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

Final Regulatory Impact Analysis

United States
Environmental Protection
Agency

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

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

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Executive Summary

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

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

Air Quality Background and Environmental Impact of the Rule

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

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

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

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

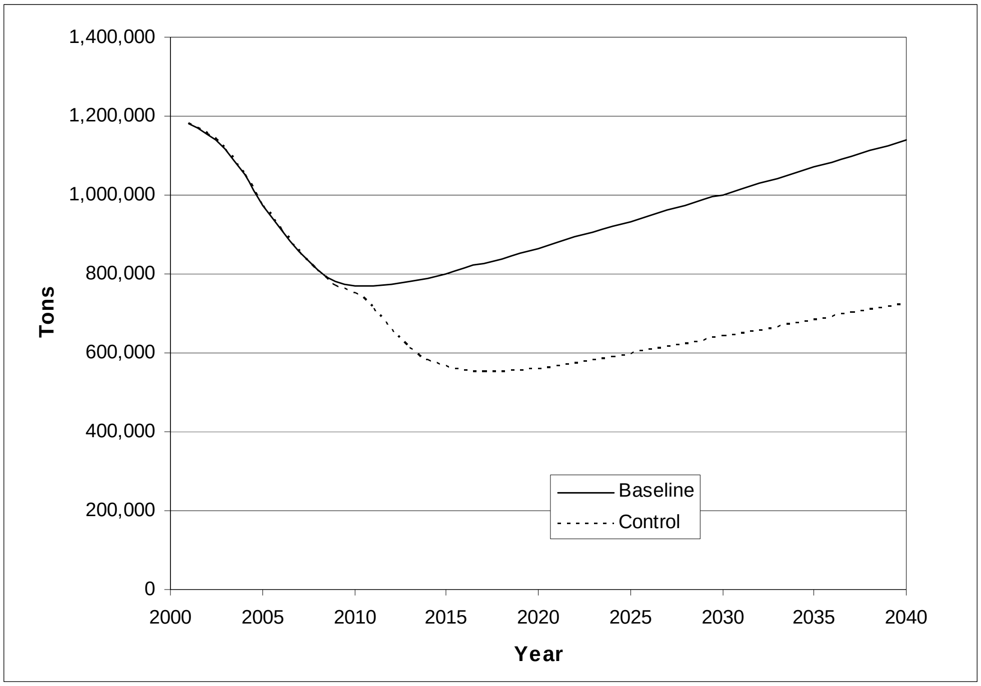
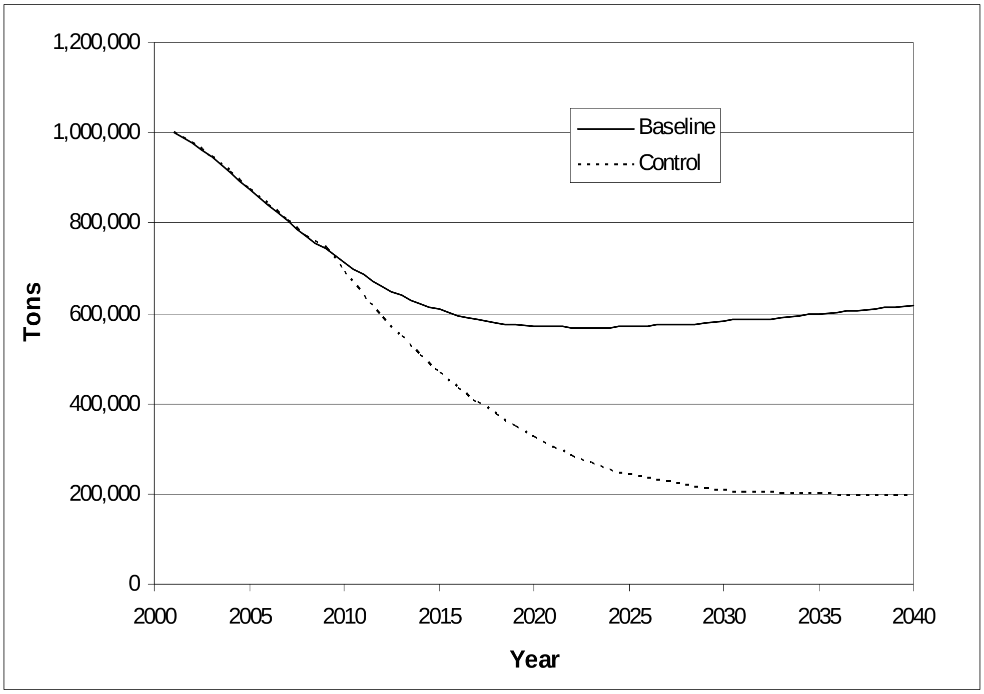


Figure 2: Marine Spark Ignition VOC+NOx Baseline and Phase 3 Control Emission Inventory



Exhaust and Evaporative Emission Standards

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

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

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

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

Table 2: Small SI Equipment Evaporative Emission Standards and Schedule

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

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

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

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

[a] These engines are also subject to not-to-exceed standards

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

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

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

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

[b] These engines are also subject to not-to-exceed standards. This category also includes engines >373 kW that do not otherwise meet the definition of "high-performance."

[c] 2011 for small-businesses and for engines built using the 4.3L or 8.1L GM engine blocks.

[d] For small businesses, the 2010 standards do not apply and the 2011 standards are delayed until 2013.

Table 4: Marine SI Engine Evaporative Emissions Standards and Schedule

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

[a] 2011 for primer bulbs. Phase-in for under cowl fuel lines, by length, on OB engines: 30% 2010, 60% 2011, 90% 2012, 100% 2015.

[b] Design standard.

[c] Fuel tanks installed in nontrailerable boats (≥ 26 ft. in length or >8.5 ft. in width) may meet a standard of 0.16 g/gal/day over an alternative test cycle.

[d] The standard is effective July 31, 2011. For boats with installed fuel tanks, this standard is phased-in 50%/100% over the first two years. As an alternative, small manufacturers may participate in a diurnal allowance program.

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

Feasibility of Meeting the Small SI Engine Exhaust Emission Standards

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

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

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

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

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

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

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

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

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

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

Feasibility of Meeting the Marine SI Exhaust Emission Standards

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

OB/PWC

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

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

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

SD/I

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

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

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

Feasibility of Meeting the Evaporative Emission Standards

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[b] Class I (125,250, or 500 hours), Class II (250, 500, or 1000 hours)

[c] Class I, Class II and handheld have fuel savings from evaporative measures. Class II engines with EFI have fuel savings of $39 based on the lifetime savings in the use of a residential ride on mower. There are no fuel savings related to compliance with the exhaust emission standard for Class I, handheld, or Class II engines without EFI.

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

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

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

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

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

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

Estimated Costs and Cost-Effectiveness for Marine SI Engines

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

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

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

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

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

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

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

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

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

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

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

Economic Impact Analysis

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

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

Benefits

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

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

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

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

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

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

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

[a] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to an estimate of PM2.5-related premature mortality derived from the ACS (Pope et al., 2002) study.

[b] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 8.4-1.

[d] Results reflect the use of a 3 percent discount rate. Monetary results presented in Table 8.6-2 use both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

[e] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

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

Impact on Small Businesses

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

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

Alternative Program Options

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

Small SI Engines

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

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

Marine SI Engines

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

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

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

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

Evaporative Emission Controls

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

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

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

Conclusion

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

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 more information on businesses that would be affected by new 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.

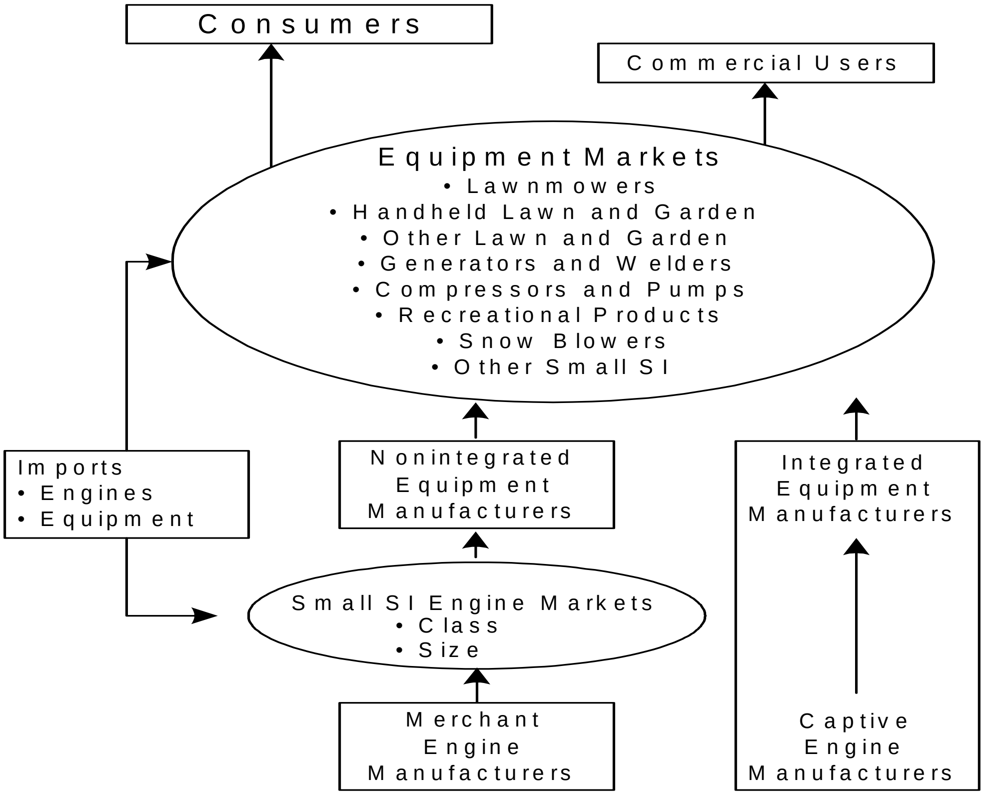
The industry profile report prepared by RTI for Small SI provides background information on the engines and equipment that make up the small nonroad SI industry, defined as those products rated less than or equal to 19 kilowatt (kW) (roughly equivalent to 25 horsepower [hp]). The profile describes markets 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 report prepared by RTI 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 report.

Figure 1-1: The Nonroad Small 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

