: 1958 to 1996
Number of Observations = 39
Total R-square = 0.9964
Durbin-Watson = 1.71 (1% critical values = 1.085, 1.517)
Goldfeld-Quandt F = 2.08 (p-value = 0.084); DF=14
Supply Elasticity = 3.4

Variable	**Estimated Coefficients**	**t-statistic**	**p value**
intercept	0.662	13.03	<0.0001
ln K	0.225	3.69	0.0008
ln L	0.068	1.79	0.0822
ln M	0.707	11.09	<0.0001
ln t	0.042	2.77	0.0091

Table 9E-7: Gensets and Marine Generators: SIC 3621 Motors and Generators: 1966 to 1996
Number of Observations = 31
Total R-square = 0.9930
Durbin-Watson = 1.749 (1% critical values = 0.960,1.510)
Goldfeld-Quandt F = 0.89 (p-value = 0.576); DF=11
Supply Elasticity = 3.3

Variable	Estimated Coefficients	t-statistic	p value
intercept	1.0119	19.6	<0.0001
ln K	0.2346	4.62	<0.0001
ln L	0.1574	3.15	0.0042
ln M	0.6081	11.64	<0.0001
ln t	–0.0127	–0.51	0.6176

9E.2 Demand Elasticities

To obtain demand elasticity parameters, we estimated a simultaneous system of demand and supply equations using instrumental variables methodology by either two-stage least squares (2SLS) or three-stage least squares (3SLS) regression. This type of partial equilibrium market supply/demand model is specified as a system of interdependent equations in which the price and output of a product are simultaneously determined by the interaction of producers and consumers in the market. In simultaneous equation models, where variables in one equation feed back into variables in another equation, the error terms are correlated with the endogenous variables (price and output). Use of a single-equation ordinary least squares (OLS) estimation of individual equations will lead to biased and inconsistent parameter estimates because it does not account for the correlation of the error term with the endogenous variables. In 2SLS or 3SLS, however, each equation is identified through the inclusion of exogenous variables as instruments that control for shifts in the supply and demand curves over time.

Exogenous variables influencing the demand for gasoline-powered boats and Small SI equipment include measures of general economic activity (per capita household or disposable income, number of households or housing starts). Exogenous variables influencing the cost of production and supply of boats and Small SI equipment include changes in prices of key inputs like labor and raw materials.

The supply/demand system for gasoline powered equipment can be defined as follows:

$$Q_t^d = f(P_t,Z_t) + u_t \quad (9E.4)$$

$$Q_t^s = g(P_t,W_t) + v_t \quad (9E.5)$$

$$Q_t^d = Q_t^s \quad (9E.6)$$

Eq. (9E.4) shows quantity demanded as a function of price, P_t; a vector of demand shifters, Z_t (e.g., measures of economic activity); and an error term, u_t. Eq. (9E.5) represents quantity supplied as a function of price and a vector of supply shifters, W_t (e.g., input prices), and an error term, v_t, while Eq. (9E.6) specifies the equilibrium condition that quantity supplied equals quantity demanded, creating a system of three equations with three endogenous variables. The interaction of the specified market forces solves this system, generating equilibrium values for the variables P_t^* and $Q_t^* = Q_t^{d*} = Q_t^{s*}$.

To generate demand and supply elasticity estimates simultaneously, we used 2SLS and/or 3SLS procedures. For the 2SLS estimates, observed price is regressed against the exogenous instruments (i.e., the supply and demand “shifter” variables). The fitted (or predicted) values for the price variable are then employed as observations of the right-hand side price variable in the supply and demand equations. In the second stage, the 2SLS estimators are generated by running OLS on these calculated instrumental variables. Also, the 2SLS estimates are used to estimate errors in the structural equations, which then can be used to estimate the variance-covariance matrix of the structural equations' errors. For the 3SLS estimates, this information is used at the third stage to perform a generalized least squares (GLS) estimation of a single large equation composed from the individual structural equations. If this process is done with all variables expressed in natural logarithms, the coefficient on the price variable in the demand equation yields an estimate of the constant elasticity of demand.

9E.2.1 Demand Equation Estimation

Demand equations were estimated using a general specification where the quantity of boats or Small SI equipment consumed is expressed as a function of price, number of households or housing starts, per capita household or disposable income, and a time trend. Trends were included as a general way to model the effects of changes in tastes and preferences. All price and income variables were deflated by the implicit gross domestic product (GDP) deflator. The endogenous variables in the equations are unit sales and own-price. The exogenous variables include the household and income variables and the time trend. The list of instruments includes these exogenous variables and supply factors influencing the price of the product: wages and a producer price index for material inputs.

9E.2.2 Data Sets

The National Bureau of Economic Research (NBER) data discussed in the supply elasticity section of the analysis plan (RTI, 2005) contain data on production quantities, price indices, and suitable instruments to inform a demand analysis for recreational boats (SIC 3732). In its Current Industrial Reports (CIR) series, the U.S. Census Bureau produces an annual summary of the production of motors and generators and a summary of production of several types of lawn and garden equipment; both of these reports include the number of units manufactured and the value of production (U.S. Census Bureau, 1998; 2000). For the walk-behind lawnmowers regression, we used several data series reported in a study by Air Improvement Resource, Inc., and National Economic Research Associates (AIR/NERA, 2003). The U.S. Census Bureau publishes historical data on household income and housing starts (U.S. Census Bureau, 2002; 2004), and we collected price, wage, and material cost indexes from the Bureau of Labor Statistics (BLS) (BLS, 2004a,b,c,d,e). Lastly, we obtained an implicit GDP price deflator from the U.S. Bureau of Economic Analysis (BEA) (BEA, 2004). The following variables from these sources were used in the regression:

- unit sales of boats (Bartlesman et al., 2000),
- price index for boats (Bartlesman et al., 2000),
- lawn and garden equipment units produced (U.S. Census Bureau, AIR/NERA),
- lawn and garden equipment value of production (U.S. Census Bureau),
- producer price index for walk-behind lawnmowers (BLS),
- households (U.S. Census Bureau),
- housing starts (U.S. Census Bureau),
- per capita income and population (U.S. Census Bureau, 2002; BEA, 2004),
- average hourly earnings for production workers (BLS; Bartlesman et al., 2000),
- price index for plastic and other materials and engines (BLS; Bartlesman et al., 2000), and GDP deflator (BEA).

Some care was needed in using the time series from the CIR data set. Occasional changes in category definition and the Census Bureau’s need to suppress some data to maintain confidentiality created difficulties in constructing consistent data series over the 2-decade time period. Nonetheless, we were able to assemble the following series: commercial nonriding mowers, commercial riding mowers, consumer lawn mowers, tillers and two-wheel tractors, snow throwers, edgers and trimmers, vacuums and blowers, and lawn and garden tractors. Statistically significant parameter estimates were obtained for commercial nonriding mowers, tillers/two-wheel tractors, edgers/trimmers, and lawn and garden tractors.

We were not able to obtain a useful elasticity estimate for consumer lawn mowers using CIR data, perhaps because of aggregation biases in that category of the CIR data set. Because consumer lawn mowers are a critical segment of the entire Small SI sector, we used an alternate data set for our demand elasticity estimate. The data AIR/NERA used in their recent study proved very useful in this regard (AIR/NERA, 2003). In that study, the authors used a single-equation OLS regression to obtain a demand elasticity parameter, a procedure that RTI believes to be inadequate because the market process simultaneously determines price and quantity in the demand equation. However, using the same data series cited by AIR/NERA supplemented by data collected by RTI, we were able to obtain a reasonable estimate using the 3SLS regression described above.

9E.2.3 Results of Demand Elasticity Estimation

In this section, we present regression results used in the EIA. Table 9E-8 shows the parameter estimate for the marine sector, which is –2.0. Although the methodology and data sets are quite different, this result is consistent with the ones obtained by Raboy (1987) in his study almost 20 years ago.

Table 9E-8: Results of Econometric Estimation of Boat Demand Equation: 1958 to 1996

	Recreational Boats—SIC 3732
Dependent Variable—Regression	**Unit Sales per Capita**
Intercept	–27.9 (–10.3)
Price	–2.0 (–2.04)
Disposable income per capita	1.83 (5.85)
Trend	–0.19 (–2.15)
Adjusted R^2	0.81
Observations (years)	39 (1958–1996)

Notes: 1. Numbers in parentheses are t-ratios (coefficient estimate divided by its standard error) (except for the year ranges in the last row of the table).
2. All exogenous and endogenous variables are in natural log.

In Table 9E-9, we present demand elasticity results for Small SI equipment. Our estimate for walk-behind lawnmowers is –0.2 (inelastic). The value obtained for other nonhandheld categories such as commercial nonriding mowers and lawn and garden tractors is higher at (–0.9, –1.0). In contrast, the demand estimate for edgers/trimmers is elastic (–1.9), suggesting that consumers are more willing to forego purchases of these items at higher prices. The edgers/trimmers' value was used for all handheld equipment. Results for generators, which range from –1.1 to –1.4, are shown in Table 9E-10.

Table 9E-9: Results of Econometric Estimation of Small SI Demand Equations: 1980 to 1997 (1973–2002 for Consumer Mowers)

Dependent Variable—Regression	Consumer Walk-Behind Mowers	Commercial Mowers	Edgers and Trimmers	Lawn and Garden Tractors
	Units Sold per Household	Units Produced	Units Produced	Units Produced
Method	3SLS	2SLS	2SLS	2SLS
Intercept	–0.64 (–2.71)	–35.19 (–4.41)	–4.69 (–0.63)	–7.22 (–1.46)
Price	–0.2 (–3.73)	–0.9 (–2.74)	–1.9 (–6.05)	–1.0 (–2.29)
Per capita income	—	4.8 (5.76)	1.47 (1.79)	2.2 (4.36)
Housing starts per HH (1 lag)	0.23 (4.71)	—	—	—
Trend	—	–0.20 (–1.58)	0.32 (2.52)	0.02 (0.26)
Adjusted or system weighted R^2	0.547	0.663	0.877	0.939
Observations (years)	29 (1973–2002)	18 (1980–97)	18 (1980–97)	18 (1980–97)

Notes:
1. Numbers in parentheses are t-ratios (coefficient estimate divided by its standard error) (except for the year ranges in the last row of the table).
2. All exogenous and endogenous variables are in natural log.
3. For lawnmowers, the income variable is actually per capita disposable income.

Table 9E-10: Results of Econometric Estimation of Gasoline-Powered Generators Demand Equations: 1973 to 1998

	Units Produced	
Dependent Variable-Regression	**Small Generators (<5kW)**	**Large Generators (>15kW)**
Intercept	16.4 (2.64)	–14.3 (–2.48)
Price	–1.4 (–3.64)	–1.1 (–8.59)
Per capita income	–0.46 (–0.71)	2.7 (4.34)
Trend	–0.02 (–0.51)	–0.16 (–1.53)
Adjusted R^2	0.609	0.723
Observations (years)	26 (1973–1998)	26 (1973–1998)

Notes:
1. Numbers in parentheses are t-ratios (coefficient estimate divided by its standard error) (except for the year ranges in the last row of the table).
2. All exogenous and endogenous variables are in natural log.

Appendix 9F: Derivation of Supply Elasticity

In economics, a production function is used to describe the relationship between inputs and outputs of the production process. The production function in general is defined as follows

$$Q^s = f(L, K, M, t)$$

Q^s = the quantity of the outputs supplied
L = the labor input or the number of labor hours
K = real capital stock or real capital consumed in the production
M = the material inputs
t = a time trend variable to reflect technology changes

In the competitive market, market forces constrain firms to produce at the cost minimizing output level. Cost minimization allows for the duality mapping of a firm's technology (summarized by the firm's production function) to the firm's economic behavior (summarized by the firm's cost function). The total cost function of an industry in the short term follows:

$$TC = h(C, K, t, Q^s)$$

where TC is the total cost of production, C is the variable cost of production (such as the cost of materials and labor), and the other variables have previous defined. This approach assumes that capital stock is fixed, or a sunk cost of production. This assumption is consistent with the goal of the modeling post-control market changes likely to occur. Firms facing proposed regulatory emission controls will consider embedded capital stock as a fixed or sunk cost in economic decision making. Differentiating the total cost function with respect to Q^s derives the marginal cost function:

$$MC = h'(C, K, t, Q^s)$$

where MC is the marginal cost of production and all other variables have been previously defined.

Profit maximizing competitive firms will choose to produce the quantity of output that equate the market price (P) to the marginal cost of the production (MC). Setting the price equal to the preceding marginal cost function and solving for Q^s yields the following implied supply function:

$$Q^s = S(P, P_L, P_M, K, t,)$$

where P is the market price of the products, P_L is the price of the labor, P_M is the price of materials, and all other variables have been previously defined.

To illustrates how the supply elasticity used in Appendix 9E can be expressed in terms of the parameters of the production function (Equation 9E.3), we assume that production function is represented by a Cobb-Douglas function with only two inputs (capital [K] and labor [L]) with a constant return to scale,

$$Q = L^{\alpha} K^{1-\alpha} \tag{9F.1}$$

where Q = output, L = labor input, and K = capital input. The cost function is written as

$$TC = wL + rK \tag{9F.2}$$

where w = wage rate or unit labor cost, r = interest cost or unit capital cost. From equation (9F.1), L can be written as,

$$L = Q^{1/\alpha} K^{(\alpha-1)/\alpha} \tag{9F.3}$$

Substituting L in the cost function with equation (9F.3),

$$TC = wL + rK = w\{Q^{1/\alpha} K^{(\alpha-1)/\alpha}\} + r\,K$$

Differentiating cost function with respect to Q, the marginal cost function is

$$MC = w\{(1/\alpha)\,Q^{(1/\alpha)-1} K^{(\alpha-1)/\alpha}\} = (w/\alpha)\,Q^{(1-\alpha)/\alpha} K^{(\alpha-1)/\alpha}$$

According to the competitive condition, P = MC, that is

$$MC = (w/\alpha)\,Q^{(1-\alpha)/\alpha} K^{(\alpha-1)/\alpha} = P$$

To rearrange the above equation, Q is expressed by a function of P and K,

$$Q = \{(\alpha/w)\,P\,K^{(1-\alpha)/\alpha}\}^{\alpha/(1-\alpha)}$$

We have

$$Q = (\alpha/w)^{\alpha/(1-\alpha)}\,P^{\alpha/(1-\alpha)}\,K \tag{9F.4}$$

Taking log function on both sides,

$$\ln Q = \alpha/(1-\alpha)\ln(\alpha/w) + \alpha/(1-\alpha)\ln P + \ln K \tag{9F.5}$$

The price elasticity of supply can be written as

$$\text{Supply elasticity} = \partial \ln Q/\partial \ln P = \alpha/(1-\alpha) \tag{9F.6}$$

Appendix 9G: Initial Market Equilibrium - Price Forecasts

The EIM analysis begins with current market conditions: equilibrium supply and demand. To estimate the economic impact of a regulation, standard practice uses projected market equilibrium (time series of prices and quantities) as the baseline and evaluates market changes from this projected baseline. Consequently, it is necessary to forecast equilibrium prices and quantities for future years.

Equilibrium price forecasts typically use one of two approaches (EPA 1999, p 5-25). The first assumes a constant (real) price of goods and services over time. The second models a specific time series where prices may change over time due to exogenous factors.

In the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time. As shown in Figure 7G-1, demand grows over time, in the long run, capacity will also grow as existing firms expand or new firms enter the market and eliminate any excess profits. This produces a flat long run supply curve. Note that in the short to medium run time frame the supply curve has a positive slope due to limitations in how quickly firms can react.

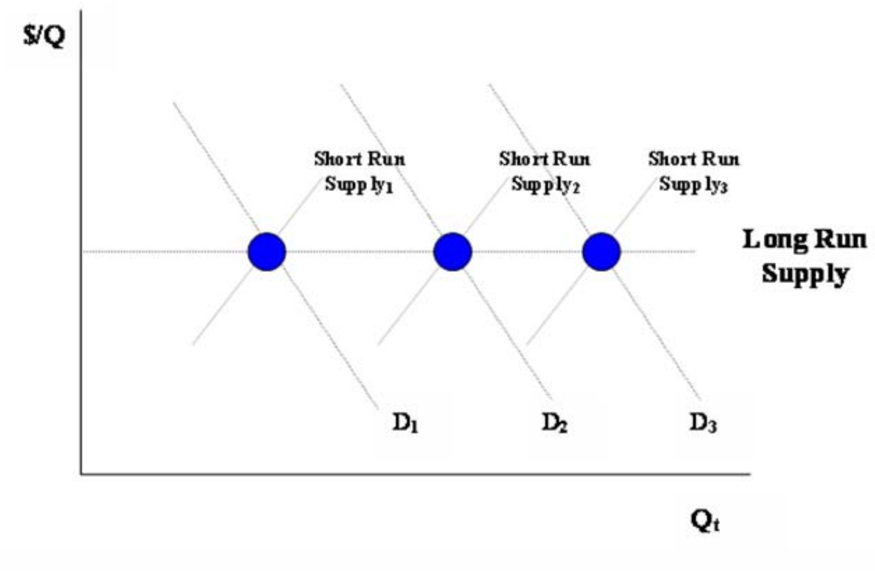

Figure 9G-1. Prices and Quantities in Long Run Market Equilibrium

If capacity is constrained (preventing the outward shift of the baseline supply curve) or if the price of production inputs increase (shifting the baseline supply curve upward over time), then prices may trend upward reflecting that either the growth in demand is exceeding supply or the commodity is becoming more expensive to produce.

It is very difficult to develop forecasts events (such as those mentioned above) that influence long run prices. As a result, the approach used in this analysis is to use a constant 2005 observed price.