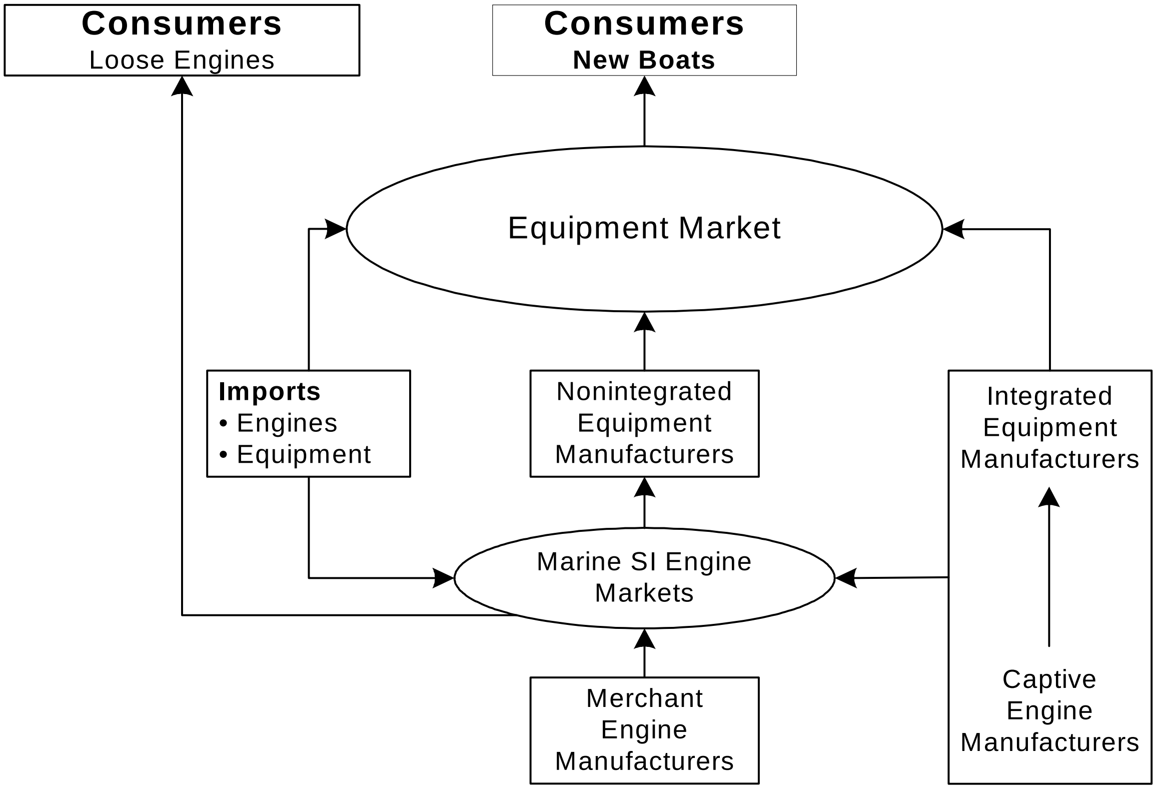


Figure 1-3: PWC Economic Model Conceptual Flow Chart

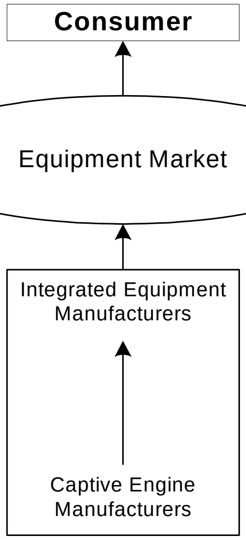
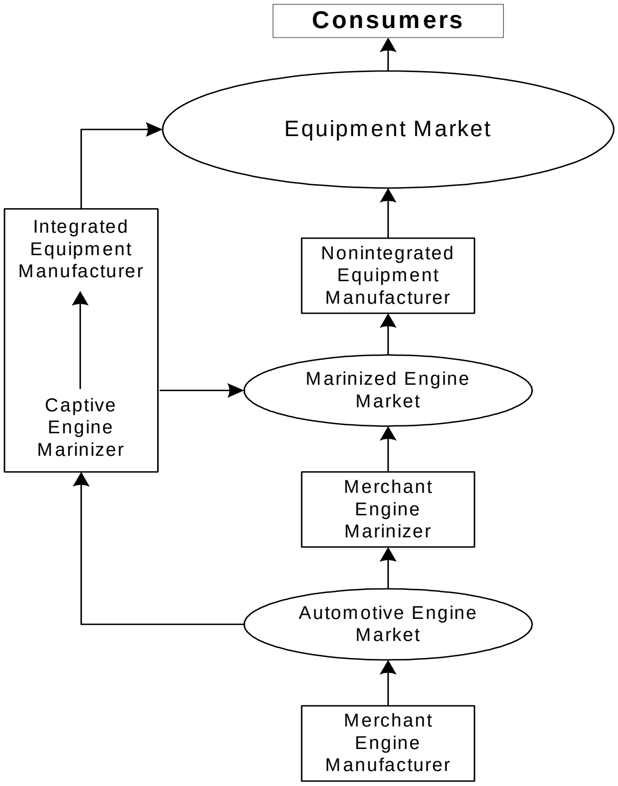


Figure 1-4: Inboard Marine Economic Model Conceptual Flow Chart



1.3 Fuel System Components

The primary fuel system components that would be affected by the 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, for which, specifications are now included 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, October 2006.

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

CHAPTER 2: Air Quality, Health, and Welfare Concerns

The standards finalized in this action will reduce emissions of hydrocarbons (HC), oxides of nitrogen (NOx), carbon monoxide (CO) and air toxics from the engines, vessels and equipment subject to this rule. Emissions of 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 also contribute to adverse environmental effects.

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, an 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 finalizing 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 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 people live in counties that are designated as nonattainment for either or both of the 8-hour ozone or $PM_{2.5}$ NAAQS. Figure 2-1 illustrates the widespread nature of the ozone and $PM_{2.5}$ nonattainment areas and also depicts mandatory class I areas. The emission standards in this rule will help reduce HC, NOx, PM, air toxic and CO emissions and their associated health and environmental effects.

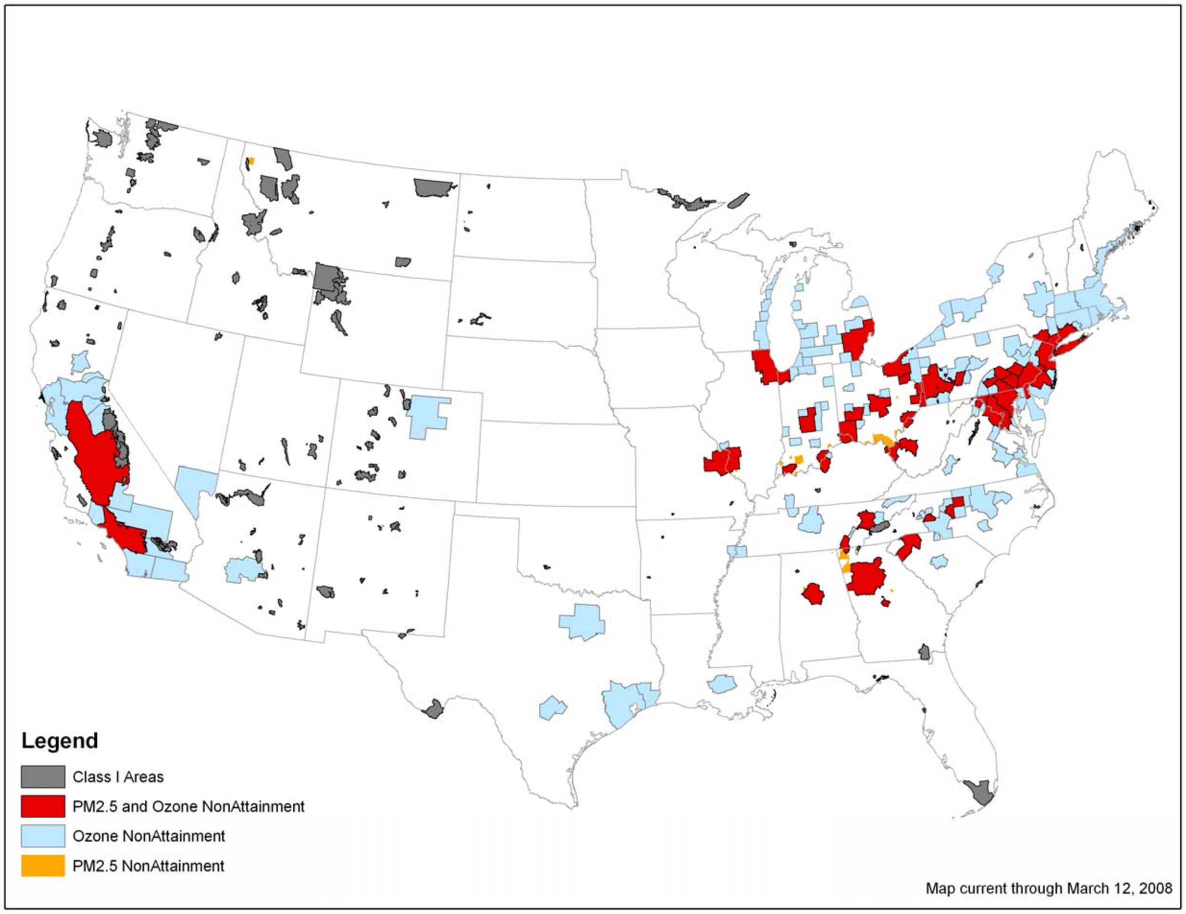


Figure 2-1: 8-Hour Ozone and PM$_{2.5}$ Nonattainment Areas and Mandatory Class I Federal Areas

2.1 Ozone

In this section we review the health and welfare effects of ozone exposure. We also describe the air quality monitoring and modeling data that indicates people in many areas across the country are exposed to levels of ambient ozone above the 1997 and 2008 ozone NAAQS. The data also indicates that in the future people will continue to live in counties with ozone levels above the NAAQS without additional federal, state or local measures. Emissions of volatile organic compounds (VOCs), of which HC are a subset, and NOx from the engines, vessels and equipment subject to this 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 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 vehicles and nonroad engines (including those subject to this 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 can be transported hundreds of miles downwind of precursor emissions, 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.

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. 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 usually 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.

2.1.2 Health Effects of Ozone Pollution

Exposure to ambient ozone contributes to a wide range of adverse health effects[A].

[A] 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

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.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory effects. Cell-level effects such as, inflammation of lungs, have been documented as well. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[4] People who appear to be more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and 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.[5, 6, 7, 8, 9, 10] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[11, 12, 13, 14, 15] 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 affect premature aging of the lungs and/or the development of chronic respiratory illnesses, such as emphysema and chronic bronchitis.[16, 17, 18, 19]

Children and adults who are outdoors and active during the summer months, such as construction workers, are among those most at risk of elevated ozone exposures.[20] Children and outdoor workers tend to have higher ozone exposure 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.[21] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported statistically significant reductions in lung function in children who are active outdoors.[22, 23, 24, 25, 26, 27, 28, 29] 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

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delivered to the lung is not only influenced by the ambient concentration but also by the individuals breathing route and rate.

ozone levels during prolonged periods of moderate exertion.[30, 31, 32, 33]

2.1.3 Current Ozone Levels

The small SI and marine SI engine emission reductions will assist ozone nonattainment areas in reaching the standard by each area's respective attainment date and/or assist in maintaining the ozone standard in the future. In this and the following section we present information on current and model-projected future 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 1997 ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 1997 Ozone NAAQS (69 FR 23858, April 30, 2004) identifies the criteria that EPA considered in making the 1997 8-hour ozone nonattainment designations, including 2001-2003 measured data, air quality in adjacent areas, and other factors.[B]

As of March 12, 2008 there are approximately 140 million people living in 72 areas designated as nonattainment with the 1997 8-hour ozone NAAQS. There are 337 full or partial counties that make up the 8-hour ozone nonattainment areas. These numbers do not include the people living in areas where there is a future risk of failing to maintain or attain the 8-hour ozone NAAQS. The 1997 8-hour ozone nonattainment areas, nonattainment counties, and populations are listed in Appendix 2A to this RIA.

EPA has recently amended the ozone NAAQS (73 FR 16436, March 27, 2008). The final ozone NAAQS rule addresses revisions to the primary and secondary NAAQS for ozone to provide increased protection of public health and welfare, respectively. With regard to the primary standard for ozone, EPA has revised the level of the 8-hour standard to 0.075 parts per million (ppm), expressed to three decimal places. With regard to the secondary standard for ozone, EPA has revised the current 8-hour standard by making it identical to the revised primary standard.

States with ozone nonattainment areas are required to take action to bring those areas into compliance in the future. The attainment date assigned to an ozone nonattainment area is based on the area's classification. Most ozone nonattainment areas will be required to attain the 1997 8-hour ozone NAAQS in the 2007 to 2013 time frame and then be required to maintain it thereafter.[C] The attainment dates associated with the potential nonattainment areas

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[B] 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 ozone 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 (including accounting for missing values and other complexities) are given in Appendices H and I of 40 CFR Part 50. 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.

[C] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area is designated as severe and will have to attain before June 15, 2021. The South Coast Air Basin has recently applied to be redesignated as an extreme based on the 2008 8-hour ozone NAAQS will likely be in the 2013 to 2021 timeframe, depending on the severity of the problem. Table 2-1 provides an estimate, based on 2004-06 air quality data, of the counties with design values greater than the 2008 ozone NAAQS. We expect many of the ozone nonattainment areas will need to adopt additional emissions reduction programs to attain and maintain the ozone NAAQS. The expected VOC and NO_x reductions from these standards, which take effect between 2009 and 2013, will be useful to states as they seek to either attain or maintain the ozone NAAQS.

Table 2-1 Counties with Design Values Greater Than the 2008 Ozone NAAQS Based on 2004-2006 Air Quality Data

	Number of Counties	Population[a]
1997 Ozone Standard: counties within the 72 areas currently designated as nonattainment	337	139,633,458
2008 Ozone Standard: additional counties that would not meet the 2008 NAAQS[b]	74	15,984,135
Total	**411**	**155,617,593**

Notes:
[a] Population numbers are from 2000 census data.
[b] Attainment designations for the 2008 ozone NAAQS have not yet been made. Nonattainment for the 2008 Ozone NAAQS will be based on three years of air quality data from later years. Also, the county numbers in the table include only the counties with monitors violating the 2008 Ozone NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

2.1.4 Projected Ozone Levels

In conjunction with this rulemaking, we performed a series of air quality modeling simulations for the continental U.S. The model simulations were performed for several emissions scenarios including the following: 2002 baseline projection, 2020 baseline projection, 2020 baseline projection with small SI/marine SI engine controls, 2030 baseline projection, and 2030 baseline projection with small SI/marine SI engine controls. Information on the air quality modeling methodology is contained in Section 2.3 as well as the air quality modeling technical support document (AQ TSD). In the following sections we describe our modeling of 8-hour ozone levels in the future with and without the controls being finalized in this action.

2.1.4.1 Projected 8-Hour Ozone Levels without this Rulemaking

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001). As a result of these programs, the number of areas that continue to violate the 8-hour ozone NAAQS in the future is expected to decrease.

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nonattainment area which will make their attainment date June 15, 2024.

The baseline air quality modeling completed for this rule predicts that without additional local, regional or national controls there will continue to be a need for reductions in 8-hour ozone concentrations in some areas 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 these levels will persist into the future.[D] Those interested in greater detail should review the air quality modeling TSD which is included in the docket for this rule.[34]

The baseline inventories that underlie the modeling conducted for this rulemaking include emission reductions from existing federal, state and local controls. There was no attempt to examine the prospects of areas attaining or maintaining the standard with future possible controls. We expect many of the areas to adopt additional emission reduction programs, but we are unable to quantify or rely upon future reductions from additional programs since they have not yet been promulgated. With reductions from programs already in place (but excluding the emission reductions from this rule), the number of counties in 2020 with projected 8-hour ozone design values at or above 85 ppb is expected to be 8 with a population of 22 million people. In addition, in 2020, 37 counties where 27 million people are projected to live, will be within 10 percent of violating the 1997 8-hour ozone NAAQS. The results should therefore be interpreted as indicating counties at risk for violating the ozone NAAQS in the future without additional federal, state or local measures in addition to this rulemaking.

2.1.4.2 Projected 8-Hour Ozone Levels with this Rulemaking

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the reductions in small SI and marine SI emissions finalized in this action. Specifically, we compare baseline scenarios to scenarios with controls. Our modeling indicates that the reductions from this rule will provide nationwide improvements in ambient ozone concentrations and minimize the risk of exposures in future years. Since some of the VOC and NO_x emission reductions from this rule go into effect during the period when some areas are still working to attain the 8-hour ozone NAAQS, the projected emission reductions will assist state and local agencies in their effort to attain the 8-hour ozone standard and help others maintain the standard. Emissions reductions from this rule will also help to counter potential ozone increases due to climate change, which are expected in many urban areas in the United States, but are not reflected in the modeling shown here.[35]

On a population-weighted basis, the average modeled future-year 8-hour ozone design values will decrease by 0.57 ppb in 2020 and 0.76 ppb in 2030. Table 2-2 shows the average change in future year eight-hour ozone design values for: (1) all counties with 2002 baseline design values, (2) counties with baseline design values that exceeded the standard in 2000-2004 ("violating" counties), (3) counties that did not exceed the standard, but were within 10 percent of it in 2000-2004, (4) counties with future year design values that exceeded the

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[D] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

standard, and (5) counties with future year design values that did not exceed the standard, but were within 10 percent of it in 2020 and 2030. Counties within ten percent of the standard are intended to reflect counties that meet the standard, but will likely benefit from help in maintaining that status in the face of growth. All of these metrics show a decrease in 2020 and 2030, indicating in five different ways the overall improvement in ozone air quality.

Table 2-2 Average Change in Projected Future Year 8-hour Ozone Design Value as a Result of the Small SI and Marine SI controls

Average[a]	Number of US Counties	Change in 2020 design value[b] (ppb)	Change in 2030 design value[b] (ppb)
All	660	-0.47	-0.66
All, population-weighted	660	-0.57	-0.76
Counties whose base year is violating the 1997 8-hour ozone standard	261	-0.62	-0.88
Counties whose base year is violating the 1997 8-hour ozone standard, population-weighted	261	-0.61	-0.80
Counties whose base year is within 10 percent of the 1997 8-hour ozone standard	223	-0.42	-0.61
Counties whose base year is within 10 percent of the 1997 8-hour ozone standard, population-weighted	223	-0.55	-0.78
Counties whose future year is violating the 1997 8-hour ozone standard	8 (2020) 6 (2030)	-0.13	-0.10
Counties whose future year is violating the 1997 8-hour ozone standard, population-weighted	8 (2020) 6 (2030)	-0.17	-0.13
Counties whose future year is within 10 percent of the 1997 8-hour ozone standard	37 (2020) 23 (2030)	-0.71	-1.05
Counties whose future year is within 10 percent of the 1997 8-hour ozone standard, population-weighted	37 (2020) 23 (2030)	-0.54	-0.79

Notes:
[a] averages are over counties with 2002 modeled design values
[b] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

Table 2-3 lists the counties with projected 8-hour ozone design values that violate or are within 10 percent of the 1997 8-hour ozone standard in 2020after application of the small SI and marine SI controls. Counties are marked with a "V" in the table if their projected design values are greater than or equal to 85 ppb. Counties are marked with an "X" in the table if their projected annual design values are greater than or equal to 76.5 ppb, but less than 85 ppb. The counties marked "X" are not projected to violate the standard, but to be close to it, so the rule will help assure that these counties continue to meet the standard. The current design values are also presented in Table 2-3. Recall that we project future design values only for counties that have current design values, so this list is limited to those counties with ambient monitoring data sufficient to calculate current 3-year design values.

Figure 2-2 illustrates the geographic impact of the small SI and marine SI engine controls on 8-hour ozone design values in 2020. Some of the most significant decreases will occur in the great lakes region, the gulf coast region, the northeast corridor and in the Seattle region. The maximum decreases in a 2020 design values is 2.0 ppb in Cape Cod, Massachusetts.

Table 2-3 Counties with 2020 8-hour Ozone Design Values in Violation or Within 10 percent of the 1997 Ozone Standard as a Result of the Small SI and Marine SI Controls

State	County	2000-2004 Average 8-Hour Ozone DV (ppb)[a]	2020 modeling projections of 8-Hour Ozone DV	2020 Population
CA	El Dorado	105.0	X	236,310
CA	Fresno	110.0	X	1,066,878
CA	Kern	114.3	X	876,131
CA	Kings	95.7	V	173,390
CA	Los Angeles	121.3	X	10,376,013
CA	Madera	91.0	V	173,940
CA	Merced	101.7	V	277,863
CA	Nevada	97.7	V	131,831
CA	Orange	85.3	V	3,900,599
CA	Placer	98.3	V	451,620
CA	Riverside	115.0	X	2,252,510
CA	Sacramento	99.0	V	1,640,590
CA	San Bernardino	128.7	X	2,424,764
CA	San Diego	92.3	V	3,863,460
CA	Stanislaus	95.0	V	607,766
CA	Tulare	105.7	X	477,296
CA	Tuolumne	91.0	V	70,570
CT	Fairfield	98.3	V	962,824
CT	New Haven	98.3	V	898,415
IN	Lake	88.3	V	509,293
LA	East Baton Rouge	87.0	V	522,399
MD	Harford	100.3	V	317,847
NJ	Camden	99.7	V	547,817
NJ	Gloucester	98.0	V	304,105
NJ	Mercer	97.7	V	392,236
NJ	Ocean	105.7	V	644,323
NY	Suffolk	97.0	V	1,598,742
OH	Ashtabula	95.7	V	108,355
OH	Geauga	99.0	V	114,438
PA	Bucks	99.0	V	711,275
PA	Philadelphia	96.7	V	1,394,176
TX	Brazoria	94.0	V	322,385
TX	Harris	102.0	X	4,588,812
TX	Jefferson	91.0	V	272,075
WI	Kenosha	98.3	V	184,825
WI	Racine	91.7	V	212,351
WI	Sheboygan	97.0	V	128,777

Notes:

[a] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

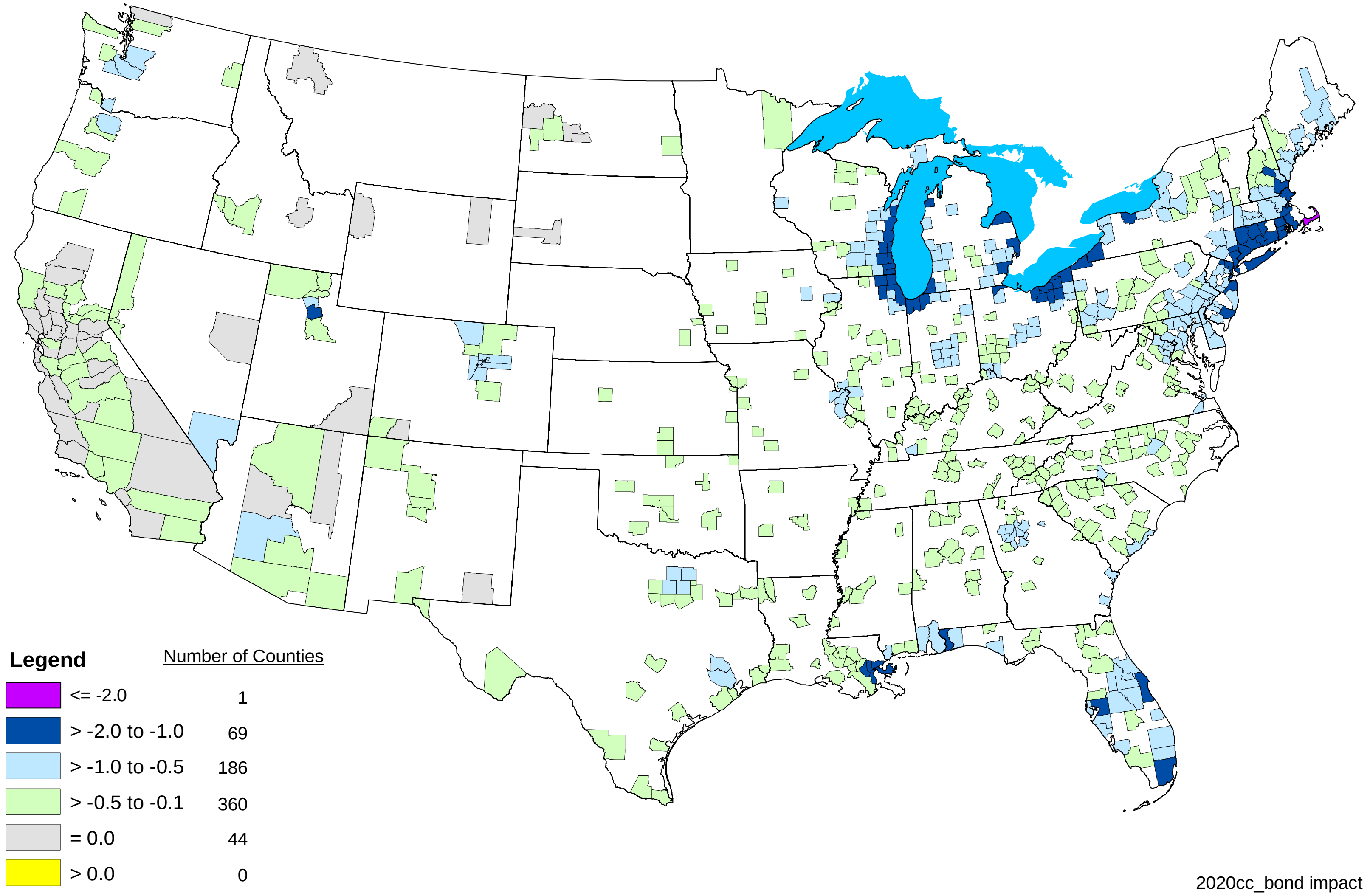

Figure 2-2 Impact of Small SI and Marine SI controls on 8-hour Ozone Design Values in 2020 (units are ppb)

2.1.5 Environmental Effects of Ozone Pollution

There are a number of public welfare effects associated with the presence of ozone in the ambient air.[36] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

2.1.5.1 Impacts on Vegetation

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. Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[37] 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.[38,39] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[40] 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 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.[41,42]

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).[43,44,45] 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.[46]

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.[47,48] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts. Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[49, 50]

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.[51] In most instances, responses to chronic or recurrent exposure in forested ecosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[52,53,54] 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.”[55] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[56, 57, 58]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. 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.[59] 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.