Appendix 9H: Sensitivity Analysis

The Economic Impact Analysis presented in this Chapter 9 is based on the Economic Impact Model (EIM) developed for this analysis. The EIM reflects certain assumptions about behavioral responses (modeled by supply and demand elasticities), how costs are treated by producers, what the baseline equipment prices are used in the model. This appendix presents a sensitivity analysis for several alternatives in the model. Three scenarios are examined:

- Scenario 1: alternative market supply and demand elasticity parameters
- Scenario 2: alternative ways to treat engineering compliance costs
- Scenario 3: alternative baseline prices for lawn mower and tractor

The results of these sensitivity analyses are presented below. The results from Scenario 1 to 3 are presented for 2013 (the highest cost year) only with 2005$. These results for the Small SI and Marine SI engine and equipment markets do not include the fuel savings. Instead, fuel savings are added into the total social costs as a separate item.

In general, varying the elasticity parameters does not significantly change the results of the economic impact assessment analysis presented above. The expected price increase remains relative stable across the scenarios in comparing with the primary case for the Small SI and Marine SI engine and equipment. The difference in expected price change between alternative and primary scenarios is around 0.5 percent. Total social costs are about the same across all sensitivity analysis scenarios, $507 million. In addition, varying these model parameters does not significantly affect the way the social costs are borne. In all cases, the end user (households) bear the majority of the burden (over 70 percent), although there are differences in the way the costs are borne among the scenarios between the change in either demand or supply elasticity. The share of social costs end users (households) bear, for example, ranges from 70 to 90 percent.

In the alternative engineering compliance cost scenario, there are differences in the way the social costs are shared among producers and consumers in the market, although total social costs are about the same. The share of the social costs borne by either engine manufacturer or equipment manufacturer increases under this scenario because engines and equipment manufactures can not recover the fixed cost required in this rule. Especially for the Small SI market, the difference in the share of social cost borne by engine and equipment manufacturer is more than 16 percent.

With regard to the scenario of alternative baseline prices, although the difference in prices is about 25.5% and 53.0% for lawn mower and tractors, respectively, the estimates on absolute price change and social cost for each market are approximately the same as in the base case. However, given that the baseline prices are different in these scenarios, there is some variation in projected relative price and quantity change across the scenarios. The expected changes in relative prices and quantity increase under the lower alternative baseline market price scenarios.

9H.1 Model Elasticity Parameters

Consumer demand and producer supply responsiveness to changes in the commodity prices are referred to by economists as “elasticity.” The measure is typically expressed as the percentage change in quantity (demanded or supplied) brought about by a percent change in own price. A detailed discussion regarding the estimation and selection of the elasticities used in the EIM are discussed in Appendix 9E. This component of the sensitivity analysis examines the impact of changes in selected elasticity values, holding other parameters constant. The goal is to determine whether alternative elasticity values significantly alter conclusions in this report.

9H.1.1 Alternative Supply and Demand Elasticity Parameters

The choice of supply and demand elasticities for the *engine and equipment market* is important because changes in quantities in the equipment markets are the key drivers in the derived demand functions used to link impacts in the engine and equipment markets. In addition, the distribution of regulatory costs depends on the *relative supply and demand elasticities* used in the analysis. For example, consumers will bear less of the regulatory burden if they are more responsive to price changes than producers.

Table 9H-1 reports the upper- and lower-bound values of the engine and equipment market elasticity parameters (supply and demand) used in the sensitivity analysis. The engine and equipment market supply elasticities are derived econometrically. Therefore, the upper and lower bound values were computed using the coefficient and standard error values associated with the econometric analysis and reflect a 95 percent confidence interval (see Appendix 9E).

Table 9H-1: Alternative Supply and Demand Elasticities Used in Sensitivity Analysis[a]

Parameter/Market	Upper Bound	Primary Case	Lower Bound
Supply Elasticities			
Engines			
Marine and Small SI	4.2	3.8	3.5
Equipment			
Marine SI			
All other vessel types	2.5	2.3	2.1
PWC	3.5	3.4	3.2
Small SI			
Small SI (handheld/nonhandheld)	3.9	3.4	3.0
Gensets/welders	3.6	3.3	2.9
Demand Elasticities			
Engines			
Marine and Small SI	Derived Demand	Derived Demand	Derived Demand
Equipment			
Marine SI			
All vessel types	–3.9	–2.0	–0.1
Small SI			
Handheld	–2.5	–1.9	–1.3
Lawn mowers	–0.3	–0.2	–0.1
Other lawn and garden	–1.5	–0.9	–0.3
Gensets/welders—Class I	–2.2	–1.4	–0.6
Gensets/welders—Class II	–1.4	–1.1	–0.8
All other handheld	–1.9	–1.0	–0.1

[a] EPA computed upper- and lower-bound estimates using the coefficient and standard error values associated with its econometric analysis and reflect a 95 percent confidence interval (Appendix 9E).

9H.1.2 Engines and Equipment Market (Supply Elasticity Parameters)

The results of the EIM using these alternative supply elasticity values for the Small SI and Marine SI engine and equipment markets are reported in Tables 9H-2. As can be seen in the table, projected changes in market prices are stable across the upper- and lower-bound sensitivity scenarios. The relative change in price is around the primary case by 0.1 percent. Absolute quantities vary but the percentage changes in output are negligible for the two scenarios. The change in total social surplus for 2013 also remains nearly unchanged across all scenarios and is approximately the same as for the rule ($507 million).

However, varying the supply elasticity changes the social impacts (how the burden is shared across markets). Manufacturers bear a *smaller* share of the social costs when they are more responsive to price changes (supply upper bound scenario). As shown for the Small SI market, engine and equipment manufacturers bear approximately 3.8 and 16.0 percent, respectively, in the supply upper bound scenario compared to 4.0 and 17.6 percent in the base case. In contrast, they bear a *higher* share of social cost when they are less responsive to price changes relative to the base case (the supply lower bound scenario). For the Marine SI market, engine and equipment manufacturers bear approximately 10.8 and 21.6 percent, respectively, in supply upper bound scenario compared to 11.4 and 22.4 percent in the base case. In contrast, they bear a *higher* share when they are less responsive to price changes relative to the base case (supply lower bound scenario).

Table 9H-2: Sensitivity Analysis for Engine and Equipment Market Supply Elasticities for 2013 [a,b]

Scenario	Primary Case		Supply Lower Bound		Supply Upper Bound	
	Absolute	Relative[b]	Absolute	Relative[b]	Absolute	Relative[b]
Marine						
Market-Level Impacts						
Price						
Engines	$256.8	2.3%	$255.1	2.3%	$259.3	2.3%
Equipment	$231.7	1.3%	$222.0	1.3%	$240.8	1.4%
Quantity						
Engines	–8,846	–2.0%	–8,406	–1.9%	–9,297	–2.1%
Equipment	–10,847	–2.7%	–10,443	–2.6%	–11,196	–2.8%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$21.5	11.4%	$22.3	11.8%	$20.4	10.8%
Change in equipment manufacturers surplus	$42.2	22.4%	$44.1	23.3%	$40.8	21.6%
Change in end user (households) surplus	$125.1	66.2%	$122.7	64.9%	$127.6	67.6%
Small SI						
Market-Level Impacts						
Price						
Engines	$22.3	11.7%	$22.2	11.7%	$22.3	11.8%
Equipment	$13.8	3.1%	$13.5	*3.1%*	$14.2	*3.2%*
Class I	$18.6	6.9%	$18.3	*6.9%*	$18.9	*7.0%*
Class II	$40.5	3.9%	$39.1	*3.8%*	$41.6	*4.0%*
HH	$0.3	0.3%	$0.3	*0.3%*	$0.3	*0.4%*
Quantity						
Engines	–371,097	–2.35	–361,097	–2.3%	–380,910	–2.4%
Equipment	–482,942	–1.9%	–467,931	*–1.8%*	–498,041	*–1.9%*
Class I	–219,400	–2.2%	–214,334	*–2.2%*	–224,691	*–2.3%*
Class II	–157,306	–4.3%	–152,207	*–4.1%*	–161,996	*–4.4%*
HH	–106,236	–0.6%	–101,390	*–0.6%*	–111,354	*–0.7%*
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$18.4	4.0%	$19.4	*4.3%*	$17.1	*3.8%*
Change in equipment manufacturers surplus	$80.2	17.6%	$88.1	*19.4%*	$72.6	*16.0%*
Change in end user (households) surplus	$356.0	78.3%	$347.1	*76.4%*	$364.6	80.3%
Subtotal Social Costs (million $)	$643.4		$643.7		$643.1	
Fuel Savings (million $)	$136.5		$136.5		$136.5	
Total Social Costs (million $)	$506.9		$507.1		$506.6	

[a] Figures are in 2005 dollars.

[b] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the distribution of total surplus changes among stakeholders (consumers and producers).

9H.1.3 Equipment Market (Demand Elasticity Parameters)

Sensitivity analysis was also conducted for the equipment market demand elasticities. The range of demand elasticity values evaluated for each market are provided in Table 9H-1. The demand elasticities for the engine markets are derived as part of the model, and therefore sensitivity analysis was not conducted on those parameters.[16] In other words, the change in the equipment market quantities determines the demand responsiveness in the engine market. As a result, the demand sensitivity analysis for engine markets is indirectly shown in Table 9H-2.

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[16] For a discussion of the concept of derived demand, see Section 9.2.3.2 Incorporating Multimarket Interactions.

Table 9H-3: Sensitivity Analysis for Equipment Market Demand Elasticities for 2013 [a,b]

	Primary Case		Demand Lower Bound		Demand Upper Bound	
Scenario	**Absolute**	**Relative[b]**	**Absolute**	**Relative[b]**	**Absolute**	**Relative[b]**
Marine						
Market-Level Impacts						
Price						
Engines	$256.8	2.3%	$301.6	2.8%	$242.5	2.1%
Equipment	$231.7	1.3%	$448.4	2.5%	$157.4	0.9%
Quantity						
Engines	–8,846	–2.0%	–972	–0.2%	–11,205	–2.6%
Equipment	–10,847	–2.7%	–1,016	–0.2%	–14,646	–3.6%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$21.5	11.4%	$2.3	1.2%	$27.6	14.7%
Change in equipment manufacturers surplus	$42.2	22.4%	$4.0	2.1%	$56.2	30.0%
Change in end user (households) surplus	$125.1	66.2%	$185.7	96.7%	$103.8	55.3%
Small SI						
Market-Level Impacts						
Price						
Engines	$22.3	11.7%	$23.0	12.1%	$21.7	11.5%
Equipment	$13.8	3.1%	$16.4	3.5%	$12.1	2.8%
Class I	$18.6	6.9%	$20.4	7.6%	$17.1	6.4%
Class II	$40.5	3.9%	$46.4	4.4%	$36.3	3.6%
HH	$0.3	0.3%	$0.3	0.4%	$0.3	0.3%
Quantity						
Engines	–371,097	–2.35	–136,358	–0.9%	–542,349	–3.4%
Equipment	–482,942	–1.9%	–219,030	*–0.8%*	–676,766	*–2.6%*
Class I	–219,400	–2.2%	–78,053	*–1.0%*	–328,416	*–3.3%*
Class II	–157,306	–4.3%	–59,011	*–3.0%*	–222,780	*–5.2%*
HH	–106,236	–0.6%	–81,967	*–0.5%*	–125,569	*–0.8%*
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$18.4	4.0%	$7.0	1.5%	$26.3	5.8%
Change in equipment manufacturers surplus	$80.2	17.6%	$26.1	5.7%	$116.1	25.7%
Change in end user (households) surplus	$356.0	78.3%	$424.9	92.8%	$309.6	68.5%
Subtotal Social Costs (million $)	$643.4		$650.0		$639.6	
Fuel Savings (million $)	$136.5		$136.5		$136.5	
Total Social Costs (million $)	**$506.9**		**$513.5**		**$503.1**	

[a] Figures are in 2005 dollars.

[b] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the distribution of total surplus changes among stakeholders (consumers and producers).

As shown in Tables 9H-3, market prices are relative stable across the upper- and lower-bound sensitivity scenarios. The relative change in price is around the primary case by 0.5 percent. Absolute quantities vary and the percentage changes in output are small for the two scenarios. There is also a small change in total social surplus for 2013 compared to the primary case ($507 million) but this is negligible in terms of the percentage change.

In comparing Table 9H-3 with Table 9H-2 , all quantitative estimates for the market impacts (price and quantity changes) by the EIM model are a little more sensitive to the alternative demand elasticities than the alternative supply elasticities. However, theses changes remain in a reasonable range when compared with the rule, across both the upper and lower bound demand elasticity scenarios for the equipment markets.

It should be noted, varying the demand elasticity changes the social impacts (how the burden is shared across markets) as in the case of changing the supply elasticity. Manufacturers bear a *smaller* share of the social costs when consumers are less responsive to price changes (demand lower bound scenario). As shown for the Small SI market, engine and equipment manufacturers bear approximately 1.5 and 5.7 percent, respectively, in the demand lower bound scenario compared to 4.0 and 17.6 percent in the base case. In contrast, they bear a *higher* share of social cost when consumers are more responsive to price changes relative to the base case (the demand upper bound scenario). For the Marine SI market, engine and equipment manufacturers bear approximately 1.2 and 2.1 percent, respectively, in demand lower bound scenario compared to 11.4 and 22.4 percent in the base case. In contrast, they bear a *higher* share when consumers are more responsive to price changes relative to the base case (demand upper bound scenario).

9H.2 Engine and Equipment Variable Cost Shift Scenario

As discussed in Section 9.2, the total costs (fixed plus variable cost) are used to shift the supply curve in the engines and equipment markets. This is because Small SI and Marine SI engine and equipment manufacturers produce a product that changes very little over time. These manufacturers do not engage in research and development to improve their products on a continuous basis (as opposed to highway vehicles or nonroad engines and equipment). The product changes that would be required to comply with the proposed standards will require these manufacturers to devote new funds and resources to product redesign and facilities changes. Therefore, Small SI and Marine SI engine and equipment manufacturers are expected to increase their prices by the full amount of the compliance costs to recover those costs. This is in contrast to the nonroad diesel engine and equipment markets: manufacturers in those markets generally allocate redesign resources each year to accommodate a changing market. The sensitivity analysis was performed to investigate the impacts under the alternative scenario of shifting the supply curve by the variable costs only. The results of that analysis are shown at Table 9H-4.

In this scenario, engine and equipment manufacturers are able to pass along the variable compliance costs only rather than full costs including the fixed compliance costs. As expected, this scenario leads to a lower projected price increases for the engine and equipment markets (from 11.7 and 3.1 percent in the baseline case to 10.3 and 2.7 percent for Small SI engine and equipment markets; from 2.3 and 1.3 percent in the baseline case to 2.2 and 1.2 percent for Marine SI engine and equipment markets). The share of the social costs borne by Small SI engine and equipment manufacturers are increased by 10.4 and 5.9 percent, respectively. The share of the social costs borne by Marine SI engine and equipment manufacturers are also increased by 2.7 and 0.4 percent, respectively. However, the total social costs of the regulation are not expected to change measurably as the lower prices lead to almost no change in the demand for equipment and engines.

Table 9H-4: Variable Costs only to Shift Supply Curve in Engine and Equipment Markets for 2013 [a,b]

	Fixed and Variable Cost Supply Shift Scenario		Variable Cost Only Supply Shift Scenario	
Scenario	**Absolute**	**Relative[b]**	**Absolute**	**Relative[b]**
Marine				
Market-Level Impacts				
Price				
Engines	$256.8	2.3%	$245.0	2.2%
Equipment	$231.7	1.3%	$219.9	1.2%
Quantity				
Engines	–8,846	–2.0%	–8,264	–1.9%
Equipment	–10,847	–2.7%	–10,136	–2.5%
Welfare Impacts (million $)				
Change in engine manufacturers surplus	$21.5	11.4%	$26.7	14.1%
Change in equipment manufacturers surplus	$42.2	22.4%	$43.0	22.8%
Change in end user (households) surplus	$125.1	66.2%	$119.3	63.1%
Small SI				
Market-Level Impacts				
Price				
Engines	$22.3	11.7%	$19.3	10.3%
Equipment	$13.8	3.1%	$11.0	2.7%
Class I	$18.6	6.9%	$16.1	6.0%
Class II	$40.5	3.9%	$30.1	3.1%
HH	$0.3	0.3%	$0.3	0.3%
Quantity				
Engines	–371,097	–2.35	–309,280	–1.9%
Equipment	–482,942	–1.9%	–419,339	–1.6%
Class I	–219,400	–2.2%	–189,939	–1.9%
Class II	–157,306	–4.3%	–125,945	–3.3%
HH	–106,236	–0.6%	–105,454	–0.6%
Welfare Impacts (million $)				
Change in engine manufacturers surplus	$18.4	4.0%	$65.8	14.4%
Change in equipment manufacturers surplus	$80.2	17.6%	$107.1	23.5%
Change in end user (households) surplus	$356.0	78.3%	$283.6	62.1%
Subtotal Social Costs (million $)	$643.4		$645.5	
Fuel Savings (million $)	$136.5		$136.5	
Total Social Costs (million $)	**$506.9**		**$509.0**	

[a] Figures are in 2005 dollars

[b] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the distribution of total surplus changes among stakeholders (consumers and producers).

9H.3 Alternative Baseline Prices for Lawn Mower & Tractor

As discussed in Section 9.3.2, the starting point for the economic impact analysis is initial market equilibrium conditions (prices and quantities) that exist prior to the implementation of new standards. At the pre-control market equilibrium conditions, consumers are willing to purchase the same amount of a product that producers are willing to produce at the market price. Since the lawn mower and tractor equipment are the most popular equipment in the Small SI market and their prices range widely, a sensitivity analysis was performed to examine how alternative baseline prices for lawn mower and tractor influence the EIM results.