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 PM, HCs and NOx from the engines, vessels and equipment subject to this rule contribute to these PM concentrations. Information on air quality was gathered from a variety of sources, including monitored PM concentrations, air quality modeling forecasts conducted for this rulemaking, 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_{10} refers to particles generally less than or equal to 10 micrometers (μm) in aerodynamic diameter. $PM_{2.5}$ refers to fine particles, generally less than or equal to 2.5 μm in aerodynamic 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 aerodynamic diameter. Ultrafine PM refers to particles generally less than 100 nanometers (0.1 μm) in aerodynamic diameter. 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.

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as “primary” particles, and the latter as “secondary” particles. In addition, there are also physical, non-chemical reaction mechanisms that contribute to secondary particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from a particle’s ability to shift between solid/liquid and gaseous phases, which is influenced by concentration, meteorology, and temperature.

2.2.2 Health Effects of PM

As stated in EPA’s Particulate Matter Air Quality Criteria Document (PM AQCD), available scientific findings “demonstrate well that human health outcomes are associated with ambient PM.”[E] We are relying 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.[60,61] We also present additional

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[E] 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.

recent studies published after the cut-off date for the PM AQCD.[F][62] Taken together this information supports the conclusion that PM-related emissions such as those controlled in this action are associated with adverse health effects. Information on PM-related mortality and morbidity is presented first, followed by information on near-roadway exposure studies, marine ports and rail yard exposure studies.

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 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 indicated a relationship between mobile source $PM_{2.5}$ and mortality.[63,64] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. This study 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 PM_{10} when compared with other sources.[65] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects

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 rulemaking, the PM AQCD also notes that the PM components of gasoline and diesel engine exhaust represent

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[F] 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.

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).[66,67,68] These studies indicate that there are significant associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. One 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.[69]

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). In another recent publication included in the 2006 Provisional Assessment, investigators in southern California reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and measures of atherosclerosis in the Los Angeles basin.[70] 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.

2.2.2.3 Roadway-Related PM Exposure and Health Studies

A recent body of studies examines traffic-related PM exposures and adverse health effects. These studies are relevant to this rule because highway SI vehicles and nonroad SI engines, vessels and equipment have similar chemical and physical exhaust properties. However, this comparison is qualitative in nature since the near-road environment is influenced by both gasoline (SI) and diesel vehicles, as well as re-entrained road dust and brake and tire wear. One study 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.[71] Other studies have found associations between traffic-generated particle concentrations at residences and adverse effects, including all-cause mortality, infant respiratory symptoms, and reduced cognitive functional development.[72,73,74,75] There are other pollutants present in the near roadway environment, including air toxics which are discussed in Section 2.4. Additional information on near-roadway health effects can be found in the recent Mobile Source Air Toxics rule (72 FR 8428, February 26, 2007).

2.2.3 Current and Projected PM Levels

The emission reductions from this rule will 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. In this and the following section we present information on current and model-projected future PM levels.

2.2.3.1 Current $PM_{2.5}$ Levels

The small SI and marine SI engine emission reductions will assist PM nonattainment areas in reaching the standard by each area's respective attainment date and/or assist in maintaining the PM standard in the future. In this and the following section we present information on current and model-projected future PM 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 and a number of other factors (70 FR 943, January 5, 2005; 70 FR 19844, April 14, 2005).[G] These areas are comprised of 208 full or partial counties with a total population exceeding 88 million. The 1997 $PM_{2.5}$ nonattainment counties, areas and populations, as of March 2008, are listed in Appendix 2B to this RIA.

EPA has recently amended the NAAQS for $PM_{2.5}$ (71 FR 61144, October 17, 2006). The final PM NAAQS rule addressed revisions to the primary and secondary NAAQS for $PM_{2.5}$ to provide increased protection of public health and welfare, respectively. The primary $PM_{2.5}$ NAAQS includes 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 $\mu g/m^3$ to 35 $\mu g/m^3$ 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 $15 \mu g/m^3$, 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 will now be within 10 percent of the spatially averaged annual mean, and (2) the daily values for each monitoring site pair will now yield a correlation coefficient of at least 0.9 for each calendar quarter.

With regard to the secondary standards for $PM_{2.5}$, 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 and retained the annual $PM_{2.5}$ secondary standard. This suite of secondary $PM_{2.5}$ 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.

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

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.[H] Nonattainment areas will be designated with respect to the 2006 $PM_{2.5}$ NAAQS in early 2010. The attainment dates associated with the potential nonattainment areas based on the 2006 $PM_{2.5}$ NAAQS will likely be in the 2014 to 2019 timeframe. Table 2-4 provides an estimate, based on 2003-05 air quality data, of the counties with design values greater than the 2006 $PM_{2.5}$ NAAQS. The emission standards being finalized in this action will become effective between 2009 and 2013. The expected $PM_{2.5}$ inventory reductions will be useful to states in attaining or maintaining the $PM_{2.5}$ NAAQS.

Table 2-4 Counties with Design Values Greater Than the 2006 $PM_{2.5}$ NAAQS Based on 2003-2005 Air Quality Data

	Number of Counties	Population[a]
1997 $PM_{2.5}$ Standards: counties within the 39 areas currently designated as nonattainment	208	88,394,000
2006 $PM_{2.5}$ Standards: additional counties that would not meet the 2006 NAAQS[b]	49	18,198,676
Total	**257**	**106,592,676**

Notes:

[a] Population numbers are from 2000 census data.

[b] Attainment designations for the 2006 $PM_{2.5}$ NAAQS have not yet been made. Nonattainment for the 2006 $PM_{2.5}$ NAAQS will be based on three years of air quality data from later years. Also, the county numbers in the table include only the counties with monitors violating the 2006 $PM_{2.5}$ NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

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

2.2.3.2 Current PM_{10} Levels

EPA designated PM_{10} nonattainment areas in 1990.[I] As of March 2008, approximately 28 million people live in the 47 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.[J]

2.2.3.3 Projected $PM_{2.5}$ Levels

In conjunction with this rulemaking, we performed a series of air quality modeling simulations for the continental U.S. The model simulations were performed for several emissions scenarios including the following: 2002 baseline projection, 2020 baseline projection, 2020 baseline projection with small SI/marine SI engine controls, 2030 baseline projection, and 2030 baseline projection with small SI/marine SI engine controls. Information on the air quality modeling methodology is contained in Section 2.3 as well as the air quality modeling technical support document (AQ TSD). In the following sections we describe projected $PM_{2.5}$ levels in the future with and without the controls being finalized in this action.

2.2.3.2.1 Projected $PM_{2.5}$ Levels without this Rulemaking

Even with the implementation of all current state and federal regulations, including the Locomotive and Marine Rule, CAIR Rule, the NO_x SIP call, nonroad and on-road diesel rules and the Tier 2 rule, there are projected to be U.S. counties violating the $PM_{2.5}$ NAAQS well into the future. The model outputs from the 2002, 2020 and 2030 baselines, combined with current air quality data, were used to identify areas expected to exceed the $PM_{2.5}$ NAAQS in the future.

The baseline air quality modeling conducted for this final rule projects that in 2020, with all current controls in effect, up to 11 counties, with a population of 25 million people, may not attain the annual standard of 15 $\mu g/m^{3.}$ This does not account for additional areas that have air quality measurements within 10 percent of the $PM_{2.5}$ standard. These areas, although not violating the standard, will also benefit from the emissions reductions, ensuring long term maintenance of the PM NAAQS. For example, in 2020, an additional 16 million people are projected to live in 13 counties that have air quality measurements within 10 percent of the 2006 PM NAAQS. This modeling supports the conclusion that there are a substantial number of counties across the US projected to experience $PM_{2.5}$ concentrations at or above the $PM_{2.5}$ NAAQS into the future. Emission reductions from small SI and marine SI engines will be helpful for these counties in attaining and maintaining the $PM_{2.5}$ NAAQS.

[I] 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.

[J] The PM_{10} nonattainment areas are listed in Appendix 2C to this RIA.

2.2.3.2.2 Projected $PM_{2.5}$ Levels With this Rulemaking

The impacts of the small SI and marine SI engine controls were determined by comparing the model results in the future year control runs against the baseline simulations of the same year. On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design value (DV) for all counties is expected to decrease by 0.02 $\mu g/m^3$ in 2020 and 2030. There are areas with larger decreases in their future-year annual $PM_{2.5}$ DV, for instance the Chicago region will experience a 0.08 $\mu g/m^3$ reduction by 2030. Figure 2-3 illustrates the geographic impact of the small SI and marine SI engine controls on annual $PM_{2.5}$ design values in 2020.

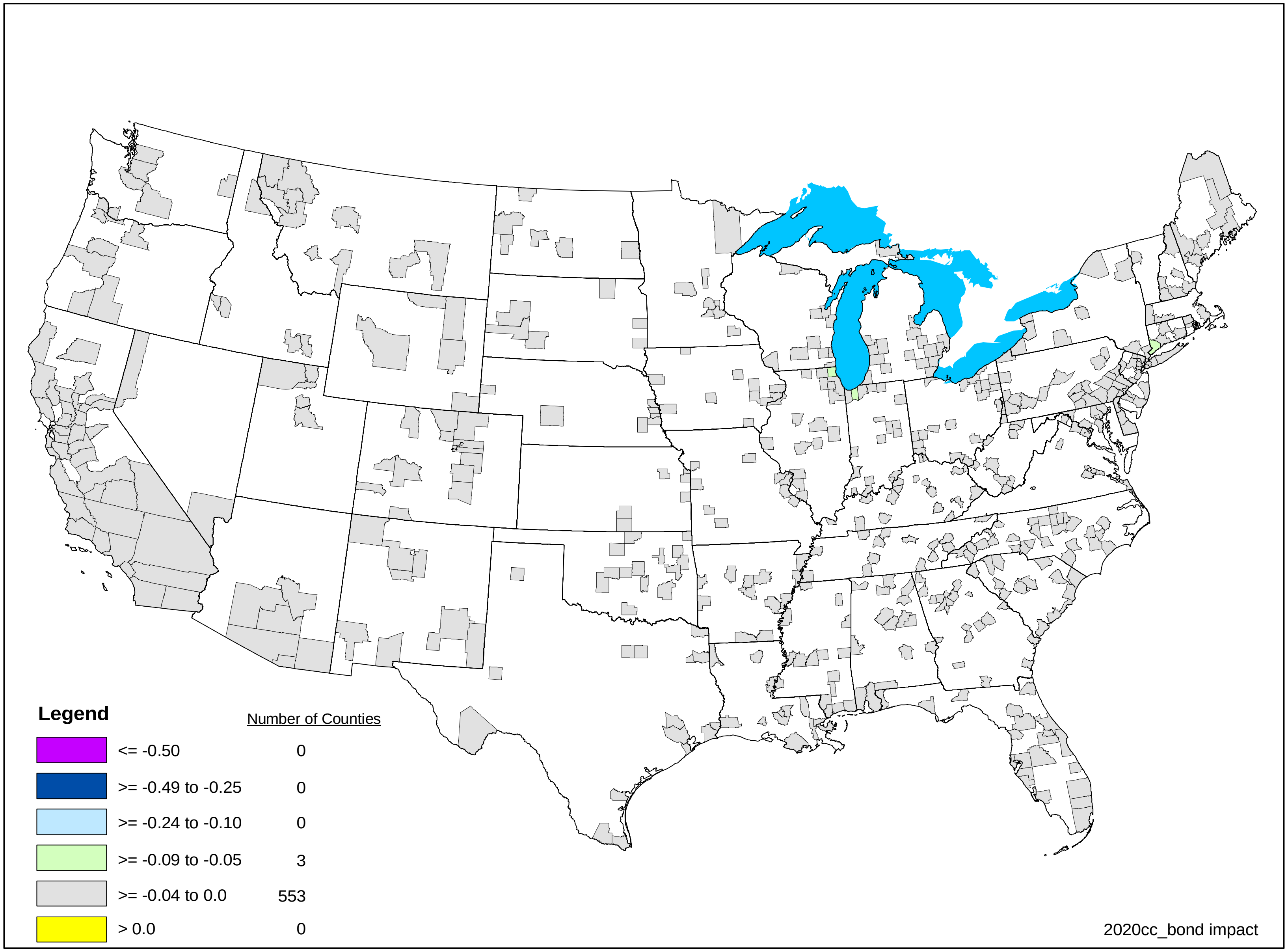

Figure 2-3 Impact of Small SI and Marine SI controls on annual $PM_{2.5}$ Design Values (DV) in 2020 (units are µg/m^3)