Table 9H-5: Market Sensitivity Analysis for Alternative Baseline for Lawnmower & Tractor Prices in 2013 [a,b]

		Market Results				Welfare Results		
Scenario	Average Baseline Price	Change in Price (Absolute)	Change in Price (%)	Change in Quantity (Absolute)	Change in Quantity (%)	Change in End Users (Households) Surplus (Million $)	Change in Equipment Manufacturer Surplus (Million $)	Change in Total Surplus (Million $)
Lawn Mowers								
Primary scenario	$243	$14.38	5.9%	–90,263	–1.1%	–$115	–$6	–$121
Low price scenario	$181	$14.29	7.9%	–120,912	–1.5%	–$114	–$6	–$120
Tractors								
Primary scenario	$1,937	$35.15	1.8%	–35,706	–1.8%	–$69	–$20	–$89
Low price scenario	$928	$34.69	3.7%	–73,559	–3.7%	–$67	–$20	–$87

[a] Figures are in 2005 dollars.

We selected the lower end market prices as the alternative baseline prices for lawn mower and tractor in this sensitivity analysis. As shown in Table 9H-5, when these pre-control baseline prices are allowed to vary, the absolute change in market prices remains nearly unchanged when compared with the rule, although the relative price change and absolute quantity change are expected to be higher in the alternative baseline price case. This is because the change in absolute price is ultimately determined by the per unit compliance cost and market supply and demand elasticities. In contrast, the change in relative price is determined by the ratio between the per-unit compliance cost and the baseline price. The lower the initial baseline price, the higher the ratio is for a given per unit compliance cost. Therefore, the change in the relative price is higher. In this market, consumers are expected to response to the higher relative price change by purchasing less equipment. As a result, the expected change for quantity is higher in the lower baseline prices case. Also as seen in Table 9H-5, varying the baseline prices are not expected to substantially change the social cost estimates in these markets or alter the distribution of the social costs across the stakeholders.

CHAPTER 10: Small-Business Flexibility Analysis

This chapter discusses our Initial Regulatory Flexibility Analysis (IRFA) which evaluates the potential impacts of the proposed standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Pursuant to this requirement, we have prepared an IRFA for the proposed rule. Throughout the process of developing the IRFA, we conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking to gain feedback, including recommendations, on how to reduce the impact of the rule on these entities. The small business recommendations stated here reflect the comments of the small entity representatives (SERs) and members of the Small Business Advocacy Review Panel (SBAR Panel, or ‘the Panel’).

10.1 Overview of the Regulatory Flexibility Act

In accordance with section 609(b) of the Regulatory Flexibility Act, we convened an SBAR Panel before conducting the IRFA. A summary of the Panel’s recommendations is presented in the preamble of this proposed rulemaking. Further, a detailed discussion of the Panel’s advice and recommendations is found in the Final Panel Report contained in the docket for this proposed rulemaking.

Section 609(b) of the Regulatory Flexibility Act further directs the Panel to report on the comments of small entity representatives and make findings on issues related to identified elements of the IRFA under section 603 of the Regulatory Flexibility Act. Key elements of an IRFA are:

- A description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;
- Projected reporting, record keeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record;
- An identification to the extent practicable, of all other relevant Federal rules which may duplicate, overlap, or conflict with the proposed rule;
- Any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the proposed rule on small entities.

The Regulatory Flexibility Act was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although we are not required by the Clean Air Act to provide special treatment to small businesses, the Regulatory Flexibility Act requires us to carefully consider the economic impacts that our rules will have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with Clean Air Act requirements.

10.2 Need for the Rulemaking and Rulemaking Objectives

A detailed discussion on the need for and objectives of this proposed rule are located in the preamble to the proposed rule. As presented in Chapter 8, controlling exhaust and evaporative emissions from Small SI engines and equipment and Marine SI engines and vessel has important public health and welfare benefits.

Section 213(a) of the CAA directs EPA to: (1) conduct a study of emissions from nonroad engines and vehicles; (2) determine whether emissions of CO, NOx, and VOCs from nonroad engines and vehicles are significant contributors to ozone or CO in more than one area which has failed to attain the National Ambient Air Quality Standard (NAAQS) for ozone or CO; and (3) if nonroad emissions are determined to be significant, regulate those categories or classes of new nonroad engines and vehicles that cause or contribute to such air pollution. Section 213(a)(3) states that the emission standards "shall achieve the greatest degree of emission reduction achievable through the application of technology" giving appropriate consideration to cost, noise, energy, safety, and lead time.

The Nonroad Engine and Vehicle Emission Study required by section 213(a)(1) was completed in November 1991. The determination of the significance of emissions from nonroad engines and vehicles in more than one NAAQS nonattainment area was published on June 17, 1994. At the same time, the first set of regulations for new land-based nonroad compression-ignition (CI) engines at or above 37 kW was promulgated. EPA has also issued proposed or final rules for most other categories of nonroad engines, including engines used in lawn and garden equipment, recreational marine vessels, forklifts, recreational vehicles, locomotives, and ships. In addition, EPA has revised the emission standards for many of these categories of nonroad engines one or more times to achieve further emission reductions.

In addition to the general authority to regulate nonroad engines under the CAA, section 428 of the Omnibus Appropriations Bill for 2004 requires EPA to propose and finalize new regulations for nonroad spark-ignition engines less than 50 horsepower (hp). The Bill directs EPA to propose regulations by December 1, 2004 and finalize them by December 31, 2005. EPA's assessment of new standards is to be carried out under section 213 of the CAA.

Finally, section 205 of Public Law 109-54 included an additional requirement that EPA complete a technical study, to look at safety issues related to the potential standards called for under the Omnibus Appropriations Bill for 2004. The law directed EPA to complete the study prior to issuing the proposal called for in the Omnibus Appropriations Bill for 2004. In response to this requirement, EPA prepared a technical study on safety in coordination with the Consumer Product Safety Commission (CPSC). The study analyzes the incremental risk of fire and burn to consumers that could result from the new standards. EPA published the study in March 2006.

In response to these requirements, today's action proposes controls on exhaust and evaporative emissions from Small SI engines and equipment and Marine SI engines and vessels.

10.3 Definition and Description of Small Entities

Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the proposed rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration's (SBA) size standards (see Table 10.3-1); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field. Table 10.3-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 10.3-1: Small Business Definitions for Entities Affected by this Rule

Industry	NAICS Codes[a]	Defined as small entity by SBA if less than or equal to:[b]
Nonroad SI Engine Manufacturers	333618	1,000 employees
Equipment Manufacturers:		
Farm Machinery	333111	500 employees
Lawn and Garden	333112	500 employees
Construction	333120	750 employees
Sawmill and Woodworking	333210	500 employees
Pumps	333911	500 employees
Air and Gas Compressors	333912	500 employees
Generators	335312	1,000 employees
Boat Builders	336612	500 employees
Fuel Tank Manufacturers:		
Other Plastic Products	326199	500 employees
Metal Stamping	332116	500 employees
Metal Tank (Heavy Gauge)	332420	500 employees
Fuel Hose Manufacturers:		
Rubber and Plastics Hoses	326220	500 employees

[a] North American Industry Classification System

[b] As defined in SBA's regulations at 13 CFR part 121.

10.3.1 Small SI Engines and Equipment

For Small SI engines and equipment, the SBA small business size standards are 1,000 employees for engine manufacturers, 1,000 employees for generator manufacturers, 750 employees for construction equipment manufacturers, and 500 employees for manufacturers of other types of equipment. To identify companies that meet these criteria, we compiled a list of engine manufacturers and equipment manufacturers using information from a database prepared by Power Systems Research (PSR) that contains data on Small SI engines and equipment sold in the United States. EPA augmented this information with the list of engine manufacturers currently certifying with EPA under the Small SI engine regulations. We then found employment data for each company (or parent company if an individual company is part of a larger group) using databases such as the Thomas Register and Dunn and Bradstreet.

The SBA small business size standard for manufacturers that produce fuel tanks or fuel hose is 500 employees. To identify companies that meet this criterion, we compiled a list of manufacturers that produce fuel tanks and fuel hoses for the Small SI equipment market. The list was based on information from the California Air Resources Board, who has recently adopted requirements for Small SI engine fuel tank and fuel hose manufacturers, and additional information from Small SI equipment manufacturers and the Association of Rotational Molders International. We then found employment data for each of the companies (or parent company if an individual company is part of a larger group) using databases such as Thomas Register and onesourceexpress.com and discussions with some of the manufacturers.

10.3.2 Marine SI Engines and Vessels

For Marine SI engines and vessels, the SBA small business size standards are 1,000 employees for engine manufacturers and 500 employees for boat builders. To identify companies that meet these criteria, we used a number of different sources. For engine manufacturers, we compiled a list based on the engine manufacturers currently certifying with EPA and the California Air Resources Board (CARB) under the existing Marine SI engine regulations and augmented the list with additional information on SD/I manufacturers, who do not currently have to certify with EPA. We gathered additional information from boat shows, the Internet, trade magazines, the National Marine Manufacturers Association (NMMA), and discussions with individual manufacturers. For vessel manufacturers, we used information from a database of boat builders maintained by the U.S. Coast Guard.

The SBA small business size standard for manufacturers that produce fuel tanks or fuel hose is 500 employees. For fuel tank and fuel hose manufacturers, we compiled a list based on information gathered from the NMMA, trade shows, the Internet and discussions with manufacturers. We then found employment data for these companies (or parent company if an individual company is part of a larger group) using databases such as Thomas Register and discussions with trade groups and individual manufacturers.

10.4 Summary of Small Entities to Which the Rulemaking Will Apply

As noted above, for each sector impacted by this proposal, SBA defines small entities by number of employees. This section gives an overview of the Small SI engine and equipment industries and the Marine SI engine and vessel industries, specifically related to small businesses.

10.4.1 Small SI Engines and Equipment

Based on EPA certification records, the Small SI nonhandheld engine industry is made up primarily of large manufacturers including Briggs and Stratton, Tecumseh, Honda, Kohler and Kawasaki. The Small SI handheld engine industry is also made up primarily of large manufacturers including Electrolux Home Products, MTD, Homelite, Stihl and Husqvarna. EPA has identified 10 Small SI engine manufacturers that qualify as a small business under SBA definitions. Half of these small manufacturers certify gasoline engines and the other half certify liquefied petroleum gas (LPG) engines.

The Small SI equipment market is dominated by a few large businesses including Toro, John Deere, MTD, Briggs and Stratton, and Electrolux Home Products. While the Small SI equipment market may be dominated by just a handful of companies, there are many small businesses in the market; however these small businesses account for less than 10 percent of equipment sales. We have identified over three hundred equipment manufacturers that qualify as a small business under the SBA definitions. More than 90 percent of these small companies manufacture less than 5,000 pieces of equipment per year. The median employment level is 65 employees for nonhandheld equipment manufacturers and 200 employees for handheld equipment manufacturers. The median sales revenue is approximately $9 million for nonhandheld equipment manufacturers and $20 million for handheld equipment manufacturers.

EPA has identified 25 manufacturers that produce fuel tanks for the Small SI equipment market that meet the SBA definition of a small business. Fuel tank manufacturers rely on three different processes for manufacturing plastic tanks – rotational molding, blow molding and injection molding. EPA has identified small business fuel tank manufacturers using the rotational molding and blow molding processes but has not identified any small business manufacturers using injection molding. In addition, EPA has identified two manufacturers that produce fuel hose for the Small SI equipment market that meet the SBA definition of a small business. The majority of fuel hose in the Small SI market is made by large manufacturers including Avon Automotive and Dana Corporation.

10.4.2 Marine SI Engines and Vessels

Based on EPA certification records, the OB/PWC market is made up primarily of large manufacturers including, Brunswick (Mercury), Bombardier Recreational Products, Yamaha, Honda, Kawasaki, Polaris, Briggs & Stratton, Nissan, and Tohatsu. One company that qualifies as a small business under the SBA definitions has certified their product as a PWC. This company is Surfango who makes a small number of motorized surfboards.

The SD/I market is made up mostly of small businesses; however, these businesses account for less than 20 percent of engine sales. Two large manufacturers, Brunswick

(Mercruiser) and Volvo Penta, dominate the market. We have identified 28 small entities manufacturing SD/I marine engines. The third largest company is Indmar, which qualifies as a small business based on the SBA threshold of 1,000 employees. Based on sales estimates, number of employees reported by Thomas Register, and typical engine prices, we estimate that the average revenue for the larger small SD/I manufacturers is about $50-60 million per year. However, the vast majority of the SD/I engine manufacturers produce low production volumes of engines and typically have less than 50 employees.

The two largest boat building companies are Brunswick and Genmar. Brunswick owns approximately 25 boat companies and Genmar owns approximately 12 boat companies. Based on a manufacturer list maintained by the U.S. Coast Guard, there are over 1,600 boat builders in the United States. We estimate that, based on manufacturer identification codes, more than 1,000 of these companies produce boats using gasoline marine engines. According to the National Marine Manufacturers Association (NMMA), most of these boat builders are small businesses. These small businesses range from individuals building one boat per year to businesses near the SBA small business threshold of 500 employees.

We have identified 15 marine fuel tank manufacturers in the United States that qualify as small businesses under the SBA definition. These manufacturers include five rotational molders, three blow molders, six aluminum fuel tank manufacturers, and one specialty fuel tank manufacturer. The small rotational molders average less than 50 employees while the small blow-molders average over 100 employees. Moeller qualifies as a large business because they are owned by Moore; however, their rotational molding business is a small part of the company and operates similar to the smaller businesses. Other blow-molders are in the same situation such as Attwood which is owned by Brunswick.

We have only identified one small hose manufacturer that produces for the Marine SI market. Novaflex primarily distributes hoses made by other manufacturers, but does produce its own fill neck hose. Because we expect vessel manufacturers will design their fuel systems such that there will not be standing liquid fuel in the fill neck (and therefore the proposed low permeation fuel hose requirements will not apply to the fill neck), we have not included this manufacturer in our analysis. The majority of fuel hose in the Marine SI market is made by large manufacturers including Goodyear and Parker-Hannifin.

10.5 Related Federal Rules

For Small SI engines and equipment, the primary federal rules that are related to the rule under consideration are EPA Phase 1 rule for Small SI engines (60 FR 34582, July 3, 1995), EPA Phase 2 rule for Small SI nonhandheld engines (64 FR 15208, March 30, 2004), and EPA Phase 2 rule for Small SI handheld engines (65 FR 24268, April 25, 2000). For Marine SI engines and vessels, the primary federal rule that is related to the rule under consideration is EPA October 1996 final rule (61 FR 52088, October 4, 1996).

Three other federal agencies have regulations that relate to the equipment and vessels under consideration. These agencies are the Consumer Product Safety Commission (CPSC), United States Department of Agriculture (USDA), and the United States Coast Guard (USCG). CPSC has safety requirements that apply to walk-behind lawnmowers to protect operators of such equipment. USDA has design requirements intended to reduce the potential fire threat of Small SI equipment. The USCG has safety regulations for marine engine and fuel system designs. The USCG safety regulations include standards for exhaust system temperature, fuel tank durability, and hose designs, including specific requirements related to system survivability in a fire. Manufacturers will need to consider both EPA and other federal standards when certifying their products.

10.6 Projected Reporting, Recordkeeping, and Other Compliance Requirements

For any emission control program, EPA must have assurances that the regulated products will meet the standards. Historically, EPA programs for Small SI engines and Marine SI engines have included provisions placing engine manufacturers responsible for providing these assurances. The program that EPA is considering for manufacturers subject to this proposal may include testing, reporting, and record keeping requirements for manufacturers of engines, equipment, and vessels, and may also include fuel system component manufacturers if they choose to certify their fuel tank, fuel hose, and fuel cap products.

For Small SI engine manufacturers and OB/PWC engine manufacturers, EPA is proposing to continue the same reporting, record keeping, and compliance requirements prescribed in the current regulations. For SD/I engine manufacturers, which are not currently subject to EPA regulation, EPA is proposing to apply similar reporting, record keeping, and compliance requirements to those for OB/PWC engine manufacturers. Testing requirements for engine manufacturers would include certification emission (including deterioration factor) testing and production line testing. Reporting requirements would include emission test data and technical data on the engines. Manufacturers would also need to keep records of this information.

Because of the proposed evaporative emission requirements, there would be new reporting, record keeping and compliance requirements for Small SI equipment manufacturers. Small SI equipment manufacturers participating in the proposed transition program would also be subject to reporting, record keeping and compliance requirements. Depending on who chooses to certify fuel system components, there may also be new reporting, record keeping and compliance requirements for fuel tank manufacturers, fuel hose manufacturers, fuel cap manufacturers, and marine vessel manufacturers. Testing requirements for these manufacturers could include certification emission testing. Reporting requirements could include emission test data and technical data on the designs. Manufacturers would also need to keep records of this information.

10.7 Regulatory Alternatives

The Panel developed a wide range of regulatory alternatives to mitigate the impacts of the rulemaking on small businesses, and recommended that we propose and seek comment on the flexibilities. The Panel's findings and discussions are based on the information that was available during the term of the Panel and issues that were raised by the SERs during the outreach meetings and in their written comments. It was agreed that EPA should consider the issues raised by the SERs (and issues raised in the course of the Panel) and that EPA should consider the comments on flexibility alternatives that would help to mitigate any negative impacts on small businesses. Alternatives discussed throughout the Panel process include those offered in the development of the upcoming rule. Though some of the recommended flexibilities may be appropriate to apply to all entities affected by the rulemaking, the Panel's discussions and recommendations are focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations, along with those provisions that we are actually proposing in this action, are detailed below. A full discussion of the regulatory alternatives and hardship provisions discussed and recommended by the Panel, all written comments received from SERs, and summaries of the two outreach meetings that were held with the SERs can be found in the SBREFA Final Panel Report.[1] In addition, all of the flexibilities that are being proposed in the rulemaking for small businesses, as well as those for all entities that may be affected by the rulemaking, are described in the preamble to the proposed rule.