Table 2-5 lists the counties with projected annual $PM_{2.5}$ design values that violate or are within 10 percent of the annual $PM_{2.5}$ standard in 2020. Counties are marked with a "V" in the table if their projected design values are greater than or equal to 15.05 µg/m^3. Counties are marked with an "X" in the table if their projected annual design values are greater than or equal to 13.55 µg/m^3, but less than 15.05 µg/m^3. The counties marked "X" are not projected to violate the standard, but to be close to it, so the rule will help assure that these counties continue to meet the standard. The current design values are also presented in Table 2-5. Recall that we project future design values only for counties that have current design values, so this list is limited to those counties with ambient monitoring data sufficient to calculate current 3-year design values.

Table 2-5 Counties with 2020 Projected Annual $PM_{2.5}$ Design Values in Violation or Within 10 percent of the Annual $PM_{2.5}$ Standard as a Result of the Small SI and Marine SI Controls

State	**County**	**2000-2004 Average annual $PM_{2.5}$ DV (ug/m^3)**	**2020 modeling projections of annual $PM_{2.5}$ DV**	**2020 Population**
Alabama	Jefferson Co	18.36	V	681,549
California	Fresno Co	20.02	X	1,066,878
California	Imperial Co	14.44	V	161,555
California	Kern Co	21.77	X	876,131
California	Kings Co	18.77	X	173,390
California	Los Angeles Co	23.16	X	10,376,013
California	Merced Co	16.47	X	277,863
California	Orange Co	18.27	X	3,900,599
California	Riverside Co	27.15	X	2,252,510
California	San Bernardino Co	24.63	X	2,424,764
California	San Diego Co	15.65	V	3,863,460
California	San Joaquin Co	14.84	V	743,469
California	Stanislaus Co	16.49	V	607,766
California	Tulare Co	21.33	X	477,296
Georgia	Fulton Co	18.29	V	929,278
Illinois	Cook Co	17.06	V	5,669,479
Illinois	Madison Co	17.27	V	278,167
Kentucky	Jefferson Co	16.58	V	726,257
Michigan	Wayne Co	19.32	X	1,908,196
Montana	Lincoln Co	15.85	V	20,147
New York	New York Co	17.16	V	1,700,384
Ohio	Cuyahoga Co	18.36	V	1,326,680
Pennsylvania	Allegheny Co	20.99	X	1,242,587
West Virginia	Hancock Co	17.30	V	30,539

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, atmospheric deposition, and materials damage and soiling.

2.2.4.1 Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[76] Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.[77] 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 of 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 area 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 has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, 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.

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 sets secondary $PM_{2.5}$ standards which work in conjunction with the regional haze program. The secondary (welfare-based) $PM_{2.5}$ NAAQS is equal to the suite of primary (health-based) $PM_{2.5}$ NAAQS. The regional haze rule (64 FR 35714, July 1999) was put in place to protect the visibility in mandatory class I federal areas. 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. A list of the mandatory class I federal areas is included in Appendix 2D. Visibility is impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.

Control of small SI and marine SI emissions will improve visibility. The small SI and marine SI engines subject to this rule emit PM and PM precursors and thus contribute to visibility impairment. In the next sections we present current information and projected estimates about 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 emission reductions from this rule will help improve visibility conditions across the country and in mandatory class I federal areas. For more information on visibility see the PM AQCD as well as the 2005 PM Staff Paper.[78,79]

2.2.4.1.1 Current Visibility Impairment in $PM_{2.5}$ Nonattainment Areas

As mentioned above, the secondary $PM_{2.5}$ standards were set as equal to the suite of primary $PM_{2.5}$ standards. Almost 90 million people live in the 208 counties that are in nonattainment for the 1997 $PM_{2.5}$ NAAQS, (see Appendix 2A for the complete list of current nonattainment areas). These populations, as well as large numbers of individuals who travel to these areas can experience visibility 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.[80,81] 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.[82]

The regional haze rule requires states to establish goals for each affected mandatory class I federal area that 1) improves visibility on the haziest days (20% most impaired days), 2) ensures no degradation occurs on the cleanest days (20% least impaired days), and 3) achieves natural background visibility levels by 2064. 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.[83]

2.2.4.1.3 Future Visibility Impairment

Additional emission reductions will be needed from a broad set of sources, including those in this action, as part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

Modeling was used to project visibility conditions in 133 mandatory class I federal areas across the US in 2020 and 2030 as a result of the small SI and marine SI engine standards. The AQ modeling TSD and Section 2.3 of this RIA provide information on the modeling methodology. Table 2-6 below indicates the current monitored deciview values, the natural background levels each area is attempting to reach, and also the projected deciview values in 2020 and 2030 with and without the standards. In 2030, the greatest visibility improvement due to this rule (0.14 deciview) will occur at Brigantine, New Jersey.

Table 2-6 Current (2002) and Future (2020 and 2030) Projected Visibility Conditions With and Without Small SI and Marine SI Rule in Mandatory Class I Federal Areas (20% Worst Days)

Class 1 Area	State	Baseline Visibility	2020 Base	2020 Bond Rule	2030 Base	2030 Bond Rule	Natural Background
Sipsey Wilderness	AL	29.03	23.73	23.72	23.66	23.64	10.99
Caney Creek Wilderness	AR	26.36	22.05	22.03	21.92	21.89	11.58
Upper Buffalo Wilderness	AR	26.27	22.35	22.33	22.19	22.17	11.57
Chiricahua NM	AZ	13.43	13.09	13.09	13.09	13.09	7.21
Chiricahua Wilderness	AZ	13.43	13.09	13.09	13.09	13.09	7.21
Galiuro Wilderness	AZ	13.43	13.07	13.06	13.09	13.09	7.21
Grand Canyon NP	AZ	11.66	11.09	11.09	11.08	11.08	7.14
Mazatzal Wilderness	AZ	13.35	12.72	12.71	12.73	12.71	6.68
Petrified Forest NP	AZ	13.21	12.83	12.82	12.75	12.75	6.49
Pine Mountain Wilderness	AZ	13.35	12.58	12.56	12.54	12.53	6.68
Saguaro NM	AZ	14.83	14.47	14.48	14.44	14.45	6.46
Sierra Ancha Wilderness	AZ	13.67	13.20	13.20	13.15	13.14	6.59
Sycamore Canyon Wilderness	AZ	15.25	14.94	14.93	14.93	14.93	6.69
Agua Tibia Wilderness	CA	23.50	21.14	21.13	20.94	20.94	7.64
Caribou Wilderness	CA	14.15	13.60	13.60	13.51	13.51	7.31
Cucamonga Wilderness	CA	19.94	17.36	17.38	17.10	17.10	7.06
Desolation Wilderness	CA	12.63	12.13	12.13	12.12	12.12	6.12
Dome Land Wilderness	CA	19.43	18.34	18.34	18.11	18.11	7.46
Emigrant Wilderness	CA	17.63	17.21	17.20	17.19	17.19	7.64
Hoover Wilderness	CA	12.87	12.72	12.72	12.74	12.74	7.91
Joshua Tree NM	CA	19.62	17.93	17.97	17.71	17.72	7.19
Lassen Volcanic NP	CA	14.15	13.54	13.54	13.43	13.43	7.31
Lava Beds NM	CA	15.05	14.42	14.42	14.32	14.32	7.86
Mokelumne Wilderness	CA	12.63	12.30	12.30	12.31	12.30	6.12
Pinnacles NM	CA	18.46	17.36	17.34	17.09	17.09	7.99
Point Reyes NS	CA	22.81	21.99	21.98	21.79	21.79	15.77
Redwood NP	CA	18.45	17.86	17.86	17.79	17.78	13.91
San Gabriel Wilderness	CA	19.94	17.25	17.25	16.93	16.93	7.06
San Gorgonio Wilderness	CA	22.17	20.22	20.24	19.70	19.71	7.30
San Jacinto Wilderness	CA	22.17	19.87	19.90	19.55	19.52	7.30
South Warner Wilderness	CA	15.05	14.59	14.59	14.52	14.52	7.86
Thousand Lakes Wilderness	CA	14.15	13.52	13.52	13.41	13.40	7.31
Ventana Wilderness	CA	18.46	17.64	17.63	17.62	17.62	7.99
Yosemite NP	CA	17.63	17.14	17.14	17.11	17.11	7.64
Black Canyon of the Gunnison NM	CO	10.33	9.79	9.79	9.77	9.77	6.24
Eagles Nest Wilderness	CO	9.61	9.03	9.03	8.96	8.95	6.54
Flat Tops Wilderness	CO	9.61	9.25	9.25	9.24	9.24	6.54
Great Sand Dunes NM	CO	12.78	12.35	12.35	12.34	12.34	6.66

Class 1 Area	State	Baseline Visibility	2020 Base	2020 Bond Rule	2030 Base	2030 Bond Rule	Natural Background
La Garita Wilderness	CO	10.33	9.89	9.89	9.88	9.87	6.24
Maroon Bells-Snowmass Wilderness	CO	9.61	9.21	9.21	9.20	9.20	6.54
Mesa Verde NP	CO	13.03	12.39	12.39	12.37	12.37	6.83
Mount Zirkel Wilderness	CO	10.52	10.05	10.05	10.04	10.03	6.44
Rawah Wilderness	CO	10.52	10.04	10.03	10.04	10.02	6.44
Rocky Mountain NP	CO	13.83	13.08	13.06	13.01	12.99	7.24
Weminuche Wilderness	CO	10.33	9.85	9.85	9.85	9.84	6.24
West Elk Wilderness	CO	9.61	9.15	9.15	9.14	9.14	6.54
Chassahowitzka	FL	26.09	21.94	21.92	21.91	21.88	11.21
Everglades NP	FL	22.30	19.77	19.76	19.94	19.91	12.15
St. Marks	FL	26.03	21.82	21.81	21.83	21.81	11.53
Cohutta Wilderness	GA	30.30	23.33	23.32	23.28	23.26	11.14
Okefenokee	GA	27.13	23.42	23.41	23.40	23.39	11.44
Wolf Island	GA	27.13	23.37	23.35	23.32	23.29	11.44
Craters of the Moon NM	ID	14.00	12.97	12.96	12.82	12.80	7.53
Sawtooth Wilderness	ID	13.78	13.63	13.63	13.63	13.63	6.43
Mammoth Cave NP	KY	31.37	25.48	25.47	25.44	25.42	11.08
Acadia NP	ME	22.89	19.77	19.75	19.81	19.78	12.43
Moosehorn	ME	21.72	18.63	18.62	18.64	18.62	12.01
Roosevelt Campobello International Park	ME	21.72	18.45	18.44	18.47	18.45	12.01
Isle Royale NP	MI	20.74	19.10	19.08	19.04	19.01	12.37
Seney	MI	24.16	21.72	21.70	21.66	21.63	12.65
Voyageurs NP	MN	19.27	17.58	17.56	17.43	17.41	12.06
Hercules-Glades Wilderness	MO	26.75	22.93	22.92	22.81	22.78	11.30
Anaconda-Pintler Wilderness	MT	13.41	13.14	13.13	13.11	13.11	7.43
Bob Marshall Wilderness	MT	14.48	14.13	14.12	14.08	14.07	7.74
Cabinet Mountains Wilderness	MT	14.09	13.54	13.53	13.46	13.44	7.53
Gates of the Mountains Wilderness	MT	11.29	10.91	10.91	10.87	10.86	6.45
Medicine Lake	MT	17.72	16.19	16.19	16.09	16.09	7.90
Mission Mountains Wilderness	MT	14.48	14.04	14.04	13.99	13.99	7.74
Scapegoat Wilderness	MT	14.48	14.16	14.15	14.12	14.11	7.74
Selway-Bitterroot Wilderness	MT	13.41	13.04	13.04	12.99	12.99	7.43
UL Bend	MT	15.14	14.64	14.63	14.58	14.57	8.16
Linville Gorge Wilderness	NC	28.77	22.45	22.44	22.41	22.39	11.22
Swanquarter	NC	25.49	21.15	21.11	21.15	21.10	11.94
Lostwood	ND	19.57	17.70	17.70	17.60	17.60	8.00
Theodore Roosevelt NP	ND	17.74	16.49	16.48	16.34	16.34	7.79

Class 1 Area	State	Baseline Visibility	2020 Base	2020 Bond Rule	2030 Base	2030 Bond Rule	Natural Background
Great Gulf Wilderness	NH	22.82	19.45	19.43	19.46	19.43	11.99
Presidential Range-Dry River Wilderness	NH	22.82	19.45	19.43	19.46	19.43	11.99
Brigantine	NJ	29.01	24.85	24.75	24.91	24.77	12.24
Bandelier NM	NM	12.22	11.35	11.35	11.29	11.28	6.26
Bosque del Apache	NM	13.80	12.85	12.85	12.73	12.73	6.73
Gila Wilderness	NM	13.11	12.54	12.54	12.54	12.53	6.69
Pecos Wilderness	NM	10.41	9.97	9.97	9.97	9.97	6.44
Salt Creek	NM	18.03	16.59	16.58	16.52	16.52	6.81
San Pedro Parks Wilderness	NM	10.17	9.43	9.43	9.40	9.40	6.08
Wheeler Peak Wilderness	NM	10.41	9.88	9.88	9.87	9.87	6.44
White Mountain Wilderness	NM	13.70	12.88	12.89	12.87	12.86	6.86
Jarbidge Wilderness	NV	12.07	11.86	11.85	11.85	11.85	7.87
Wichita Mountains	OK	23.81	20.62	20.60	20.55	20.53	7.53
Crater Lake NP	OR	13.74	13.27	13.25	13.20	13.18	7.84
Diamond Peak Wilderness	OR	13.74	13.20	13.19	13.12	13.11	7.84
Eagle Cap Wilderness	OR	18.57	17.83	17.82	17.71	17.70	8.92
Gearhart Mountain Wilderness	OR	13.74	13.37	13.37	13.33	13.33	7.84
Hells Canyon Wilderness	OR	18.55	17.20	17.19	17.04	17.01	8.32
Kalmiopsis Wilderness	OR	15.51	14.98	14.97	14.93	14.92	9.44
Mount Hood Wilderness	OR	14.86	14.13	14.12	14.14	14.12	8.44
Mount Jefferson Wilderness	OR	15.33	14.77	14.76	14.76	14.75	8.79
Mount Washington Wilderness	OR	15.33	14.75	14.74	14.72	14.71	8.79
Mountain Lakes Wilderness	OR	13.74	13.24	13.23	13.17	13.16	7.84
Strawberry Mountain Wilderness	OR	18.57	17.73	17.72	17.60	17.59	8.92
Three Sisters Wilderness	OR	15.33	14.82	14.81	14.79	14.78	8.79
Cape Romain	SC	26.48	22.74	22.72	22.71	22.68	12.12
Badlands NP	SD	17.14	15.84	15.83	15.74	15.74	8.06
Wind Cave NP	SD	15.84	14.91	14.91	14.87	14.86	7.71
Great Smoky Mountains NP	TN	30.28	23.93	23.92	23.86	23.85	11.24
Joyce-Kilmer-Slickrock Wilderness	TN	30.28	23.43	23.42	23.37	23.35	11.24
Big Bend NP	TX	17.30	16.13	16.13	16.15	16.14	7.16
Carlsbad Caverns NP	TX	17.19	15.89	15.89	15.87	15.87	6.68
Guadalupe Mountains NP	TX	17.19	15.87	15.86	15.84	15.84	6.68
Arches NP	UT	11.24	11.11	11.11	11.03	11.01	6.43
Bryce Canyon NP	UT	11.65	11.34	11.34	11.31	11.31	6.86

Class 1 Area	State	Baseline Visibility	2020 Base	2020 Bond Rule	2030 Base	2030 Bond Rule	Natural Background
Canyonlands NP	UT	11.24	10.81	10.81	10.82	10.85	6.43
Zion NP	UT	13.24	12.92	12.95	12.81	12.83	6.99
James River Face Wilderness	VA	29.12	23.34	23.31	23.26	23.23	11.13
Shenandoah NP	VA	29.31	22.80	22.78	22.76	22.73	11.35
Lye Brook Wilderness	VT	24.45	21.08	21.06	21.11	21.08	11.73
Alpine Lake Wilderness	WA	17.84	16.71	16.69	16.60	16.57	8.43
Glacier Peak Wilderness	WA	13.96	13.60	13.60	13.67	13.66	8.01
Goat Rocks Wilderness	WA	12.76	12.05	12.03	12.03	12.02	8.36
Mount Adams Wilderness	WA	12.76	12.01	12.00	11.97	11.96	8.36
Mount Rainier NP	WA	18.24	17.24	17.23	17.21	17.18	8.55
North Cascades NP	WA	13.96	13.57	13.57	13.67	13.66	8.01
Olympic NP	WA	16.74	15.82	15.82	15.89	15.86	8.44
Pasayten Wilderness	WA	15.23	14.84	14.84	14.81	14.81	8.26
Dolly Sods Wilderness	WV	29.04	22.35	22.34	22.33	22.31	10.39
Otter Creek Wilderness	WV	29.04	22.29	22.28	22.27	22.25	10.39
Bridger Wilderness	WY	11.12	10.80	10.80	10.79	10.78	6.58
Fitzpatrick Wilderness	WY	11.12	10.85	10.85	10.84	10.84	6.58
Grand Teton NP	WY	11.76	11.35	11.35	11.31	11.31	6.51
North Absaroka Wilderness	WY	11.45	11.16	11.16	11.13	11.12	6.86
Red Rock Lakes	WY	11.76	11.43	11.42	11.39	11.39	6.51
Teton Wilderness	WY	11.76	11.40	11.39	11.36	11.36	6.51
Washakie Wilderness	WY	11.45	11.17	11.16	11.14	11.14	6.86
Yellowstone NP	WY	11.76	11.38	11.37	11.34	11.33	6.51

[a] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a “deciview”, which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

2.2.4.2 Particulate Matter Deposition

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominately from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). Reflecting this fact, the PM AQCD concludes that regardless of size fractions, particles containing nitrates and sulfates have the greatest potential for widespread environmental significance, while effects are also related to other chemical constituents found in ambient PM, such as trace metals and organics. The following characterizations of the nature of these welfare effects are based on the information contained in the PM AQCD and PM Staff Paper.

2.2.4.2.1 Deposition of Nitrates and Sulfates

At current ambient levels, risks to vegetation from short-term exposures to dry deposited particulate nitrate or sulfate are low. However, when found in acid or acidifying deposition, such particles do have the potential to cause direct leaf injury. Specifically, the responses of forest trees to acid precipitation (rain, snow) include accelerated weathering of leaf cuticular surfaces, increased permeability of leaf surfaces to toxic materials, water, and disease agents; increased leaching of nutrients from foliage; and altered reproductive processes—all which serve to weaken trees so that they are more susceptible to other stresses (e.g., extreme weather, pests, pathogens). Acid deposition with levels of acidity associated with the leaf effects described above are currently found in some locations in the eastern U.S.[84] Even higher concentrations of acidity can be present in occult depositions (e.g., fog, mist or clouds) which more frequently impacts higher elevations. Thus, the risk of leaf injury occurring from acid deposition in some areas of the eastern U.S**.** is high. Nitrogen deposition has also been shown to impact ecosystems in the western U.S. A study conducted in the Columbia River Gorge National Scenic Area (CRGNSA), located along a portion of the Oregon/Washington border, indicates that lichen communities in the CRGNSA have shifted to a higher proportion of nitrophilous species and the nitrogen content of lichen tissue is elevated.[85] Lichens are sensitive indicators of nitrogen deposition effects to terrestrial ecosystems and the lichen studies in the Columbia River Gorge clearly show that ecological effects from air pollution are occurring.

Some of the most significant detrimental effects associated with excess reactive nitrogen deposition are those associated with a syndrome known as nitrogen saturation. These effects include: (1) decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) fluctuation of ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms.[86]

In the U.S. numerous forests now show severe symptoms of nitrogen saturation. These forests include: the northern hardwoods and mixed conifer forests in the Adirondack and Catskill Mountains of New York; the red spruce forests at Whitetop Mountain, Virginia, and Great Smoky Mountains National Park, North Carolina; mixed hardwood watersheds at Fernow Experimental Forest in West Virginia; American beech forests in Great Smoky Mountains National Park, Tennessee; mixed conifer forests and chaparral watersheds in southern California and the southwestern Sierra Nevada in Central California; the alpine tundra/subalpine conifer forests of the Colorado Front Range; and red alder forests in the Cascade Mountains in Washington.

Excess nutrient inputs into aquatic ecosystems (i.e. streams, rivers, lakes, estuaries or oceans) either from direct atmospheric deposition, surface runoff, or leaching from nitrogen saturated soils into ground or surface waters can contribute to conditions of severe water oxygen depletion; eutrophication and algae blooms; altered fish distributions, catches, and physiological states; loss of biodiversity; habitat degradation; and increases in the incidence of disease.

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 a 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. [87]

2.2.4.2.2 Deposition of 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).[88] Investigation of trace metals near roadways and industrial facilities indicate that a substantial load 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). This hypothesized relationship/correlation was further explored in high elevation forests in the northeastern U.S. These studies measured levels of a group of intracellular compounds found in plants that bind with metals and are produced by plants as a response to sublethal concentrations of heavy metals. These studies indicated a systematic and significant increase in concentrations of these compounds associated with the extent of tree injury. These data strongly imply that metal stress causes tree injury and contributes to forest decline in the northeastern United States (PM AQCD 4-76,77).[89] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops (PM AQCD, p. 4-75). As the fallen leaves decompose, the heavy metals are transferred into the soil.[90,91]

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 mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[92,93] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[94] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[95] 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.[96,97] 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.[98] Plant uptake of platinum has been observed at these locations.

2.2.4.2.3 Deposition of 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.[99] 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.[100]

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.[101,102] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[103,104] 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.[105] PAHs that enter a water body through gas exchange likely partition into organic rich particles and can be biologically recycled, while dry deposition of aerosols containing PAHs tend to be more resistant to biological recycling.[106] 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.[107] Van Metre et al. noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlate with increases in automobile use.[108]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[109] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[110]

2.2.4.2.4 Materials Damage and Soiling

The effects of the deposition of atmospheric pollution, including ambient PM, on materials are related to both physical damage and impaired aesthetic qualities. The deposition of PM (especially sulfates and nitrates) can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Only chemically active fine particles or hygroscopic coarse particles contribute to these physical effects. In addition, the deposition of ambient PM can reduce the aesthetic appeal of buildings and culturally important articles through soiling. Particles consisting primarily of carbonaceous compounds cause soiling of commonly used building materials and culturally important items such as statues and works of art.