10.7.1 Small SI Exhaust Emission Standards

Described below are the flexibility options recommended by the Panel and our proposed regulatory alternatives related to the Small SI nonhandheld engine exhaust emission standards.

10.7.1.1 Regulatory Flexibility Options for Nonhandheld Engine Manufacturers

10.7.1.1.1 SBAR Panel Recommendations

Additional Lead Time for Nonhandheld Engine Manufacturers - The Panel recommended that EPA propose two additional years of lead time before the Phase 3 standards take effect for small business engine manufacturers. For Class I engines, the effective date for small business engine manufacturers would be 2014. For Class II engines, the effective date for small business engine manufacturers would be 2013.

Assigned Deterioration Factors - The Panel recommended EPA propose that small business engine manufacturers be allowed the option to use EPA-developed assigned deterioration factors in demonstrating compliance with the Phase 3 exhaust emission standards.

Production Line Testing Exemption - The Panel recommended EPA propose that small business engine manufacturers be exempted from the production line testing requirements for the Phase 3 exhaust emission standards.

Broader Definition of Engine Family - The Panel recommended that EPA propose allowing small business engine manufacturers to group all of their Small SI engines into a single engine family for certification by engine class and useful life category, subject to good engineering judgment.

__Eligibility for the Small Business Flexibilities__ - For purposes of determining which engine manufacturers are eligible for the small business flexibilities described above, EPA is proposing criteria based on a production cut-off of 10,000 nonhandheld engines per year for engine manufacturers. The Panel recommended that EPA propose to allow engine manufacturers which exceed the production cut-off levels noted above but meet the SBA definitions for a small business (i.e., fewer than 1,000 employees for engine manufacturers), to request treatment as a small business.

10.7.1.1.2 EPA's Proposed Regulatory Flexibility Options

In general, we have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions.

__Additional Lead Time for Nonhandheld Engine Manufacturers__ - We are proposing that small-volume engine manufacturers could delay implementation of the Phase 3 exhaust emission standards for two years (see §1045.145). Small-volume engine manufacturers would be required to comply with the Phase 3 exhaust emission standards beginning in model year 2014 for Class I engines and model year 2013 for Class II engines. Under this approach, we propose that manufacturers would be able to apply this delay to all their nonhandheld engines or to just a portion of their production. They could therefore sell engines that meet the Phase 3 standards on some product lines while delaying introduction of emission control technology on more challenging product lines. This option provides more time for small-volume engine manufacturers to redesign their products. They would also be able to learn from some of the hurdles overcome by larger manufacturers.

__Assigned Deterioration Factors__ - We are proposing that small-volume engine manufacturers may rely on an assigned deterioration factor to demonstrate compliance with the standards rather than doing service accumulation and additional testing to measure deteriorated emission levels at the end of the regulatory useful life (see §1054.240). EPA is not proposing actual levels for the assigned deterioration factors with this proposal. EPA intends to analyze emissions deterioration information that becomes available over the next few years to determine what deterioration factors would be appropriate for nonhandheld engines. This data is likely to include deterioration data for engines certified to comply with CARB's Tier 3 standards and engines certified early to EPA's Phase 3 standards. Prior to the implementation date for the Phase 3 standards, EPA would provide guidance to engine manufacturers specifying the levels of the assigned deterioration factors for small-volume engine manufacturers.

__Production Line Testing Exemption__ - We are proposing that small-volume engine manufacturers would be exempt from the production-line testing requirements (see §1054.301). While we are proposing to exempt small volume engine manufacturers from production line testing, we believe requiring limited production-line testing could be beneficial to remind manufacturers they have an ongoing obligation to assure production engines are complying with the standards. Therefore, we request comment on the alternative of applying limited production-line testing to small volume engine manufacturers with a requirement to test one production engine per year.

Broader Definition of Engine Family - We are proposing that small-volume engine manufacturers may use a broader definition of engine family for certification purposes. Under the existing engine family criteria specified in the regulations, manufacturers group their various engine lines into engine families that have similar design characteristics including the combustion cycle, cooling system, cylinder configuration, number of cylinders, engine class, valve location, fuel type, aftertreatment design, and useful life category. We are proposing to allow small-volume engine manufacturers to group all of their Small SI engines into a single engine family for certification by engine class and useful life category, subject to good engineering judgment (see §1054.230).

Eligibility for the Small Business Flexibilities - We are proposing to retain the current criteria (i.e., 10,000 units per year of nonhandheld engines) for determining who is a small-volume engine manufacturer and, as a result, eligible for the Phase 3 flexibilities described above (see §1054.801). Based on confidential sales data provided to EPA by engine manufacturers, the 10,000 unit cut-off for engine manufacturers would include all of the small business engine manufacturers using SBA's employee-based definition. However to ensure all small businesses that meet SBA's employee-based definition have access to the flexibilities described below, EPA is also proposing to allow engine manufacturers which exceed the production cut-off level noted above but have fewer than 1,000 employees, to request treatment as a small volume engine manufacturer (see §1054.635). In such a case, the manufacturer would need to provide information to EPA demonstrating that the manufacturer has fewer employees than the 1,000 cut-off level established by SBA.

10.7.1.2 Regulatory Flexibility Options for Nonhandheld Equipment Manufacturers

10.7.1.2.1 SBAR Panel Recommendations

Additional Lead Time for Small SI Equipment Manufacturers - The Panel recommended that EPA propose a transition program that would allow small business equipment manufacturers to continue using Phase 2 engine designs (i.e., engines meeting the Phase 2 exhaust emission standards) during the first two years that the Phase 3 standards take effect. (For equipment using Class I engines, the provision would apply in 2012 and 2013. For equipment using Class II engines, the provision would apply in 2011 and 2012.) The Panel also recommended that EPA propose to allow small business equipment manufacturers to use Phase 3 engines without the catalyst during this initial two year period, provided the engine manufacturer has demonstrated that the engine without the catalyst would comply with the Phase 2 exhaust emission standards and labels it appropriately.

Simplified Engine Certification for Equipment Manufacturers - Generally, it has been engine manufacturers who certify with EPA for the exhaust emission standards, where the standards are engine standards. However, a number of equipment manufacturers, especially those that make low-volume models, believe it may be necessary for equipment manufacturers to certify their own unique engine/muffler designs with EPA (but using the same catalyst substrate already used in a muffler certified by the engine manufacturer. The Panel recommended that EPA propose a simplified engine certification process for small business equipment manufacturers in such situations. Under such a simplified certification process, the equipment manufacturer would need to demonstrate that it is using the same catalyst substrate as the approved engine manufacturer's family, provide information on the differences between their engine/exhaust system and the engine/exhaust system certified by the engine manufacturer, and explain why the deterioration data generated by the engine manufacturer would be representative for the equipment manufacturer's configuration.

Eligibility for the Small Business Flexibilities - For purposes of determining which equipment manufacturers are eligible for the small business flexibilities described above, EPA is proposing criteria based on a production cut-off of 5,000 pieces of nonhandheld equipment per year for equipment manufacturers. The Panel recommended that EPA propose to allow equipment manufacturers which exceed the production cut-off levels noted above but meet the SBA definitions for a small business (i.e., fewer than 500 employees for most types of equipment manufacturers), to request treatment as a small business.

10.7.1.2.2 EPA's Proposed Regulatory Flexibility Options

In general, we have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions.

Additional Lead Time for Small SI Equipment Manufacturers - We are proposing that small-volume equipment manufacturers would have two extra years beyond the implementation dates for the Phase 3 standards to continue using Phase 2 engines in their Class II equipment. Alternatively, the manufacturer could use Phase 3 engines without the catalysts, provided the engine manufacturer submitted data at the time of certification showing that the engine without the catalyst complied with EPA's Phase 2 standards. As described in Section V.E.3 of the preamble, EPA is proposing a flexibility program for all equipment manufacturers that produce Class II equipment. Under that program, equipment manufacturers can install Phase 2 engines in limited numbers of Class II equipment over the first four years the Phase 3 standards apply (i.e., 2011 through 2015). The number of equipment that can use Phase 2 engines is based on 30 percent of an average annual production level of Class II equipment. In an effort to provide additional flexibility to small-volume equipment manufacturers within the context of the flexibility program, EPA is proposing that small-volume manufacturers may use Phase 2 engines at a level of 200 percent of an average annual production level of Class II equipment over the four year period (see §1054.625). Therefore, a small-volume equipment manufacturer could potentially use Phase 2 engines on all their Class II equipment for two years (consistent with the SBAR Panel's recommendation) or they might, for example, sell half their Class II equipment with Phase 2 engines for four years.

Simplified Engine Certification for Equipment Manufacturers - We are proposing a simplified engine certification procedure for small-volume equipment manufacturers. (As discussed in Section V.E.4 of the preamble, we are also proposing this provision for other manufacturers, regardless of the company's size.) Generally, it has been engine manufacturers who certify with EPA for the exhaust emission standards because the standards are engine-based standards. However, because the Phase 3 standards under consideration are expected to result in the use of catalysts, a number of equipment manufacturers, especially those that make low-volume models, believe it may be necessary to certify their own unique engine/muffler designs with EPA, but using the same catalyst substrate already used in a muffler certified by the engine manufacturer. In order to allow the possibility of an equipment manufacturer certifying an engine/muffler design with EPA, we are proposing a simplified engine certification process for small-volume equipment manufacturers (see §1054.612). Under such a simplified certification process, the equipment manufacturer would need to demonstrate that it is using the same catalyst substrate as the approved engine manufacturer's family, provide information on the differences between their engine/exhaust system and the engine/exhaust system certified by the engine manufacturer, and explain why the emissions deterioration data generated by the engine manufacturer would be representative for the equipment manufacturer's configuration.

Eligibility for the Small Business Flexibilities - EPA is proposing to retain the current criteria (i.e., 5,000 units per year of nonhandheld equipment) for determining who is a small-volume equipment manufacturer and, as a result, eligible for the Phase 3 flexibilities described above (see §1054.801). Based on sales data, the 5,000 unit cut-off for equipment manufacturers would include the vast majority of the small business equipment manufacturers using SBA's employee-based definition. However to ensure all small businesses that meet SBA's employee-based definition have access to the flexibilities described below, EPA is also proposing to allow equipment manufacturers which exceed the production cut-off level noted above but have fewer employees than the SBA definition of small business (i.e., 500 employees for manufacturers of most types of equipment), to request treatment as a small-volume equipment manufacturer (see §1054.635). In such a case, the manufacturer would need to provide information to EPA demonstrating that the manufacturer has fewer employees than the applicable employee cut-off level established by SBA.

10.7.2 Marine SI Exhaust Emission Standards—Regulatory Flexibility Options for SD/I Engine Manufacturers

Described below are the flexibility options recommended by the Panel and our proposed regulatory alternatives related to the exhaust emission standards for marine SD/I engine manufacturers.

10.7.2.1 SBAR Panel Recommendations

Additional Lead Time for SD/I Engine Manufacturers - The Panel recommended that EPA propose an implementation date of 2011 for ≤373 kW SD/I engines produced by small business marine engine manufacturers and an implementation date of 2013 for small business manufacturers of high performance (>373 kW) SD/I marine engines. Based on the proposed 2009 implementation date for the remaining SD/I engine manufacturers (i.e., the large businesses), these dates would provide small business SD/I engine manufacturers with 2 years additional lead time for ≤373 kW SD/I engines and 4 years additional lead time for >373 kW SD/I engines.

Exhaust Emission ABT - EPA is proposing an averaging, banking and trading (ABT) program for the SD/I engine standards. Because EPA is proposing an ABT program for SD/I engines, the Panel recommended that EPA request comment on the desirability of credit trading between high performance and other SD/I marine engines and the impact it could have on small business.

Early Credit Generation for ABT - EPA is proposing an early banking program for SD/I marine engines. Under the early banking provisions, manufacturers can generate "bonus" credits for the early introduction of engines meeting the proposed emission standards. The Panel supports EPA proposing an early banking program and believes that bonus credits will provide greater incentive for more small business engine manufacturers to introduce advanced technology earlier than would otherwise occur.

Assigned Emission Rates for High Performance (>373 kW) SD/I Engines - The Panel recommended that EPA propose to allow the use of default emission rates that could be used by small business high performance SD/I engine manufacturers as part of their certification. Based on currently available test data, the proposed default baseline emission levels for high performance engines are 30 g/kW-hr HC+NOx and 350 g/kW-hr CO.

Alternative Standards for High Performance (>373 kW) SD/I Engines - SERs expressed concern that that catalysts have not been demonstrated on high performance engines and that they may not be practicable for this application. While EPA is proposing a standard based on the use of catalysts, EPA is requesting comment on a standard for high performance SD/I marine engines that could be met without the use of a catalyst. (Based on available data, levels of 16 g/kW-hr HC+NOx and 350 g/kW-hr CO were discussed with the SERs). The Panel recommended EPA request comment on a non-catalyst based standard for high performance marine engines.

EPA is proposing to not apply the not-to-exceed (NTE) standards to high performance SD/I engines. The Panel supports excluding high performance SD/I engines from NTE requirements.

Broad Engine Families for High Performance (>373 kW) SD/I Engines - The Panel recommended that EPA propose allowing small businesses to group all of their high performance SD/I engines into a single engine family for certification, subject to good engineering judgment.

Simplified Test Procedures for High Performance (>373 kW) SD/I Engines - For high performance SD/I engines, it may be difficult to hold the engine at idle or high power within the tolerances currently specified in existing EPA test procedures. The Panel recommended that EPA propose less restrictive specifications and tolerances for small businesses testing high performance SD/I engines, which would allow the use of portable emission measurement equipment.

Eligibility for the Small Business Flexibilities - For purposes of determining which engine manufacturers are eligible for the small business flexibilities described above for SD/I engine manufacturers, EPA is proposing criteria based on a production cut-off of 5,000 SD/I engines per year. The Panel recommended EPA propose to allow engine manufacturers that exceed the production cut-off level noted above but meet the SBA definitions for a small business (i.e., fewer than 1,000 employees for engine manufacturers), to request treatment as a small business.

10.7.2.2 EPA's Proposed Regulatory Flexibility Options

In general, we have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions.

Additional Lead Time for SD/I Engine Manufacturers - One small business marine engine manufacturer is already using catalytic converters on some of its ≤373 kW production SD/I marine engines. These engines have been certified to meet standards adopted by CARB that are roughly equivalent to the proposed standards. However, other small businesses producing SD/I engines have stated that they are not as far along in their catalyst development efforts. These manufacturers support the concept of receiving additional time for compliance, beyond the implementation date for large manufacturers. For these reasons, EPA is proposing an implementation date of 2011 for ≤373 kW SD/I engines produced by small business marine engine manufacturers and a date of 2013 for small business manufacturers of high-performance (>373 kW) marine engines (see §1045.145).

Exhaust Emission ABT - We are proposing an averaging, banking, and trading (ABT) credit program for exhaust emissions from SD/I marine engines (see part 1045, subpart H). Small businesses expressed some concern that ABT could give a competitive advantage to large businesses. Specifically, there was an equity concern that if credits generated by traditional (≤373 kW) SD/I engines could be used for high-performance SD/I engines, that one large manufacturer could use these credits to meet the high-performance SD/I engine standards without making any changes to their engines. In response, EPA is requesting comment on the desirability of credit trading between high-performance and other SD/I marine engines and the impact it could have on small business.

Early Credit Generation for ABT - We are proposing an early banking program in which bonus credits can be earned for certifying early (see §1045.145). This program, combined with the additional lead time for small businesses, would give small-volume SD/I engine manufacturers ample opportunity to bank emission credits prior to the proposed implementation date of the standards and provide greater incentive for more small business engine manufacturers to introduce advanced technology earlier than would otherwise occur.

Assigned Emission Rates for High Performance (>373 kW) SD/I Engines - We are proposing assigned baseline HC+NOx and CO emission rates for all high-performance SD/I engines. These assigned emission rates are based on test data presented in Chapter 4 of the draft RIA. We are also proposing assigned deterioration factors for small-volume high-performance

SD/I manufacturers. (See §1045.240.)

Alternative Standards for High Performance (>373 kW) SD/I Engines - Small businesses expressed concern that that catalysts have not been demonstrated on high-performance engines and that they may not be practicable for this application. In addition, the concern was expressed that emission credits may not be available at a reasonable price. In response, we are requesting comment on the need for and level of alternative standards for high-performance marine engines. Also, we are not proposing to apply NTE standards to high-performance SD/I engines (See §1045.105).

Broad Engine Families for High Performance (>373 kW) SD/I Engines - Typically in EPA engine and equipment programs, manufacturers are able to group their engine lines into engine families for certification to the standards. Engines in a given family must have many similar characteristics including the combustion cycle, cooling system, fuel system, air aspiration, fuel type, aftertreatment design, number of cylinders and cylinder bore sizes. A manufacturer would then only perform emission tests on the engine in that family that would be most likely to exceed an emission standard. We are proposing to allow small businesses to group all of their high performance SD/I engines into a single engine family for certification, subject to good engineering judgment (see §1045.230).

Simplified Test Procedures for High Performance (>373 kW) SD/I Engines - Existing testing requirements include detailed specifications for the calibration and maintenance of testing equipment and tolerances for performing the actual tests. For high performance SD/I engines, it may be difficult to hold the engine at idle or high power within the tolerances currently specified by EPA in the test procedures. Therefore, we are proposing less restrictive specifications and tolerances, for small businesses testing high performance SD/I engines, which would allow the use of portable emission measurement equipment (see §1065.901(b)). This would facilitate less expensive testing for these small businesses without having a negative effect on the environment.

Eligibility for the Small Business Flexibilities - For purposes of determining which engine manufacturers are eligible for the small business flexibilities described above for SD/I engine manufacturers, we are proposing criteria based on a production cut-off of 5,000 SD/I engines per year. Under this approach, we would allow engine manufacturers that exceed the production cut-off level noted above to request treatment as a small business if they have fewer than the number of employees specified above under the SBA definition of small business. In such a case, the manufacturer would need to provide information to EPA demonstrating that the manufacturer has fewer employees than the applicable employee cut-off level established by SBA.

10.7.3 Small SI and Marine SI Evaporative Emission Standards— Flexibility Alternatives for Equipment, Vessel, and Fuel Tank Manufacturers

Described below are the flexibility options recommended by the Panel and our proposed regulatory alternatives related to the evaporative emission standards for Small SI engines and equipment and Marine SI engines and vessels. SERs raised many of the same issues regarding evaporative emission standards for both Small SI and marine applications. In fact, many of the SERs supply fuel system components to both industries. For these reasons, the Panel's recommendations on regulatory flexibility discussed below would apply to Small SI equipment and to SD/I marine vessels, except where noted.

Because the majority of fuel tanks produced for the Small SI equipment and the SD/I marine vessel market are made by small businesses, the details of the evaporative emissions program under consideration and the flexibility provisions shared by EPA with the SERs were noted as being available to all fuel tank manufacturers. Therefore, EPA is proposing the Panel recommendations on regulatory flexibility discussed below for small business fuel tank manufacturers for all fuel tank manufacturers.

10.7.3.1 SBAR Panel Recommendations

Consideration of Appropriate Lead Time - The Panel recommended that EPA propose to implement the fuel tank permeation standards in 2011 with an additional year (2012) for rotationally-molded marine fuel tanks. The extra year for rotational-molded marine tanks would give manufacturers time to address issues that are specific to the marine industry.

With regard to diurnal emissions control, SERs commented that they would like additional time to install carbon canisters in their vessels because of deck and hull changes that might be needed to accommodate the carbon canisters. SERs commented that they would consider asking EPA to allow the use of low permeation fuel hose prior to 2009 as a method of creating an emission neutral flexibility option for providing extra time for canisters. The Panel recommended that EPA continue discussions with the marine industry and request comment on environmentally neutral approaches to provide more flexibility in meeting the potential diurnal emission standards.

Fuel Tank ABT and Early Incentive Program - The Panel recommended that EPA propose an ABT program for fuel tank permeation. The Panel also recommended that EPA request comment on including service tanks (i.e., replacement tanks) in the ABT program. Finally, the Panel recommended that EPA request comment and on an early incentive program for tank permeation.

Broad Definition of Evaporative Emission Family for Fuel Tanks - The Panel recommended that EPA propose a broad emission family definition for Small SI fuel tanks and for marine fuel tanks similar to that in the regulations for recreational vehicles. Under the recreation vehicle evaporative emission regulations, EPA specifies that fuel tank permeation emission families be based on type of material (including additives such as pigments, plasticizers, and ultraviolet (UV) inhibitors), emission-control strategy, and production methods. Fuel tanks of different sizes, shapes, and wall thicknesses may be grouped into the same emission family.

Compliance Progress Review for Marine Fuel Tanks - While there is clearly a difference of opinion among the SERs involved in tank manufacturing, some SERs expressed concern that there is not an established low permeation technology available for rotationally-molded marine fuel tanks. These SERs stated that they are working on developing such technology, but do not have in-use experience to demonstrate the durability of low-permeation rotationally molded fuel tanks. The Panel recommended that if a rule is implemented, EPA undertake a "compliance progress review" assessment with the manufacturers. In this effort, EPA should continue to engage on a technical level with rotationally-molded marine fuel tank manufacturers and material suppliers to assess the progress of low permeation fuel tank development and compliance.

Design-Based Certification - The Panel recommended that EPA propose a design-based certification for carbon canisters and fuel tanks. For the carbon canisters, the design requirement would call for a ratio of carbon volume (liters) to fuel tank capacity (gallons) of 0.04 liter/gallon for boats less than 26 feet in length, and 0.016 liter/gallon for larger boats. The different canister sizes are intended to account for the difference between boats normally trailered to the water for use versus boats normally stored in the water between uses. For fuel tanks, the Panel recommended that EPA propose to allow design-based certification for metal tanks and plastic fuel tanks with a continuous EVOH barrier.

SERs commented that the American Boat and Yacht Council (ABYC) and the Society of Automotive Engineers (SAE) have industry recommended practices for boat designs that must be met as a condition of membership in the National Marine Manufacturers Association (NMMA). NMMA is working to update these recommended practices to include carbon canister installation specifications and a low-permeation hose designation. The Panel recommended that EPA propose to accept data used for meeting the voluntary requirements as part of the EPA certification.

Additional Lead Time for Small SI Fuel Hose Requirement - EPA is proposing to apply the fuel hose permeation requirements beginning with the 2008 model year for Small SI nonhandheld equipment. Given the short lead time before 2008, small business equipment manufacturers may not be ready for such a requirement. The Panel recommended EPA propose a 2009 implementation date for low permeation fuel hose for small business equipment manufacturers producing Small SI nonhandheld equipment.

10.7.3.2 EPA's Proposed Regulatory Flexibility Options

In general, we have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions.

Consideration of Appropriate Lead Time - Consistent with the Panel recommendations, we are proposing to implement the tank permeation standards in 2011 with an additional year (2012) for rotational-molded marine fuel tanks (see §1054.110 and §1045.107). With regard to the proposed diurnal emission control requirements, we are requesting comment on environmentally neutral approaches to provide more flexibility in meeting the potential diurnal emission standards.

Fuel Tank ABT and Early Incentive Program - Consistent with the Panel recommendations, we are proposing an ABT program for fuel tank permeation and an early-allowance program for fuel tank permeation. We are requesting comment on including service tanks in the ABT program. Service tanks are fuel tanks sold as replacement parts for in-use equipment.

Broad Definition of Evaporative Emission Family for Fuel Tanks - We are proposing that permeation emission families be based on type of material (including additives such as pigments, plasticizers, and UV inhibitors), emission-control strategy, and production methods. Fuel tanks of different sizes, shapes, and wall thicknesses could be grouped into the same emission family (see §1045.230 and §1054.230). Manufacturers therefore would be able to broadly group similar fuel tanks into the same emission family and then only test the configuration most likely to exceed the emission standard. Although Small SI and Marine SI fuel tanks would not be allowed in the same emission family, it would be possible to carry-across certification test data from one category to another.

Compliance Progress Review for Marine Fuel Tanks - Some major manufacturers of rotational-molded marine fuel tanks have expressed concern that they do not have significant in-use experience to demonstrate the durability of low-permeation rotational-molded fuel tanks in boats. However, one manufacturer of rotational-molded fuel tanks has stated that they are already selling low permeation tanks into the Small SI market and they have plans to sell them into marine applications. To address this uncertainty, EPA notes in the preamble for the rule that it intends to continue to engage on a technical level with rotational-molded marine fuel tank manufacturers and material suppliers to assess the progress of low permeation fuel tank development and compliance. If systematic problems are identified across the industry, this would give EPA the opportunity to address the problem. If problems were identified only for individual businesses, this would give EPA early notice of the issues that may need to be addressed through the proposed hardship relief provisions.

Design-Based Certification - We are proposing design-based certification for carbon canisters for boats. For the carbon canisters, the design requirement would call for a ratio of carbon volume (liters) to fuel tank capacity (gallons) of 0.04 liter/gallon for boats less than 26 feet in length, and 0.016 liter/gallon for larger boats. We are also proposing design-based certification for certain fuel tanks. For fuel tanks, we are proposing to allow design-based certification for metal tanks as well as plastic fuel tanks with a continuous EVOH barrier. With regard to the Panel recommendation that EPA accept data for its certification program that is used for meeting industry recommended practices (such as those recommended by NMMA, ABYC and SAE), we are proposing that this data could be used as part of EPA certification as long as it is collected consistent with the test procedures and other requirements proposed today.

Additional Lead Time for Small SI Fuel Hose Requirement - We are proposing an implementation date of 2008 for Small SI hose permeation standards for non-handheld equipment (see §90.127). Consistent with the Panel recommendations, we are proposing a 2009 implementation date for low permeation fuel hose for small businesses producing Small SI non-handheld equipment.

10.7.4 Hardship Provisions—Regulatory Flexibility Options for Engine, Equipment, Vessel, and Fuel System Component Manufacturers

The Panel recommended that EPA propose two hardship programs for manufacturers. EPA has adopted similar hardship provisions in a number of previous rules. The following section summarizes the hardship provisions recommended by the Panel which would be available to engine manufacturers, equipment manufacturers, vessel manufacturers, and fuel system component manufacturers (i.e., fuel tank, fuel hose, and fuel cap manufacturers).

10.7.4.1 SBAR Panel Recommendations

Unusual Circumstances Hardship - The Panel recommended that EPA propose a provision allowing for hardship relief under unusual circumstances for manufacturers affected by this rule. Manufacturers would be able to apply for hardship relief if circumstances outside their control cause the failure to comply and if failure to sell the subject engines or equipment would jeopardize the company's solvency. An example of an unusual circumstance outside a manufacturer's control may be an "Act of God," a fire at the manufacturing plant, or the unforeseen shut down of a supplier with no alternative available.

Economic Hardship - The Panel recommended that EPA propose economic hardship provisions for small businesses affected by this rule. Small manufacturers would be able to petition EPA for limited additional lead time to comply with the standards. A manufacturer would have to make the case that it has taken all possible business, technical, and economic steps to comply, but the burden of compliance costs would have a significant impact on the company's solvency.

10.7.4.2 EPA's Proposed Hardship Provisions

We have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions.

Unusual Circumstances Hardship - Under the proposed unusual circumstances hardship provision, manufacturers would be able to apply for hardship relief if circumstances outside their control cause the failure to comply and if failure to sell the subject engines or equipment would jeopardize the company's solvency (see §1068.245). The terms and time frame of the relief would depend on the specific circumstances of the company and the situation involved. As part of its application for hardship, a company would be required to provide a compliance plan detailing when and how it would achieve compliance with the standards. This hardship provision would be available to all business engine manufacturers, equipment manufacturers, vessel manufacturers, and fuel system component manufacturers, regardless of size.

Economic Hardship - Under the proposed economic hardship provision, small business manufacturers would be able to petition EPA for limited additional lead time to comply with the standards (see §1068.250). A manufacturer would have to make the case that it has taken all possible business, technical, and economic steps to comply, but the burden of compliance costs would have a significant impact on the company's solvency. Hardship relief could include requirements for interim emission reductions and/or purchase and use of emission credits. The length of the hardship relief would be established during the initial review and would likely need to be reviewed annually thereafter. As part of its application for hardship, a company would be required to provide a compliance plan detailing when and how it would achieve compliance with the standards. This hardship provision would be available only to engine manufacturers, equipment manufacturers, vessel manufacturers, and fuel system component manufacturers that are small businesses.

10.8 Projected Economic Effects of the Proposed Rulemaking

The following section summarizes the economic impact on small businesses of the proposed exhaust and evaporative emission standards for both Small SI engines and equipment and Marine SI engines and vessels. As noted earlier, the types of companies that will be affected by the proposed Marine SI standards include OB/PWC engine manufacturers, SD/I engine manufacturers, boat builders, and marine fuel system component manufacturers (e.g., fuel tank and fuel hose manufacturers). Similarly, the types of companies that will be affected by the Small SI standards include nonhandheld engine manufacturers, equipment manufacturers, and Small SI fuel system component manufacturers (e.g., fuel tank and fuel hose manufacturers). For the purposes of this analysis, it is assumed that engine manufacturers will bear the cost of complying with the exhaust emission standards, whereas equipment manufacturers and vessel manufacturers will bear the cost of complying with the evaporative emission standards.

To gauge the impact of the proposed standards on small businesses, EPA employed a cost-to-sales ratio test to estimate the number of small businesses that would be impacted by less than one percent, between one and three percent, and above three percent. The costs used in this analysis are based on the cost estimates developed in Chapter 6 of this Draft RIA. A description of the inputs used for each affected industry sector and the methodology used to develop the estimated impact on small businesses in each industry sector is presented in the docket for this rulemaking.[2]

For OB/PWC engine manufacturers, EPA identified one small business. The one small business identified by EPA manufactures their personal watercraft today using four-stroke engines with certified emission levels below the proposed standards. As a result, the estimated costs for upgrading their engines would not apply. We therefore believe the impact of the rule is well below one percent of revenues for this OB/PWC engine manufacturer.

For <373 kW SD/I engine manufacturers, EPA identified nine small businesses. Of these companies, eight produce conventional SD/I engines and the remaining one company produces SD/I engines for airboats. Of the conventional SD/I small business engine manufacturers, five of the small businesses may incur compliance costs between one and three percent of their annual revenues. Three of the small businesses that produce <373 kW SD/I engines as part of a much broader line of work (such as engine rebuilding or selling land-based engines) will be impacted by less than one percent of annual revenues.

Using available information for the airboat engine manufacturer, we project that the manufacturer will have compliance costs between one and three percent of annual revenues. Some of this company's engines are >373 kW, so their estimated compliance burden reflects a combination of costs for conventional SD/I engines and for high-performance >373 kW engines. (They are included in the conventional SD/I category for this impact analysis.) This company is unique in that it manufacturers many of its engines for sale to other airboat manufacturers, resulting in a concentrated cost impact relative to their revenues.

We also identified a number of other airboat manufacturers. These small businesses making engines for airboats are less reliant on selling engines to other boat builders, instead making engines for the boats they build themselves. Most of these businesses are very small, with little ability to marshal the technical resources needed to comply with emission standards. If these companies would take on the effort to design and certify compliant engines, they would likely experience compliance costs exceeding three percent of their revenues. However, given their place in the market and the fact that they are primarily boat builders with the resourcefulness to make their own engines, we believe the most likely approach for these companies is to buy a certified engine from manufacturers of conventional SD/I engines. As such, these companies would be treated with other boat builders, in which case their main compliance cost is related to evaporative emissions (as described below). We therefore do not consider any of these companies as engine manufacturers for the purposes of analyzing the impact of the proposed standards on engine manufacturers.

For >373 kW SD/I engine manufacturers, EPA identified 19 small businesses. Of the >373 kW SD/I small business engine manufacturers, 17 of the small businesses are projected to incur compliance costs between one and three percent of their annual revenues. Two small businesses that produce >373 kW SD/I engines as part of a broader line of work (such as engine testing) will be impacted by less than one percent of annual revenues.

For boat builders, EPA believes there are over 1,000 small business manufacturers. Many of these companies make small numbers of vessels for certain segments of the marine market. Given the high cost of most boats, EPA believes the cost impact will be below one percent for all small business boat builders, including those that manufacture SD/I vessels, and OB/PWC boat manufacturers as well.

While boat builders have the primary responsibility under the proposed regulations for complying with evaporative emission standards, fuel hose and fuel tank manufacturers will have to certify their product with EPA. EPA has identified one small business that manufactures fuel hose for marine applications and 15 small businesses that manufacturer fuel tanks for marine applications. The company producing fuel hose primarily distributes hoses made by other manufacturers but does produce its own fill neck hose. Because we expect vessel manufacturers will design their fuel systems such that there will not be standing liquid fuel in the fill neck (and therefore the proposed low permeation fuel hose requirements will not apply to the fill neck), we have not included this manufacturer in our analysis. Of the 15 fuel tank manufacturers, EPA has estimated that all of them will incur costs below one percent of annual revenues.

For Small SI engine and equipment manufacturers, EPA has identified 370 small businesses.[3] Ten of the small businesses are engine manufacturers and the remaining companies are equipment manufacturers. Based on an analysis of sales revenues by company, EPA projects that 314 of the small businesses are estimated to incur compliance costs representing less than 1 percent of their annual revenues. EPA projects that 38 companies will incur compliance costs between 1 and 3 percent of their annual revenues, and 18 companies will incur compliance costs representing more than 3 percent of their annual revenues.

Similar to the requirements noted above for boat manufacturers under the Marine SI evaporative emission regulations, equipment manufacturers will have the primary responsibility under the regulations for complying with the Small SI evaporative emission standards. However, fuel hose and fuel tank manufacturers will have to certify their product with EPA. EPA has identified two small businesses that manufactures fuel hose for Small SI applications and 25 small businesses that manufacturer fuel tanks for Small SI applications. Of these companies, EPA has estimated that all of these companies will incur costs below one percent of annual revenues.

Table 10.8-1 summarizes the impacts of the proposed regulations on small businesses impacted by the proposed exhaust and evaporative emission standards for Small SI engines and equipment and Marine SI engines and vessels.

Table 10.8-1: Summary of Impacts on Small Businesses

Market Sector	0-1 percent	1 - 3 percent	> 3 percent
Manufacturers of Marine OB/PWC engines	1	0	0
Manufacturers of Marine SD/I engines < 373 kW	4	5	0
Manufacturers of Marine SD/I engines > 373 kW (high-performance)	2	17	0
Boat Builders	>1,000	0	0
Manufacturers of Fuel Hose and Fuel Tanks for Marine SI Vessels	15	0	0
Small SI engines and equipment	314	38	18
Manufacturers of Fuel Hose and Fuel Tanks for Small SI Applications	27	0	0
Total	363 + >1,000 boat builders	60	18

For a complete discussion of the economic impacts of the proposed rulemaking, see Chapter 9, the Economic Impact Analysis chapter, of this Draft Regulatory Impact Analysis.