2.3 Air Quality Modeling Methodology

In this section we present information on the air quality modeling, including the model domain and modeling inputs. Further discussion of the modeling methodology, including evaluations of model performance, is included in the Air Quality Modeling Technical Support Document (AQM TSD).[111]

2.3.1 Air Quality Modeling Overview

A national scale air quality modeling analysis was performed to estimate future year 8-hour ozone concentrations, annual $PM_{2.5}$ concentrations, and visibility levels. These projections were used as inputs to the calculation of expected benefits from the small SI and marine SI emissions controls considered in this assessment. The 2002-based CMAQ modeling platform was used as the tool for the air quality modeling of future baseline emissions and control scenarios. It should be noted that the 2002-based modeling platform has recently been finalized and the 2001-based modeling platform was used as the tool for the air quality modeling performed for the proposal. In the next paragraph we discuss some of the differences between the 2001-based platform used for the proposal and the 2002-based platform used for this final rule.

The 2002-based modeling platform includes a number of updates and improvements to data and tools compared to the 2001-based platform that was used for the proposal modeling. For the final rule modeling we used the new 2002 National Emissions Inventory along with updated versions of the models used to project future emissions from electric generating units (EGUs) and onroad and nonroad vehicles. The proposal modeling was based on the 2001 National Emissions Inventory. The new platform also includes 2002 meteorology and more recent ambient design values which were used as the starting point for projecting future air quality. For proposal, we used meteorology for 2001 for modeling the East and 2002 for modeling the West. The updates to CMAQ between proposal and final include (1) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH; (2) improved vertical convective mixing; (3) heterogeneous reaction involving nitrate formation; (4) an updated gas-phase chemistry mechanism, Carbon Bond 2005 (CB05); and (5) an aqueous chemistry mechanism that provides a comprehensive simulation of aerosol precursor oxidants.

The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations and deposition over regional and urban spatial scales (e.g., over the contiguous U.S.).[112,113,114] Consideration of the different processes that affect primary (directly emitted) and secondary (formed by atmospheric processes) PM at the regional scale in different locations is fundamental to understanding and assessing the effects of pollution control measures that affect PM, ozone and deposition of pollutants to the surface. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial/boundary condition data which are inputs to this model.

The CMAQ model was peer-reviewed in 2003 for EPA as reported in “Peer Review of CMAQ Model”.[115] The latest version of CMAQ (Version 4.6.1) was employed for this modeling analysis. This version reflects updates, as mentioned above, in a number of areas to improve the underlying science which include (1) use of a state-of-the science inorganic and organic aerosol module, (2) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH, (3) improved vertical convective mixing, (4) heterogeneous reaction involving nitrate formation and (5) an updated Carbon Bond 05 (CB05) gas-phase chemistry mechanism and aqueous chemistry mechanism that provides a comprehensive simulation of aerosol precursor oxidants.

2.3.2 Model Domain and Configuration

The CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico. The modeling domain is made up of a large continental U.S. 36 km grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 2-4. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

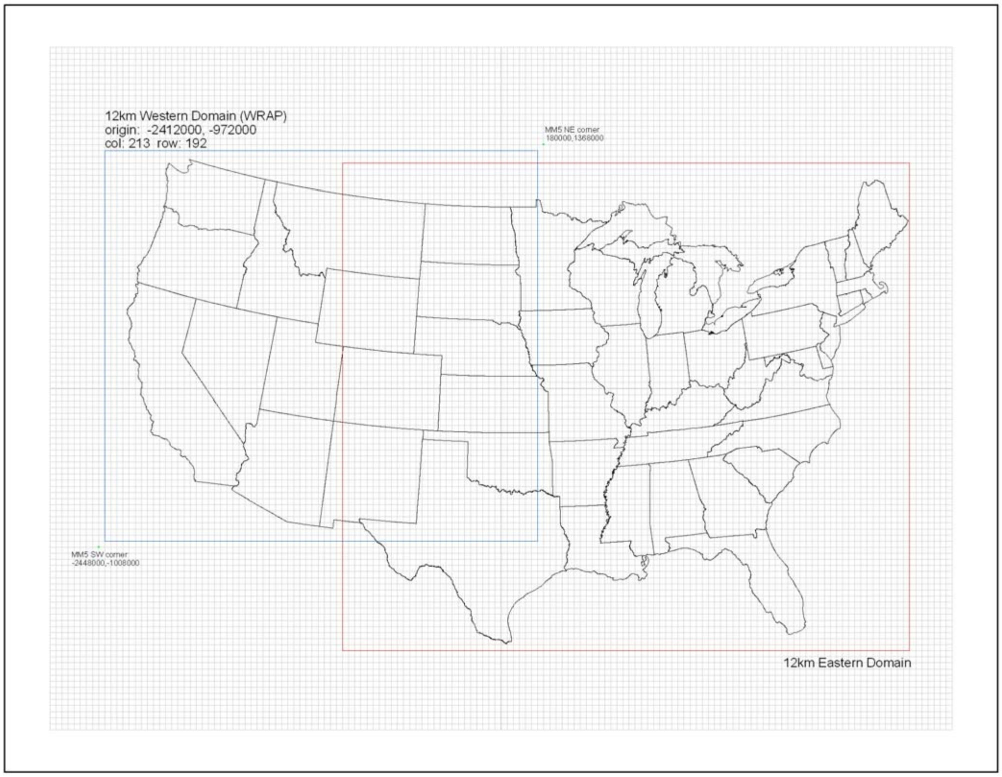

Figure 2-4. Map of the CMAQ modeling domain

2.3.3 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from a simulation of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model[116] for the entire year of 2002. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. The meteorology for the national 36 km grid and the 12 km Eastern U.S. grid were developed by EPA and are described in more detail within the AQM TSD. The meteorology for the 12 km Western U.S. grid was developed by the Western Regional Air Partnership (WRAP) Regional Planning Organization. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.1 to derive the specific inputs to CMAQ, for example: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[117]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[118] The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth

Observing System (GEOS). This model was run for 2002 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36 km CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

The emissions inputs used for the 2002 base year and each of the future year base cases and control scenarios are summarized in Chapter 3 of this RIA.

2.3.4 CMAQ Evaluation

An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using the 2002 data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. In summary, model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[K] The “acceptability” of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies.[L] Overall, the performance for the 2002 modeling platform is within the range of these other applications. A detailed summary of the 2002 CMAQ model performance evaluation is available within the AQM TSD.

2.3.5 Model Simulation Scenarios

As part of our analysis for this rulemaking the CMAQ modeling system was used to calculate 8-hour ozone concentrations, annual $PM_{2.5}$ concentrations, and visibility estimates for each of the following emissions scenarios:

2002 base year
2020 base line projection
2020 base line projection with small SI and marine SI controls
2030 base line projection
2030 base line projection with small SI and marine SI controls

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[K] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANE-VU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and Western Regional Air Partnership (WRAP).

[L] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

It should be noted that the emission control scenarios used in the air quality and benefits modeling are slightly different than the emission control program being finalized. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of this RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario. These refinements to the program would not significantly change the results summarized here or our conclusions drawn from this analysis.

We use the predictions from the model in a relative sense by combining the 2002 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, and visibility levels for each of the 2020 and 2030 scenarios. The ambient air quality observations are average conditions, on a site by site basis, for a period centered around the model base year (i.e., 2000-2004). After completing this process, we then calculated the effect of changes in PM, ozone and visibility air quality metrics resulting from this rulemaking on the health and welfare impact functions of the benefits analysis.

The projected annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses an Federal Reference Method FRM mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the US. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[119] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the AQM TSD. The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.

2.3.6 Visibility Modeling Methodology

The modeling platform described in this section was also used to project changes in visibility. The estimate of visibility benefits was based on the projected improvement in annual average visibility at mandatory class I federal areas. There are 156 Federally mandated Class I areas which, under the Regional Haze Rule, are required to achieve natural background visibility levels by 2064. These mandatory class I federal areas are mostly national parks, national monuments, and wilderness areas. There are currently 116 Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites (representing all 156 mandatory class I federal areas) collecting ambient $PM_{2.5}$ data at mandatory class I federal areas, but not all of these sites have complete data for 2002. For this analysis, we quantified visibility improvement at the 133 mandatory class I federal areas which have complete IMPROVE ambient data for 2002 or are represented by IMPROVE monitors with complete data.[M]

Visibility impairment is quantified in extinction units. Visibility degradation is directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient (b_{ext}) and visual range. The light extinction coefficient is based on the work of Sisler, which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil.[120]

Visual range is a measure of visibility that is inversely related to the extinction coefficient. Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. Visual range (in units of kilometers) can be calculated from b_{ext} using the formula: Visual Range (km) = $3912/b_{ext}$ (b_{ext} units are inverse megameters [Mm^{-1}])
The future year visibility impairment was calculated using a methodology which applies modeling results in a relative sense similar to the Speciated Modeled Attainment Test (SMAT).

In calculating visibility impairment, the extinction coefficient is made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility is calculated as the percent change in the extinction coefficient for each of the PM species (on a daily average basis). The individual daily species extinction coefficients are summed to get a daily total extinction value. The daily extinction coefficients are converted to visual range and then averaged across all days. In this way, we can calculate annual average extinction and visual range at each IMPROVE site. Subtracting the annual average control case visual range from the base case visual range gives a projected improvement in visual range (in km) at each mandatory class I federal area. This serves as the visibility input for the benefits analysis (See Chapter X).

[M] There are 100 IMPROVE sites with complete data for 2002. Many of these sites collect data that is "representative" of other nearby unmonitored mandatory class I federal areas. There are a total of 133 mandatory class I federal areas that are represented by the 100 sites. The matching of sites to monitors is taken from "Guidance for Tracking Progress Under the Regional Haze Rule".

For visibility calculations, we are continuing to use the IMPROVE program species definitions and visibility formulas which are recommended in the modeling guidance.[121] Each IMPROVE site has measurements of $PM_{2.5}$ species and therefore we do not need to estimate the species fractions in the same way that we did for FRM sites (using interpolation techniques and other assumptions concerning volatilization of species).

2.4 Air Toxics

Small SI and Marine SI emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to air toxics.[122] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. 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.

Table2-7 Mobile Source Inventory Contribution to 1999 Emissions of NATA Risk Drivers[a]

1999 NATA Risk Driver	Percent of Emissions Attributable to All Mobile Sources	Percent of Emissions Attributable to Non-road Sources
Benzene	68%	19%
1,3-Butadiene	58%	17%
Formaldehyde	47%	20%
Acrolein	25%	11%
Polycyclic organic matter (POM)[b]	5%	2%
Naphthalene	27%	6%
Diesel PM and Diesel exhaust organic gases	100%	62%

[a] This table is generated from data contained in the pollutant specific Microsoft Access database files found in the County-Level Emission Summaries section of the 1999 NATA webpage (http://www.epa.gov/ttn/atw/nata1999/tables.html).

[b] This POM inventory includes the 15 POM compounds: benzo[b]fluoranthene, benz[a]anthracene, indeno(1,2,3-c,d)pyrene, benzo[k]fluoranthene, chrysene, benzo[a]pyrene, dibenz(a,h)anthracene, anthracene, pyrene, benzo(g,h,i)perylene, fluoranthene, acenaphthylene, phenanthrene, fluorine, and acenaphthene.

According to NATA for 1999, mobile sources were responsible for 44 percent of outdoor toxic emissions and almost 50 percent of the cancer risk. Benzene is the largest contributor to cancer risk of all 133 pollutants quantitatively assessed in the 1999 NATA and mobile sources were responsible for 68 percent of benzene emissions in 1999. In response, EPA has recently finalized vehicle and fuel controls that address this public health risk.[N]

People are exposed to toxics from spark-ignition engines as a result of operating these engines and from intrusion into the home of emissions that occur in residential attached garages. A study of aldehyde exposures among lawn and garden equipment operators found formaldehyde and acetaldehyde exposure concentrations, during approximately 30 to 120 minutes of engine use, that were one to two orders of magnitude greater than those measured at an upwind monitor.[123] The study also reported measurable concentrations of transition metals emitted from most test engines, in addition to high organic carbon concentrations in $PM_{2.5}$ samples. Analyses of organic material emitted from hand-held engines have detected PAHs and other compounds, suggesting that exposures to hand-held engine emissions are similar in composition to those found in motor vehicle-affected environments, such as near major roadways.[124] Numerous studies have reported elevated benzene concentrations in residential attached garages.[125,126,127] These studies indicate the potential for elevated exposures as a result of the use and storage of small spark-ignition engines.