Chapter 10 References

1. Final Panel Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule—Control of Emissions from Nonroad Spark-Ignition Engines and Equipment, October 17, 2006. (A copy has been placed in docket EPA-HQ-OAR-2004-0008.)

2. “Small Business Impact Memo, Control of Emissions from Nonroad Spark-Ignition Engines and Equipment,” EPA memorandum from Phil Carlson to the EPA Docket, March 6, 2007. (Docket Identification EPA-HQ-OAR-2004-0008-0547.)

3. “Small Entity Analysis of Small Spark Ignition Nonroad Engine and Equipment Manufacturers,” memorandum from Alex Rogozhin and Brooks Depro, RTI Interational, to Phil Carlson, U.S. EPA, December 15, 2006. (Docket Identification EPA-HQ-OAR-2004-0008-0541.)

CHAPTER 11: Regulatory Alternatives

Our proposed program represents a blend of exhaust and evaporative emission standards for small nonroad spark-ignition (SI) engines used in land-based or auxiliary marine applications, and also recreational Marine SI engines. We believe that the combination of emission standards and their associated timing are superior to the alternative program options we considered given their feasibility, cost, and environmental impact. In this chapter we present and discuss the options that we evaluated in order to make this determination.

Section 11.1 presents each element of our proposed requirements and discusses a variety of specific alternatives that are either less and more stringent. After this initial assessment, options that merit a more rigorous examination are identified for analysis in subsequent sections. Section 11.2 describes the cost of the selected options for each affected engine or system. Section 11.3 presents the emissions inventory impacts associated with each option. Section 11.4 describes the cost effectiveness ($/ton of emission reduced) of the selected options. Finally, we present our assessment of the rationale, feasibility, and issues associated with each alternative in Section 11.5.

The costs, emission reductions, and cost effectiveness of the options analyzed in Sections 11.2 through 11.5 are incremental to the base case (i.e., current requirements) ignoring this proposal, unless otherwise specified. For example, the more stringent recreational marine exhaust standards for OB/PWC are evaluated as follow-on requirements to the proposed requirements and would begin in a later year. Therefore, the analysis for that option reflects only the more stringent subsequent standards.

For the more stringent options, it is important to note that the analyses depend on data supporting them. Generally, a scenario was picked for analysis because there was evidence to suggest that controls such as those identified in the write-ups could be technically feasible at some point in the future. However, there is some uncertainty with regard to the technical feasibility of implementing the standards or requirements across all products, the level of the potential standards selected for analysis (if applicable), the timing for potential introduction, and the costs of control. However, while these standards were ultimately not selected as the basis for this proposal, it appears that in some cases they could form the basis for potential future rulemaking actions.

11.1 Identification of Alternative Program Options

This section provides our description of potential options for each element of our proposal. Options that do not merit further consideration are eliminated and those that warrant additional analysis in subsequent sections are identified.

11.1.1 Alternative Exhaust Emission Requirements

11.1.1.1 Small SI Engine HC + NOx Standards

11.1.1.1.1 Class I

We considered, but rejected, proposing a less stringent HC + NOx emission standard for Class I spark-ignition engines. The proposed standard of 10 g/kW-hr is readily achievable with reasonably priced emission control technology. Furthermore, the lead time for implementing the proposed standard in 2012 is adequate for applying the catalyst-based technology that will be used on many of these engines. A less stringent emission standard would not be consistent with the requirements of section 213 of the Clean Air Act.

A more stringent standard was also considered. Under this option an 8 g/kW-hr HC + NOx standard would be implemented. For purposes of this analysis we elected to begin the requirement in the 2015 model year. Due to the technical design relationship between the engine and running loss control requirement we modeled running loss controls to start in 2015 as well. This standard represents about a 50 reduction from the existing Phase 2 standard, rather than the approximately 38 percent reduction associated with the proposal. As analyzed this option also provides 3 more years of lead time. We believe that manufacturers of side-valve (SV) engines would choose to convert these families to overhead-valve (OHV) designs. The emissions from OHV engine are typically lower and deteriorate less than SV engines and thereby result in the need for only a slightly more active catalyst and improved cooling relative to the technology changes needed for the proposal. Cooling for the slightly more active OHV catalyst would be supplied by the engine improvements included in the proposal, such as include optimized head design for cooling and fan design for cooling air generation. The slightly more active catalyst can be achieved with either a larger volume and/or a more active mix of precious metals in the catalyst substrate. It may be possible for SV engines to meet the more stringent emission standards using catalysts. For SV engines the catalysts would likely need to be larger and more active. This would result in higher costs and greater catalyst heat generation which may or may not be able to be handled by the engine’s cooling system.

11.1.1.1.2 Class II

For Class II spark-ignition engines, we considered an alternative program option that was less stringent than the proposal. However, for the same reasons previously stated for Class I engines, we rejected this alternative from further consideration; the proposal is readily achievable at a reasonable cost within the lead time provided. A less stringent standard, such as one at a level not depending on catalyst technology, would not have been consistent with section 213 of the Clean Air Act.

An alternative for a more stringent exhaust HC + NOx emission standard would be 4.0 g/kW-hr along with a delay in the corresponding running loss requirement such that engine changes are made at one time. For analytical purposes we started this requirement in 2015, four years beyond that for the proposed standard. Such an exhaust emission standard represents a 67 percent reduction relative to the existing Phase 2 standard, rather than the 34 percent reduction associated with the proposal. It also provides four more years of lead time; a phase-in could be needed since implementation would require the equipment manufacturers involvement for non-integrated products. In order to achieve the 4.0 g/kW-hr HC + NOx emission standard, we expect manufacturers would need to make widespread use of closed loop control EFI and three-way catalysts. The EFI systems would keep engine air-to-fuel mixture closer to stoichiometry and provide an optimum environment for the maximum reduction in HC+NOx by a three way catalyst. Changes to the catalyst would likely involve a more active mix of precious metals in the catalyst substrate. In addition, engine upgrades would be required in some of the Class II engines commonly used in residential lawn care equipment.

11.1.1.2 Marine Auxiliary Engine CO Standard

The proposed standards for marine auxiliary engines include a CO standard that would require the use of highly efficient catalytic control. This proposed standard would require the use of technology to meet emission levels demanded by the market. Manufacturers of gasoline marine generators are equipping their engines with catalysts for the primary purpose of reducing ambient CO concentrations around boats. Therefore, we do not believe that it would be useful to consider a less stringent standard which could enable market penetration of new engine offerings which potentially endanger public health. At the same time, the standard we are proposing is very stringent and manufacturers are already designing for reductions which are more than 95 percent below the current CO emission standard. A more stringent standard would do little more to push technology. Thus, we do not believe that it would be useful to analyze a more stringent standard.

11.1.1.3 Outboard/Personal Watercraft (OB/PWC) Engine HC + NOx and CO Emission Standards

The proposed standards for OB/PWC are based on technology that manufacturers are already certifying and selling nationwide. To meet the proposed requirements, manufacturers would continue to sell this technology and discontinue their sale of high-emitting old technology carbureted two-stroke engines. Because the proposed standards can be met with existing technology, we do not believe that there is an alternative between the proposed standards and the current standards which would be consistent with the CAA section 213 requirement. Therefore, we did not analyze a less stringent alternative.

For a more stringent alternative, we considered a set of follow-on standards to those proposed. We analyzed these as beginning in 2012. For OB/PWC engines greater than 40 kW these would be at a level of 10 g/kW-hr. For engines less than 40 kW, we adjusted the proposed standard equation to $28 - 0.45 \times$ rated power(kW) to maintain a continuous curve function. This alternative also considered a lower CO standard of 200 g/kW-hr for engines greater than 40 kW with an adjusted standard of $500 - 7.5 \times$ rated power(kW) for engines less than 40 kW to maintain a continuous standard function. Such standards would be consistent with currently certified emission levels from some four-stroke outboard engines. Although many four-stroke engines may be able to meet a 10 g/kW-hr standard with improved engine calibration, it is not clear that all engines could meet this standard without applying yet unproven catalyst technology in this application. To model this scenario, we evaluated the costs and emission reductions that could be achieved through the combined use of calibrated four-stroke engines and four-stroke engines with catalytic control. This analysis applied catalytic control to larger OB/PWC engines, which already use or are expected to use electronic fuel injection.

11.1.1.4 Sterndrive/Inboard (SD/I) Engine HC + NOx and CO Standards

For the purposes of this analysis, we subdivided the SD/I category into traditional and high-performance engine categories. Based on our proposed definitions, high-performance engines have a rated power greater than or equal to 373 kW (500 hp).

11.1.1.4.1 SD/I <373 kW

In developing regulatory alternatives for SD/I engines, we considered both what was achievable without catalysts and what could be achievable with larger, more efficient catalysts than those we evaluated in our test programs.

With regard to a less stringent option, we considered non-catalyst based standards to be implemented in the 2009 model year. Chapter 4 presents data on SD/I engines equipped with exhaust gas recirculation (EGR). HC+NOx emission levels below 10 g/kW-hr were achieved for each of the engines. CO emissions ranged from 25 to 185 g/kW-hr. For this less stringent alternative, we consider standards of 10 g/kW-hr HC+NOx and 150 g/kW-hr CO. The current California HC+NOx standard for these engines is 160 g/kW-hr.

For a more stringent option, we considered more stringent catalyst-based standards than we are proposing. Many of the SD/I marine engines with catalysts described in Chapter 4 had HC+NOx emission rates in the 3-4 g/kW-hr range, even with deteriorated catalysts. In the development testing for this proposed rulemaking, we did not investigate larger catalysts for SD/I applications. The goal of the development testing was to demonstrate catalysts that would work within the packaging constraints associated with water jacketing the exhaust and fitting the engines into engine compartments on boats. However, we did perform testing on engines equipped with both catalysts and EGR. These engines showed emission results in the 2-3 g/kW-hr range. We expect that these same reductions could be achieved more simply through the use of larger catalysts or catalysts with higher precious metal loading. As a more stringent regulatory alternative, we considered a standard of 2.5 g/kW-hr HC+NOx, with no change in the proposed CO standard, based on the use of larger catalysts. To account for additional development work that would need to be performed by manufacturers to achieve a lower standard than the existing California standard, we consider a later implementation date of 2012 for this more stringent alternative with no standard before that time.

11.1.1.4.2 SD/I ≥373 kW

For high-performance SD/I marine engines, we considered a less stringent alternative based on engine fuel system upgrades, calibration, or other minor changes such as an air injection pump rather than catalytic control. These less stringent standards were modeled for the 2009 model year. Manufacturers expressed concern that catalysts may not be practical for these engines due to the high exhaust flow rates, high emission rates, and low useful life period between rebuild. For analytical purposes, we selected an alternative standard of 22 g/kW-hr HC+NOx and 350 g/kW-hr CO, but lower levels in the range of 15-20g/kW-hr HC+NOx and 300g/kW-hr CO may be achievable with the engine modifications identified above. For these engines, we did not consider a more stringent alternative.

11.1.2 Alternative Evaporative Emission Requirements

11.1.2.1 Small SI Engines

For Small SI engines, we are proposing both permeation and venting emission standards. The proposed permeation standards are for fuel tanks and fuel lines. We believe that the proposed standards are reflective of available technology and represent a step change in emissions performance. Venting emissions include diurnal breathing losses, diffusion, and running loss emissions. For non-handheld Small SI engines (i.e., Classes I and II), we are proposing standards for running loss and diffusion emissions, but not for diurnal emissions. We are not proposing any type of venting emissions control for handheld equipment.

For a less stringent alternative, we considered not requiring venting emission control (running loss and diffusion emissions) for non-handheld Small SI engines. These requirements would be deleted from the proposal and thus modeled as being deleted in the years otherwise required in the proposal.

For a more stringent alternative, we considered applying running loss and diurnal standards to handheld equipment and setting a diurnal standard for non-handheld (Classes I and II). In these alternatives, we consider an implementation date of 2012 for handheld and Class I equipment, and a date of 2011 for Class II equipment.

11.1.2.2 Marine

Similar to the analysis described above for Small SI equipment, we base the less stringent and more stringent regulatory alternatives on changes in the proposed venting emission standards. For marine vessels, we proposed diurnal emission standards for all vessel types. For portable fuel tanks and PWC fuel tanks, the anticipated technology of a sealed system with pressure relief is fairly straightforward and commonly used today. However, we anticipate that the proposed diurnal emissions standards for vessels with installed fuel tanks would be based on the use of passively purged carbon canisters. For a less stringent alternative, we consider not setting a diurnal emission standard for marine vessels in 2010.[1] For a more stringent scenario,

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[1] Note that PWC already meet the proposed standard and would not be affected differently for the less stringent standard. PWC use sealed systems with pressure relief to prevent fuel spillage during operation.

we consider a diurnal requirement wherein boat builders would be required to employ active purge of carbon canister with installed tanks. This means that, when the engine is operating, it would draw air through the canister to purge the stored hydrocarbons. These purged gasoline vapors would be used in the engine as fuel.

11.1.3 Summary of Alternative Standards

Table 11.1-1 and Table 11.1-2 show the alternative program options that were selected above for further consideration.

Table 11.1-1: Exhaust Alternative Program Options for Quantitative Analysis

Source	Alt	Target	Proposal	less/ more	Alternative Description
Exhaust	1	Class I	• 10 g/kW-hr HC+NOx • Begins 2012	more	• 8 g/kW-hr HC+NOx • Begins 2015 in lieu of proposed
	2	Class II	• 8 g/kW-hr HC+NOx • Begins 2011	more	• 3.5 g/kW-hr HC+NOx • Begins 2015 in lieu of proposed
	3	OB/PWC	< 40kW • Decreases with power output (P) • HC+NOx g/kW-hr equation is 28-0.3P • CO g/kW-hr equation is 500-5P > 40kW • 16 g/kW-hr HC+NOx • 300 g/kW-hr CO • Both begin 2009	more	< 40kW • power output (P) • HC+NOx g/kW-hr equation is 28-0.45P • COg/kW-hr equation is 500-7.5P > 40 kW • 10 g/kW-hr HC+NOx • 200 g/kW-hr CO •Both begin 2012 in addition to 2009 standards
	4	SD/I <373 kW	• 5 g/kW-hr HC+NOx • 75 g/kW-hr CO • Begins 2009[a]	less	• 10 g/kW-hr HC+NOx • 150 g/kW-hr CO • Same effective dates as proposal
	5			more	• 2.5 g/kW-hr HC+NOx • 75 g/kW-hr CO • Begins 2012 in lieu of proposed standards[a]
	6	SD/I ≥373 kW	• 5 g/kW-hr HC+NOx • 350 g/kW-hr CO • Begins 2009[a]	less	• 22 g/kW-hr HC+NOx • 350 g/kW-hr CO • Begins 2009

[a] Does not include small business flexibilities that will delay the effective date of the requirements for some companies.

Table 11.1-2: Evaporative Alternative Program Options for Quantitative Analysis

Source	Alt	Target	Proposal	less/ more	Alternative Description
Evap	7	HH diurnal/ running loss	• None	more	• Begins 2012
	8	Class I & Class II diffusion & running loss	• 0.8 g/day HC diffusion standard • Running loss is a "zero emission" design standard • Class I begins 2012 and Class II begins 2011	less	• No running loss and no diffusion
	9	Class I & Class II diurnal	• None	more	• Requirement would begin in 2012 for Class I and 2011 for Class II
	10	Installed marine fuel tank diurnal	• 0.4g/gal/day HC trailerable boat • 0.16 g/gal/day HC non-trailerable boat • Begins 2010	less	• No diurnal for 2010
	11			more	• More stringent test procedure. If charcoal canister is used, active purge required. • Would begin 2010
	12	Portable marine fuel tank diurnal	• Diurnal is a "zero emission" design standard • Begins 2012	less	• No diurnal

11.2 Cost per Engine

This section describes the estimated cost of complying with the alternative program options. We developed the costs for individual technologies using estimates from ICF Incorporated,[1,2,3] conversations with manufacturers, other information including the published literature, and our best technical judgment. Also, the cost estimates for the alternatives rely heavily on the methodology and in some cases the actual cost data, used to characterize the proposed standards. For ease of presentation, we have not repeated the methodology or those detailed cost data here. Instead, we focus on presenting information regarding the requirements or changes that we expect will be needed to comply with the alternative options. The reader is encouraged to refer to Chapter 6 for more information. Finally, we did not specifically analyze the incremental costs of setting standards which would not result in technology which would allow certification in all 50 states (a harmonized program).

The costs of complying with the alternative program options are presented as incremental to the base case (current requirements) without considering the proposal. The only exception to this is the second phase of OB/PWC standards where costs are incremental to the proposal. The alternatives and the requisite technology are described in Section 11.1. Further, results are provided as the average cost per affected engine and the total net present value

(NPV) for a 30-year period beginning in 2008. The NPV estimates are based on a seven percent discount rate. All costs are in 2005 dollars.

11.2.1 Costs for Exhaust Emission Standards

11.2.1.1 More Stringent Small SI Engine HC + NOx Standards

11.2.1.1.1 Class I

Meeting more stringent standards would require OHV engines to use a slightly larger or more active catalyst than for the proposed standards. For current SV engines they would need to utilize larger and more active catalysts than considered in the analysis for the proposed standards, or convert to OHV design and use a slightly larger catalyst or more active catalyst than for the proposed standards.

The cost for the SV sized catalyst is outlined in Chapter 6. The cost for the conversion from SV to OHV design is drawn from ICF International's 2006 report "Small SI Engine Technologies and Costs[4]," and is listed as $9.42 in variable costs per engine, $2,010,147 in tooling changes and design and development, as well as $15 million in facility upgrades per Class I SV engine family. The 2005 EPA certification database lists five SV engine families certified to Phase 2 of which two engines have OHV engine designs in the same power range and one engine family is listed as a small volume engine family. The remaining two engine families have sales estimates in the millions of engines. As a result, fixed costs are applied two engine families and variable costs are applied to all SV engines.

The cost for improvements in OHV current engine designs includes improved cylinder head design for improved engine cooling, redesign of the engine flywheel to provide optimum cooling for the catalyst muffler as well as carburetor improvements. Research and development and tooling for these changes are estimated at $456,450 per engine family as shown in Chapter 6.

Upgrades in catalysts for OHV engines include additional precious metal for more active catalysts. The catalyst estimates for the SV engine families, that are replaced by OHV engine families, are also replaced with the OHV catalyst costs. These costs for improved OHV engines, upgraded catalysts for OHV engines are included in Table 11.2-1 together with those for SV engines.

11.2.1.1.2 Class II

Technologies for the more stringent option include improved engine design (redesign of cooling fins, fan design, combustion chamber design), closed loop control electronic fuel injection (EFI), catalysts and pressurized oil lube system for engines intended for residential use. The fixed costs for improved engine design are $456,000 per engine family and include R&D and tooling costs, as listed in Chapter 6. The same Chapter lists EFI variable costs at $79 per engine when it includes the credit for the removal of the carburetor. The fixed costs for closed loop fuel injection design is estimated at $103,000 per engine family. Increased catalyst efficiency is achieved through use of a larger catalyst and increased precious metal loading at an estimated increased catalyst cost of $4 (1000 hr engine) - $16 (250 hr engine) per engine. A pressurized lube oil system is listed by ICF[5] to be $15.48 in variable costs and $210,000 in fixed costs per engine family for the residential engines which often do not use it in today's design. Overall, fuel savings would be increased due to the application of electronic fuel injection to all Class II engines.

Table 11.2-1: Small SI Per-Engine Cost Estimates (Without Fuel Savings)
Sales Weighted Averages

	Short Term (years 1-5)	Long Term (years 6-10)
Proposed		
Class I	$11-$23	$9-$15
Class II	$39-$86	$27-$45
More Stringent		
Class I	$18-$23	$16-$17
Class II	$121-$153	$79-$97

11.2.1.2 Outboard/Personal Watercraft (OB/PWC) Engine HC + NOx and CO Emission Standards

We believe that, to meet the more stringent alternative considered here, manufacturers would need to convert their product lines primarily to a mix of calibrated four-stroke engines and engines equipped with catalysts. To model this approach, we looked at a technology mix that would achieve the 10 g/kW-hr HC+NOx limit, with appropriate considerations given to emissions deterioration rates and compliance margins. This technology mix was developed by assuming that all carbureted two-stroke engines would be removed from the fleet and replaced with four-stroke engines. All engines over 75 kW (100 hp) were modeled as using catalytic control. Detailed costs for converting engines from two-stroke to four-stroke and for equipping OB/PWC engines with catalysts are presented in Chapter 6. Table 11.2-2 compares the average per-engine equipment costs for the primary and the more stringent alternatives for OB/PWC engines.

Table 11.2-2: OB/PWC Per-Engine Cost Estimates (Without Fuel Savings) Sales Weighted Averages

		Short Term (years 1-5)	Long Term (years 6-10)
Proposed	OB PWC	$284 $359	$219 $272
More Stringent	OB PWC	$369 $518	$256 $389
Incremental Cost[a]	OB PWC	$85 $159	$37 $117

[a] Incremental cost is presented here because the more stringent alternative for OB/PWC includes the primary standard in 2009 plus a second, more stringent, standard in 2012.

We did not model differences in fuel savings between the primary and more stringent alternatives. The fuel savings for all three alternatives primarily come from the replacement of carbureted two-stroke engines with cleaner engine designs. In both the primary and more stringent scenarios, we model the discontinuation of sales of carbureted two-stroke engines.

11.2.1.3 Sterndrive/Inboard (SD/I) Engine HC + NOx and CO Emission Standards

With regard to the less stringent alternative, Chapter 4 presents costs for using exhaust gas recirculation (EGR) on SD/I engines. To estimate the costs for the less stringent alternative, all SD/I engines less than 373 kW were modeled to be equipped with electronic closed loop control fuel injection and EGR.

Engines greater than 373 kW were modeled to meet the less stringent alternative standard through engine calibration and increased use of electronic fuel injection (from 50 percent use to 75 percent use). This increased fuel injection use is intended to account for some carbureted engines that would not be able to meet the standard while acknowledging the data in Chapter 4 suggesting that some carbureted engines would be able to meet this alternative standard. using calibration changes or other engine modifications.

For the more stringent case, we consider a larger catalyst size with a higher precious metal loading for engines less than 373 kW and no change from the primary catalyst alternative for engines greater than 373 kW. Specifically, for engines less than 373 kW, we model a 25 percent larger catalyst and an additional 25 percent precious metal loading. We do not model a difference in fuel consumption for any of the three scenarios because, in each case, all engines are anticipated to use electronic fuel injection. To reiterate, we did not include a more stringent standard for high performance SD/I engines. Table 11.2-3 compares the per-engine cost estimates for the primary, less stringent, and more stringent alternatives.

Table 11.2-3: SD/I Per-Engine Cost Estimates (Without Fuel Savings)
Sales Weighted Averages

		Short Term (years 1-5)	Long Term (years 6-10)
Proposed	<373 kW	$360	$272
	≥373 kW	$920	$672
Less Stringent	<373 kW	$216	$160
	≥373 kW	$284	$155
More Stringent	<373 kW	$435	$337
	≥373 kW	$920[a]	$672[a]

[a] There is no more stringent option for these engines. Costs shown are for the proposal and are used later to develop aggregate values for the combination of more stringent marine options later in this section.

11.2.2 Costs for Evaporative Emission Standards

11.2.2.1 Small SI Engine

For the less stringent case, we simply subtract the costs of running loss and diffusion controls for non-handheld equipment. For the more stringent case, we add the incremental costs of diurnal emission control for all nonhandheld engines and diurnal emission control, diffusion control, and running losses for handheld engines. These technology costs are presented in Chapter 6. Table 11.2-4 compares the per-equipment cost estimates for the primary, less stringent, and more stringent alternatives.

Table 11.2-4: Evaporative Small SI Per-Equipment Cost Estimates (Without Fuel Savings) Sales Weighted Averages

		Short Term (years 1-5)	Long Term (years 6-10)
Proposed	Aggregate	$3.36	$2.54
	Handheld	$0.82[a]	$0.69[a]
	Class I	$3.16	$2.29
	Class II	$6.90	$5.30
Less Stringent		$1.82	$1.31
Aggregate		$0.82[a]	$0.69[a]
	Handheld	$1.11	$0.65
	Class I	$4.40	$3.30
	Class II		
More Stringent	Aggregate	$7.24	$5.64
	Handheld	$4.40	$3.55
	Class I	$6.12	$4.66
	Class II	$11.25	$8.78

[a] Values reflect the proposed permeation standards. These costs are used in the alternative analysis only to develop aggregate values for comparison purposes.

Table 11.2-5 presents the fuel savings for the three alternatives, based on the evaporative emission reductions for each of the scenarios. Because evaporative emissions are basically gasoline vapor lost to the atmosphere, these hydrocarbon reductions can be directly translated to gasoline savings using a gasoline cost of $1.81 per gallon. Cost savings are presented both with a 3 percent and a 7 percent discount factor over the life of the equipment.

Table 11.2-5: Projected Evaporative Fuel Savings for Small SI Equipment Sales Weighted Averages

		Lifetime Gallons Saved	Discounted Cost Savings	
			3 percent	7 percent
Proposed	Aggregate	1.4	$2.34	$2.18
	Handheld	0.2[a]	$0.32[a]	$0.31[a]
	Class I	0.8	$1.39	$1.32
	Class II	4.7	$7.24	$5.98
Less Stringent		0.9	$1.51	$1.41
Aggregate		0.2[a]	$0.32[a]	$0.31[a]
	Handheld	0.5	$0.89	$0.85
	Class I	3.0	$4.60	$3.80
	Class II			
More Stringent	Aggregate	1.5	$2.61	$2.42
	Handheld	0.3	$0.46	$0.46
	Class I	0.9	$1.50	$1.43
	Class II	5.3	$8.12	$6.70

[a] Values reflect the proposed permeation standards. These costs are used in the alternative analysis only to develop aggregate values for comparison purposes.

11.2.2.2 Marine

For the less stringent case, we simply subtract the costs of diurnal emission controls from marine vessels with installed and portable fuel tanks. For the more stringent case, we add the incremental costs of actively purged diurnal emission control for vessels with installed fuel tanks. These technology costs are presented in Chapter 6. Table 11.2-6 compares the per-equipment cost estimates for the primary, less stringent, and more stringent alternatives. Cost savings are presented both with a 3 percent and a 7 percent discount factor over the life of the vessel.

Table 11.2-6: Per-Vessel Cost Estimates (Without Fuel Savings)
Sales Weighted Averages

		Short Term (years 1-5)	Long Term (years 6-10)
Proposed	Aggregate	$55	$36
	portable	$12[a]	$8[a]
	PWC	$17[a]	$11[a]
	installed	$74	$62
Less Stringent	Aggregate	$33	$27
	portable	$11	$7
	PWC	$17[a]	$11[a]
	installed	$42	$36
More Stringent	Aggregate	$69	$56
	portable	$12[a]	$8[a]
	PWC	$17[a]	$11[a]
	installed	$94	$77

[a] Values reflect the proposed permeation and diurnal standards. These costs used in the alternative analysis only to develop aggregate values for comparison purposes.

Table 11.2-7 presents the fuel savings for the three alternatives. These fuel savings are based on the evaporative emission reductions for each of the scenarios. Because evaporative emissions are basically gasoline vapor lost to the atmosphere, preventing these hydrocarbon emissions can be directly translated to gasoline savings using a gasoline cost of $1.81 per gallon.

Table 11.2-7: Projected Evaporative Fuel Savings for Marine Vessels
Sales Weighted Averages

		Lifetime Gallons Saved	Discounted Cost Savings	
			3 percent	7 percent
Proposed	Aggregate	31	$45	$36
	portable	15[a]	$22	$19[a]
	PWC	9[a]	$15	$13[a]
	installed	41	$59	$45
Less Stringent		22	$33	$26
Aggregate		12	$18	$15
	portable	9[a]	$15	$13[a]
	PWC	28	$41	$32
	installed			
More Stringent	Aggregate	32	$47	$37
	portable	15[a]	$23	$19[a]
	PWC	9[a]	$15	$13[a]
	installed	43	$62	$47

[a] Values reflect the proposed permeation and diurnal standards. These costs used in the alternative analysis only to develop aggregate values for comparison purposes.

11.2.3 Cost Summary of Regulatory Alternatives

Table 11.2-8 summarizes the average cost per engine for the various alternative program options described above. The costs presented are for the short term and do not include fuel savings.

Table 11.2-8: Engine Cost Summary Range for Alternative Program Options ($/Engine) Sales Weighted Averages of Short-Term Costs without Fuel Savings, 2005$

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	$11-$23	more	$18-$23
	2	Class II	$39-$86	more	$121-$153
	3[a]	OB/PWC	$-	more	$70
	4	SD/I <373 kW	$360	less	$216
	5			more	$435
	6	SD/I ≥373 kW	$920	less	$284
Evap	7[b]	HH	$-	more	$3.58
	8	Class I & Class II	$4.41	less	$2.19
	9[b]	Class I & Class II	$-	more	$3.45
	10	Installed marine fuel tank	$74	less	$42
	11			more	$94
	12	Portable marine fuel tank	$12	less	$11

[a] Costs are presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 proposal.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

Table 11.2-9 summarizes the 30-year net present value for costs for the proposal and the various alternative program options described in Table 11.2-1. Cost results are provided as the total net present value (NPV) for a 30-year period. The NPV estimates are based on a 7 percent discount rate. These costs do not include fuel savings. Table 11.2-10 presents the same information with a 3 percent discount rate.

Table 11.2-9: 30-Year Net Present Value Cost Summary for Alternative Small SI Program Options with a 7 Percent Discount Rate (Million 2005$)

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	$1225	more	$1499
	2	Class II	$2080	more	$4360
	3[a]	OB/PWC	$-	more	$297
	4	SD/I <373 kW	$396	less	$239
	5			more	$391
	6	SD/I ≥373 kW	$11	less	$3
Evap	7[b]	HH	$-	more	$319
	8	Class I & Class II	$829	less	$382
	9[b]	Class I & Class II	$-	more	$570
	10	Installed marine fuel tank	$291	less	$166
	11			more	$361
	12	Portable marine fuel tank	$17	less	$16

[a] Costs are presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 proposal.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

Table 11.2-10: 30-Year Net Present Value Cost Summary for Alternative Small SI Program Options with a 3 Percent Discount Rate (Million 2005$)

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	$2,105	more	$2,770
	2	Class II	$3,387	more	$7,910
	3[a]	OB/PWC	$-	more	$465
	4	SD/I <373 kW	$596	less	$359
	5			more	$638
	6	SD/I ≥373 kW	$16	less	$4
Evap	7[b]	HH	$-	more	$544
	8	Class I & Class II	$1,367	less	$617
	9[b]	Class I & Class II	$-	more	$963
	10	Installed marine fuel tank	$458	less	$265
	11			more	$567
	12	Portable marine fuel tank	$24	less	$22

[a] Costs are presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 proposal.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and

diurnal/running loss/diffusion for handheld.

11.3 Emission Reduction

This section describes the estimated emission reductions associated with each of the alternative program options. We developed these estimates using the NONROAD emissions inventory model and methodology described in Chapter 3. The modeling inputs for alternative options are provided in Appendix 11A and Appendix 11B.

The incremental emission reductions of complying with the alternative program options are presented as incremental to the base case without the proposal. The only exception to this is the second phase of OB/PWC standards. The alternatives and the requisite technology are described in Section 11.1. Further, emission inventory results are provided as the total net present value (NPV) for a 30-year period. The NPV estimates are calculated based on both a 7 percent and a 3 percent discount rate. Small SI and Marine SI emission reductions are presented separately in Tables 11.3-1 and 11.3-2.

Table 11.3-1: 30-Year Net Present Value Emission Reduction Summary for Alternative Small SI Program Options with a 7 Percent Discount Rate (Million Tons)

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	0.78	more	0.67
	2	Class II	1.01	more	1.26
	3[a]	OB/PWC	0	more	0.23
	4	SD/I <373 kW	0.33	less	0.21
	5			more	0.30
	6	SD/I ≥373 kW	0.004	less	0.002
Evap	7[b]	HH	0	more	0.04
	8	Class I & Class II	1.02	less	0.60
	9[b]	Class I & Class II	0	more	0.12
	10	Installed marine fuel tank	0.40	less	0.28
	11			more	0.42
	12	Portable marine fuel tank	0.08	less	0.06

[a] Tons reduced are presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 proposal.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

Table 11.3-2: 30-Year Net Present Value Emission Reduction Summary for Alternative Small SI Program Options with a 3 Percent Discount Rate (Million Tons)

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	1.41	more	1.30
	2	Class II	1.82	more	2.48
	3[a]	OB/PWC	0	more	0.44
	4	SD/I <373 kW	0.61	less	0.38
	5			more	0.58
	6	SD/I ≥373 kW	0.007	less	0.003
Evap	7[b]	HH	0	more	0.07
	8	Class I & Class II	1.80	less	1.04
	9[b]	Class I & Class II	0	more	0.21
	10	Installed marine fuel tank	0.76	less	0.53
	11			more	0.78
	12	Portable marine fuel tank	0.14	less	0.12

[a] Tons reduced are presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 proposal.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

11.4 Cost Effectiveness

This section describes the cost effectiveness associated with each of the alternative program options. The costs are expressed as millions of dollars and the emission reductions are in terms of short tons. All results are presented as incremental to the base case without the proposal. The only exception to this is the second phase of OB/PWC standards where the values are calculated based on costs and emission reductions incremental to the proposal. Tables 11.4-1 and 11.4-2 present cost per ton estimates, using both a 7 percent and a 3 percent discount rate, for Small SI engines/equipment and Marine SI engines/vessels as outlined in Table 11.2-1.

Table 11.4-1: Comparison of Cost Effectiveness for Proposal and Alternatives Without Fuel Savings, 7 Percent Discount Rate ($/ton) 2005$

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	$1585	more	$2240
	2	Class II	$2055	more	$3470
	3[a]	OB/PWC	$740	more	$1280
	4	SD/I <373 kW	$1200	less	$1160
	5			more	$1330
	6	SD/I ≥373 kW	$2940	less	$1920
Evap	7[b]	HH	NA	more	$8150
	8	Class I & Class II	$770	less	$640
	9[b]	Class I & Class II	NA	more	$4910
	10	Installed marine fuel tank	$720	less	$600
	11			more	$870
	12	Portable marine fuel tank	$230	less	$250

[a] Cost effectiveness of more stringent alternative is presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 primary alternative.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

Table 11.4-2: Comparison of Cost Effectiveness for Proposal and Alternatives Without Fuel Savings, 3 Percent Discount Rate ($/ton) 2005$

Source	Alt	Target	Proposal	Scenario	Alternative
Exhaust	1	Class I	$1,500	more	$2,130
	2	Class II	$1,860	more	$3,180
	3[a]	OB/PWC	$630	more	$1050
	4	SD/I <373 kW	$980	less	$950
	5			more	$1100
	6	SD/I ≥373 kW	$2370	less	$1440
Evap	7[b]	HH	NA	more	$8150
	8	Class I & Class II	$720	less	$640
	9[b]	Class I & Class II	NA	more	$4910
	10	Installed marine fuel tank	$600	less	$500
	11			more	$730
	12	Portable marine fuel tank	$180	less	$190

[a] Cost effectiveness of more stringent alternative is presented incremental to the proposal for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the 2009 primary alternative.

[b] Only considers standards for venting emission control which are not in the proposal. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss/diffusion for handheld.

Ideally, this analysis would include an assessment of the monetized benefits which would potentially accompany each alternative as was provided in Chapter 8. This would provide further information for decision making and comparison to the proposed program. Unfortunately, the emissions data needed to conduct such an analysis, such as the potential PM benefits for the more stringent exhaust emission scenarios, is not available for this NPRM. This limits the utility of any comparisons which could be made since monetized benefits are partially dependent on PM health benefits.

11.5 Summary and Analysis of Alternative Program Options

This section presents a comparative summary of the important aspects related to the various alternative program options and our rationale for not pursuing an option relative to the proposal.

11.5.1 Exhaust Emission Standards

11.5.1.1 Small SI Engine HC + NOx Standards

11.5.1.1.1 Class I

This alternative considers a more stringent standard of 50 percent HC+NOx emission reduction beginning in 2015 for Phase 3 Class I engines instead of a reduction of 38 percent beginning in 2012 . While these emission standards may be feasible it is clearly in the in the longer term relative to the timing of the standards we are proposing. For analytical purposes the time line to begin implementation of the new standards was set at the 2015 model year. This is three model years past the implementation year for the proposed standards. For the analytical period we considered, the proposal provides more emission reductions than the alternative by 211,000 tons between 2012 and 2020. Postponing the exhaust emission standards to 2015 could likely also lead to postponing controls on running loss emissions with an additional loss of 44,000 tons of control. States with air quality problems would benefit from emission reductions in an earlier time frame. Thus, while both approaches are cost effective, we elected to go with the 38 percent reduction in 2012. In the context of section 213(a)(3) of the Clean Air Act, it represents the most stringent standards feasible within the lead time considered.

11.5.1.1.2 Class II

This alternative considers a more stringent standard of 4g/kW-hr HC+NOx , a reduction of about 67 percent for Class II engines over phase 2. These standards assume the use of closed loop electronic fuel injection and catalysts on all Class II engines. For the current proposal, we are expecting engine manufacturers to meet the standards by applying closed loop EFI on a portion of their V-twin engines and for the engine manufacturers or equipment manufacturers to use catalytic mufflers on the remaining engines. While these emission standards may be feasible it is clearly in the in the longer term relative to the timing of the standards we are proposing. For analytical purposes the time line to begin implementation of the new standards was set at the 2015 model year. This is four model years past the implementation year for the proposed standards. For the 30 year analytical period we considered, the proposal provides fewer overall emission reductions than the alternative, but between 2011 and 2020 the proposal gives 177,000 tons more reduction than the alternative assuming that running loss control is also postponed to begin in the 2015 model year. States with air quality problems would benefit from emission reductions in an earlier time frame. Thus, while both approaches are cost effective, we elected to go with the 34 percent reduction in 2011. In the context of section 213(a)(3) of the Clean Air Act, it represents the most stringent standards feasible within the lead time considered.

11.5.1.2 Outboard/Personal Watercraft (OB/PWC) Engine HC + NOx and CO Emission Standards

We analyzed the costs and emission reductions associated with more stringent standards for OB/PWC engines. We have concerns with proposing this second tier of OB/PWC standards at this time. 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. Direct injection two-strokes engines would face additional challenges. At this time, we believe it is not appropriate to base standards in this rule on the use of catalysts for OB/PWC engines. Although this technology may be attractive in the longer term, little development work has been performed on the application of 3-way catalysts to OB/PWC engines.
For this alternative, our modeling assumes all OB/PWC engines which need to can successfully apply aftertreatment technology.

11.5.1.3 Sterndrive/Inboard (SD/I) Engine HC + NOx and CO Emission Standards

11.5.1.3.1 SD/I <373 kW

With regard to less stringent standards, we believe that EGR would be a technologically feasible and cost-effective approach to reducing emissions from SD/I marine engines. However, we believe that greater reductions could be achieved through the use of catalysts. We considered basing an interim standard on EGR, but were concerned that this would divert manufacturers' resources away from catalyst development and could have the effect of delaying emission reductions from this sector. Setting a less stringent standard would likely be inconsistent with the requirements of section 213 of the Clean Air Act because at least one SD/I engine manufacturer offers a compliant product for sale in the US. In the NPRM we do ask for comment on a short-phase-in to deal with a change in the engine a supplier’s product lines.

With regard to more stringent requirements, we do not believe that they would necessarily lead to any further significant emission reductions in HC+NOx. Because this is the first generation of emission standards for this category of recreational marine engines, we believe that most manufacturers will strive to achieve emission levels below the proposed standards to give them certainty that they will pass the standards in-use, especially as catalysts on SD/I engines are a new technology. Therefore, we do not believe that it is necessary at this time to consider a lower standard for these engines.

11.5.1.3.2 SD/I ≥373 kW

This section addresses the alternative of setting less stringent standards for high performance SD/I engines. These engines have very high power outputs, large exhaust gas flow rates, and relatively high concentrations of hydrocarbons and carbon monoxide in the exhaust gases. From a conceptual perspective, the application of catalytic converter technology to these engines is feasible. As is the case in similar heavy-duty on-highway gasoline engines, these catalytic converters would have to be quite large in volume, perhaps on the order of the same volume as the engine displacement, and would involve significant heat rejection issues.

Manufacturers have expressed concern that catalysts may not be practical for these engines due to the high exhaust flow rates and short low useful life periods. We are requesting comment on an alternative approach not based on catalysts but based on engine and fuel system modifications. This option is less costly and more cost effective than our primary proposal, but provides less emission reductions. This alternative remains under active consideration. We intend to continue to work with the marine industry to gather additional data in order to further investigate this option.

11.5.2 Evaporative Emission Standards

11.5.2.1 Small SI Engine

We analyzed requiring diurnal and running loss control from handheld equipment in 2012. Even though it would be feasible from a strict technical perspective it is not a attractive option at this time. Fuel tanks from this equipment are very small, most less than one liter, and, with the exception of commercial equipment, their use is less than 15 hours per year. Adding hardware to control diurnal and running loss emissions would add weight which could be problematic on handheld equipment. In addition, it could create the potential for fuel leaks in equipment which can be used in rotated and inverted positions in the field. In addition, this option does not appear cost effective. For these reasons we elected not to pursue it.

With regard to controlling running loss and diffusion emissions from non-handheld equipment we believe it is feasible at a relatively low cost. Running loss emissions can be controlled by sealing the fuel cap and routing vapors from the fuel tank to the engine intake. Other approaches would be to move the fuel tank away from heat sources or to use heat protection such as a shield or directed air flow. Diffusion can be controlled by simply using a tortuous tank vent path, which is commonly used today on Small SI equipment to prevent fuel splashing or spilling. These emission control technologies are relatively straight-forward and inexpensive and do not have the weight and in-use position issues such as mentioned above for handheld equipment. Deleting the requirement does not meaningfully improve the cost effectiveness. Not proposing these requirements would be inconsistent with the section 213 of the Clean Air Act.

California requires control diurnal fuel tank emissions from Class I and Class II equipment as part of its overall fuel evaporative certification requirements. California requires an active purge of the control system. We evaluated the alternative of adding a diurnal requirement like that in California. Even though it would be feasible from a strict technical perspective it is not a attractive option at this time. While workable, there are some important issues would need to be resolved for diurnal emission control, such as cost, packaging, and vibration. Also, California requires an active purge, but we believe that a substantial reduction on the order of 50 percent could be achieved with a less complicated and less expensive passive purge approach. Finally, the cost and cost effectiveness of this program sub-element are of concern given the relatively low emissions levels (on a per-equipment basis) from such small fuel tanks. Overall, we do not consider this to be an attractive option at this time for Small SI engines as a group.

11.5.2.2 Marine

Although we considered the alternative of not requiring diurnal emission control for installed fuel tanks, we believe that carbon canisters are feasible for boats at relatively low cost.

Carbon canisters have been installed on fourteen boats by industry in a pilot program intended to demonstrate the feasibility of this technology. The proposed standards would be achievable through engineering design-based certification with canisters that are much smaller than the fuel tanks. In addition, sealed systems, with pressure control strategies would be accepted under the proposed engineering design-based certification. Eliminating these requirements would not meaningfully affect the cost effectiveness of the marine evaporative program. Not proposing these controls would be inconsistent with the requirements of section 213 of the Clean Air Act.

We also considered the feasibility of requiring the use of carbon canisters with active purging to control diurnal emissions. However, we are concerned that active purging would occur infrequently due to the low hours of operation per year seen by many boats. In addition, active purge adds complexity into the system in that the engine must be integrated into the control strategy. This could end up involving engine, tank, and vessel manufacturers in certification processes. Although we did not model it, this approach would undoubtedly require more lead time to implement because it is more complex and involves more entities. Based on data presented in Chapter 5, carbon canisters can be used to reduce emissions by more than 50 percent with passive purging. This passive purging occurs during the normal tank breathing process caused by ambient temperature changes without creating any significant pressure in the fuel tank. The small additional benefit of an actively purged diurnal control system would likely not justify the cost and complexity of implementing such a system, even though it appears to be cost effective.

Portable marine fuel tanks are used in vessels with outboard motors. Many of these tanks employ self-sealing vents which close the tank to the atmosphere when it is not in-use. This is quite straightforward, and it can be applied to all such tanks in the future for a reasonable cost. Not proposing these controls would be inconsistent with the requirements of section 213 of the Clean Air Act.

APPENDIX 11A: Emission Factors for the Less Stringent Alternative

11A.1 Exhaust Emission Factors and Deterioration Rates

11A.1.1 Small SI Exhaust

No less stringent exhaust emission standards were quantitatively analyzed for either Class I or Class II Small SI engines.

11A.1.2 Marine SI Exhaust

In the less stringent alternative, the same standards are considered for OB/PWC engines as for the primary scenario. However, for SD/I engines, we consider less stringent standards. As discussed above, these standards are based on the use of EGR for SD/I engines less than 373 kW and engine calibration for larger engines. For engines less than 373 kW we considered less stringent alternative standards of 10 g/kW-hr HC+NOx and 150 g/kW-hr CO for SD/I engines less than 373 kW. For high-performance engines, we considered a standard of 350 g/kW-hr HC+NOx. Because these emission factors are based on engine-out emissions, we use the same deterioration factors (DF) as for the baseline case. Table A-1 presents the zero-hour SD/I emission factors and the accompanying deterioration factors used to model the less stringent alternative.

Table 11A-1: Less Stringent Alternative EFs [g/kW-hr] and DFs for SD/I

Engine Category	HC		NOx		CO		BSFC
	EF	DF	EF	DF	EF	DF	
<373 kW	4.05	1.26	4.00	1.03	96.3	1.35	345
≥373 kW	10.1	1.26	6.79	1.03	207	1.35	362

11A.2 Evaporative Emission Factors

As discussed above, no changes in the proposed hose and tank permeation standards were considered in the less stringent alternative. The less stringent scenario was modeled for Small SI equipment by using the baseline running loss and diffusion rates for Class I and Class II equipment. For marine, the less stringent alternative was modeled by using the baseline diurnal emission rates for vessels with installed fuel tanks.

APPENDIX 11B: Emission Factors for the More Stringent Alternative

11B.1 Exhaust Emission Factors and Deterioration Rates

11B.1.1 Small SI Exhaust

For analytical purposes, we identified a more stringent program option of 8 g/kW-hr HC + NOx standard for Class I engines that would be implemented beginning in 2015. This standard represents about a 50 reduction from the existing Phase 2 standard, rather than the approximately 38 percent reduction associated with the proposal. The option also provides 3 more years of lead time. For Class II engines, we identified an alternative for a more stringent exhaust HC + NOx emission standard of 4.0 g/kW-hr beginning in 2015. (This option also includes an associated delay in the corresponding proposed running loss requirement such that engine changes are made simultaneously.) Such an exhaust emission standard represents a 67 percent reduction relative to the existing Phase 2 standard, rather than the 34 percent reduction associated with the proposal.

In modeling this more stringent option, we assumed the same phase-in schedule that reflects a number of flexibilities for engine and equipment manufacturers, and allows them to sell some Phase 2 compliant engines in the early years of the program. We also assumed that Class I side-valve technology would be completely replaced with overhead valve designs, and that all of the Class II engines would require closed loop control electronic fuel injection (EFI). Since EFI equipped engines enjoy a 10 percent fuel consumption advantage over their carbureted counterparts, we also revised the brake-specific fuel consumption (BSFC) for Class II engines. The new BSFC value is 0.666 lb/hp-hr.

All the modeling inputs were developed using a methodology consistent with that described in Chapter 3 of this draft RIA. The alternative emission standards and phase-in assumptions are shown in Table B-1. The emission factors are shown in Table B-2.

Table 11B-1: More Stringent Phase 3 Emission Standards and Implementation Schedule for Class I and II Small SI Engines (g/kW-hr or Percent)

Engine Class	Requirement	2015	2016	2017	2018	2019+
Class I	HC+NOx	8	8	8	8	8
	Required Sales Percentage	95	95	100	100	100
Class II	HC+NOx	4	4	4	4	4
	Required Sales Percentage	83	83	93	93	100

Table 11B-2: More Stringent Phase 3 Modeling Emission Factors for Small SI Engines (g/KW-hr)

Class/ Technology	HC ZML	HC "A"	NOx ZML	NOx "A"	CO ZML	CO "A"
Class I - SV	4.48	1.011	1.12	0.470	319.76	0.070
Class I -	4.07	1.011	1.53	0.470	325.06	0.070
Class II	2.13	1.011		0.470	391.13	0.080

11B.1.2 Marine SI Exhaust

For OB/PWC engines, the more stringent alternative considers exhaust emissions standards that are about 40 percent lower for HC+NOx and about 30 percent lower for CO than the proposed primary standard. The more stringent alternative emission standards are modeled as a second phase of standards, beyond the primary, beginning in 2012. In determining the combined HC+NOx emission factor, we used the proposed emission standards with a 10 percent compliance margin (with deterioration factor applied). To determine the NOx emission factors, we used certification data and other emissions data presented in Chapter 4, to determine the sales weighted average NOx for low emission technologies in each power bin. HC was then determined as the difference between the HC+NOx and the NOx emission factors. Because we are proposing the same standards for OB and PWC and because they use similar engines, we use the same HC+NOx emission factors and deterioration factors for both engine types. Because the proposed CO standard primarily acts as a cap on CO for many of the engines, the CO emission factors differ somewhat for CO based on data in the certification database for low CO engines. We use the same deterioration rates as in the primary case. Table B-3 presents the zero-hour OB/PWC emission factors used in analyzing the more stringent alternative.

Table B-3: More Stringent Alternative Emission Factors for OB/PWC [g/kW-hr]

Power Bin	HC	NOx	CO		BSFC
			OB	PWC	
0-2.2 kW	11.7	3.02	362	426	563
2.3-4.5 kW	10.9	2.25	238	359	560
4.6-8.2 kW	10.5	3.50	195	162	555
8.3-11.9 kW	9.0	4.22	165	154	552
12.0-18.6 kW	9.5	2.69	137	145	543
18.7-29.8 kW	7.5	3.55	120	137	528
29.9-37.3 kW	5.7	3.70	114	137	507
37.4-55.9 kW	5.2	3.38	115	137	471
55.9-74.6 kW	5.2	3.38	115	137	471
74.7-130.5 kW	5.4	3.13	101	135	415
130.6+ kW	6.3	2.30	93	119	387

For SD/I engines greater than 373 kW, we use the same control scenario as for the primary alternative. However, for SD/I engines less than 373 kW, we considered a more stringent HC+NOx standard of 2.5 g/kW-hr. To model this standard, we used zero-hour emission factors of 0.90 g/kW-hr HC and 0.80 g/kW-hr NOx. No changes were made in other emission factors for this more stringent alternative. In addition, the same deterioration factors were used here as in the primary alternative.

11B.2 Evaporative Emission Factors

As discussed above, no changes in the proposed hose and tank permeation standards were considered in the more stringent alternative. The more stringent scenario modeled for Small SI equipment by considering diurnal standards beginning in 2011 for Class II and 2012 for handheld and Class I equipment. This diurnal emission standards was modeled using a 60 percent reduction from baseline. Also, the more aggressive option for Class II exhaust standards was modeled as also including a corresponding delay in the proposed running loss requirement such that engine changes are made simultaneously.

For marine, the more stringent alternative was a standard requiring active purging of canisters for vessels with installed fuel tanks. This was modeled by using a 70 percent reduction in diurnal emissions compared to the baseline.

Chapter 11 References

1. “Small SI Engine Technologies and Costs, Final Report,” ICF International, August 2006.

2. “Marine Outboard and Personal Watercraft SI Engine Technologies and Costs,” ICF Consulting, prepared for the U.S. Environmental Protection Agency, July 2006, Docket Identification EPA-HQ-OAR-2004-0008-0452.

3. “Sterndrive and Inboard Marine SI Engine Technologies and Costs,” ICF Consulting, prepared for the U.S. Environmental Protection Agency, July 2006, Docket Identification EPA-HQ-OAR-2004-0008-0453.

4. “Small SI Engine Technologies and Costs, Final Report,” ICF International, August 2006.

5. “Small SI Engine Technologies and Costs, Final Report,” ICF International, August 2006.