Noncancer health effects can result from chronic,[O] subchronic,[P] or acute[Q] inhalation exposures to air toxics, and include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems. According to the 1999 NATA, nearly the entire U.S. population was exposed to an average concentration of air toxics that has the potential for adverse noncancer respiratory health effects. This will continue to be the case in 2030, even though toxics concentrations will be lower. Mobile sources were responsible for 74 percent of the noncancer (respiratory) risk from outdoor air toxics in 1999. The majority of this risk was from exposure to acrolein. The confidence in the RfC for acrolein is medium and confidence in NATA estimates of population noncancer hazard from ambient exposure to this pollutant is low.[128,129]

The NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. These limitations and uncertainties are discussed on the 1999 NATA website.[130] Even so, this modeling framework is very

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[N] U.S. EPA (2007) Control of Hazardous Air Pollutants from Mobile Sources. 72 FR 8428; February 26, 2007.

[O] 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).

[P] Defined in the IRIS database as repeated exposure by the oral, dermal, or inhalation route for more than 30 days, up to approximately 10% of the life span in humans (more than 30 days up to approximately 90 days in typically used laboratory animal species)..

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

useful in identifying air toxic pollutants and sources of greatest concern, setting regulatory priorities, and informing the decision making process.

Benzene: The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes 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.[131,132,133] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[134,135]

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.[136,137] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[138,139] 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.[140,141,142,143] EPA's IRIS program has not yet evaluated these new data.

1,3-Butadiene: EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[144,145] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[146,147] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; 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.[148]

Formaldehyde: Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[149] 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.[150,151] 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.[152] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[153]

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.[154,155,156] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde.

Based on the developments of the last decade, 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. After reviewing the currently available epidemiological evidence, the IARC (2006) characterized the human evidence for formaldehyde carcinogenicity as "sufficient," based upon the data on nasopharyngeal cancers; the epidemiologic evidence on leukemia was characterized as "strong."[157] 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 (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation – including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.[158,159]

Acetaldehyde: Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[160] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[161,162] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[163] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[164,165] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[166] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

Acrolein: EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[167] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[168]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. Levels considerably lower than 1 ppm (2.3 mg/m^3) elicit subjective complaints of eye and nasal irritation and a decrease in the respiratory rate.[169,170] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein. Based on animal data, individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein. This was demonstrated in mice with allergic airway-disease by comparison to non-diseased mice in a study of the acute respiratory irritant effects of acrolein.[171]

EPA is currently in the process of conducting an assessment of acute exposure effects for acrolein. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[172]

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. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. One of these compounds, naphthalene, is discussed separately below. Polycyclic aromatic hydrocarbons (PAHs) are a subset 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 (a subclass of POM) 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.[173,174] 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 compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. 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.[175] The draft reassessment recently completed external peer review.[176] Based on external peer review comments received to date, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. Once EPA evaluates public and peer reviewer comments, the document will be revised. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[177] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[178] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[179]

The small SI and marine SI standards will reduce air toxics emitted from these engines, vessels and equipment, thereby helping to mitigate some of the adverse health effects associated with their operation. The assumption that toxic reductions track reductions in HC are supported by results from numerous test programs, including recent testing on small nonroad gasoline engines with and without controls.[180]

2.5 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.

2.5.1 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), which was published in 2000, regarding the health effects associated with CO exposure.[R][181] 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.[182,183] 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.[184] The subsequent hypoxia in brain tissue then

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[R] The NAAQS review process is underway for CO and the CO Integrated Science Assessment is scheduled to be completed in 2010.

produces behavioral effects, including decrements in continuous performance and reaction time.[185]

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.[186] Persons with heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising.[187] 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.[188]

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.[189]

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 2.6.

2.5.2 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.[S]

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

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 March 12, 2008, there are approximately 850 thousand people living in 4 areas (which include 5 counties) that are designated as nonattainment for CO, see Table 2-8. The emission reductions in this rule will help areas to attain and maintain the CO NAAQS.

Table 2-8: Classified Carbon Monoxide Nonattainment Areas as of March 2008[a]

Area	Classification	Population (1000s)
Las Vegas, NV	serious	479
El Paso, TX	moderate <= 12.7 ppm	62
Reno, NV	moderate <= 12.7 ppm	179
Total		719.5

[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, areas like Birmingham, AL and Calexico, CA have not been designated as nonattainment although monitors in these areas have recorded multiple exceedances since 1995.[190]

There are also almost 69 million people living in CO maintenance areas, see Table 2-9.[T] 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 2-9: Carbon Monoxide Maintenance Areas as of March 2008

	Number of Areas	Number of Counties	Population (1000s)
Serious	6	15	20,496,077
Moderate > 12.7ppm	4	19	17,575,606
Moderate <= 12.7ppm	30	62	23,371,653
Unclassified	33	38	7,480,907
Total	73	127	68,924,243

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

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[T] The CO nonattainment and maintenance areas are listed in Appendix 2E to this RIA.

inversions. Areas like Alaska are prone to winter inversions due to their topographic and meteorological 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.[191] The reductions in CO emissions from this rule will 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 will help states in their strategy to attain the CO NAAQS. Maintenance of the CO NAAQS is also challenging and many areas will be able to use the emissions reductions from this rule to assist in maintaining the CO NAAQS into the future.

2.6 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 air toxics, CO and PM. The standards being finalized in this action can help reduce acute exposures to emissions from Marine SI engines and vessels and Small SI engines and equipment.

2.6.1 Exposure to CO from Marine SI Engines and Vessels

In recent years, a substantial number of 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.[192] 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.[193]

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).[194] 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.

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

A large segment of the population uses small, gasoline-powered 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.[195,196] Studies investigating air pollutant exposures during small engine use did report elevated personal exposure measurements related to lawn and garden equipment use.[197,198] 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 contribute to elevated exposures to certain pollutants. The potential for elevated exposure to CO and $PM_{2.5}$ for operators of Small SI engines and equipment will be reduced by this rule.

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CHAPTER 3: Emission Inventory

This chapter presents our analysis of the emission impact of the final Phase 3 standards 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 final 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 final 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 slightly refined baseline and control scenarios reflected in the actual final rule.

The emission inventory estimates contained in Sections 3.2, 3.4, 3.5, and 3.6, for small nonroad and marine SI engines are reported for the 50-state geographic area that comprises the United States (including the District of Columbia). These inventories reflect the emissions from the engines subject to the final Phase 3 standards, i.e., federal engines. 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 has been granted a waiver under the Clean Air Act to regulate the emissions from all nonroad SI engines, except for engines with less than 175 horsepower that are used in farm and construction equipment. Therefore, these latter engines are subject to federal regulation and are included in our 50-state inventories. By contrast, we do not include any of the emissions from California marine SI engines in these inventories. As with certain nonroad engine classes, the State has been granted a waiver to regulate the exhaust emissions from all marine SI engines and evaporative emissions from outboard and personal watercraft SI engines. That State also has indicated its intent to adopt the final Phase 3 standards for evaporative emissions from sterndrive engines. Therefore, the 50-state inventories presented in Sections 3.2, 3.4, 3.5, and 3.6 only reflect the emissions from small nonroad and marine SI engines that are subject to federal regulation.

Section 3.3 presents a nationwide comparison of the emissions from small nonroad and marine SI engines to those from other source categories, i.e., stationary, area, and other mobile sources. Unlike the 50-state inventories described earlier, these inventories reflect the emissions from all sources, whether they are separately regulated by a state government or the federal government, e.g., all of California's small SI and marine SI engines are included.

Inventories are generally presented for the following pollutants: exhaust and evaporative hydrocarbons reported as total hydrocarbons (THC) and volatile organic compounds (VOC), oxides of nitrogen (NO_x), particulate matter ($PM_{2.5}$ and PM_{10}), and carbon monoxide (CO). The VOC category is a broader class of hydrocarbon compounds than THC that is primarily important for air quality modeling purposes. The additional compounds that comprise this category 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). The PM inventories for particle sizes of $\leq$2.5 microns or $\leq$10 microns in diameter include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling as noted below. Toxic pollutant inventories are also presented because the final Phase 3 requirements will 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).

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 final rule 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 final emission inventories were modeled for the small nonroad and marine SI engines that are affected by the Phase 3 standards. Generally, the inventories 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 final rule.[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 NONROAD2005d. A copy of the model and the accompanying documentation are available in the docket.[2,3,4] The inputs we used to model the effects of the Phase 3 standards are also described in Chapter 4 for exhaust emissions and Chapter 5 for evaporative emissions. Finally, the modifications we made to NONROAD2005a to reflect the baseline and control scenarios related to the final rule are summarized in Sections 3.2 and 3.4, respectively.

The nonroad model estimates emission inventories of important air pollutant species 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 final rule, 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 past, present, or future emissions between 1970 and 2050.

The chemical species NOx, PM, and CO are exhaust emissions, i.e., pollutants emitted directly as exhaust from the combustion of fuel (both liquid and gaseous fuels) 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 is 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 final Phase 3 standards for exhaust hydrocarbons, CO, and NOx from small nonhandheld nonroad and marine SI engines.[a] New standards to control evaporative emissions from hose permeation and tank permeation from these engine classes and handheld equipment are also included. Further, the final requirements also 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 final 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 final standards. For small nonroad SI equipment, California’s Air Resources Board (ARB) has promulgated standards that are roughly equivalent in stringency overall to final Phase 3 federal 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 final rule 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. However, the majority of the small nonroad SI equipment in California is subject to ARB regulations, so the effect of the federal Phase 3 standards for these engines in that State is rather limited.

For marine SI engines, ARB also has its own exhaust emission standards that are roughly equivalent overall to the final Phase 3 federal standards. In addition, ARB has stated its intend to develop evaporative emissions standards for marine SI equipment in California. Therefore, the exhaust and evaporative inventory estimates for marine SI engines/equipment completely exclude California.

3.2.1 Baseline Exhaust and Evaporative Emissions Estimates for THC, VOC, 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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[a] 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 2006. 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 NONROAD2005d. The modifications to the base model are described below.

3.2.1.1 Changes from NONROAD2005a to NONROAD2005d

As already mentioned, a number of improvements to the most publically available nonroad emissions inventory model were made to develop the NONROAD2005d, which is used in this final rulemaking. These revisions were based on recent testing programs, other information, and model enhancements. The changes are summarized below for small nonroad 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 final rule are summarized below:

1. Revised fuel tank and hose permeation emission factors;
2. Added new fuel tank diffusion losses to the diurnal emission estimates;
3. Updated or corrected 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;
5. Added the ability to specifically model the effects of ethanol blends on exhaust emissions and on fuel tank and hose permeation losses;
6. Added hot soak and running losses for handheld equipment;
7. Corrected snowblower technology types to include 4-stroke engines; and
8. Corrected running loss emission factors for Class 1 snowblowers to account for cold weather applications.

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 final rule 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 exhaust emissions and fuel tank and hose permeation losses.

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 NONROAD2005d 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. 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:

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

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

A, b = constants for a given technology type; $b \leq 1$.

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 final rule, 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)[b]

Class/ Technology	THC ZML	THC "A"	NOx ZML	NOx "A"	CO ZML	CO "A"	PM10 ZML	PM10 "A"
Class I - SV	10.30	1.753	2.57	0.180	386.53	0.070	0.35	1.753
Class I - OHV	8.73	1.753	3.28	0.180	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

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.

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[b] The nonroad model calculates VOC by multiplying THC by an adjustment factor depending on engine and fuel type for exhaust emissions as follows: 2-stroke gasoline = 1.034; 4-stroke gasoline = 0.933; liquified petroleum (LPG) = 0.995; and compressed natural gas (CNG) = 0.004. Crankcase and evaporative VOC for all fuels other than CNG is assumed to be equivalent to THC. CNG fueled equipment do not emit crankcase and evaporative VOC emissions because CNG is comprised almost exclusively of methane. $PM_{2.5}$ is calculated by multiplying PM_{10} 0.92.

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 updates to the emission rates and technology mix of marine SI engines.[5] 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.[6] However, NONROAD2005a did 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 more 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.[7] 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. A technical memorandum that documents the methodology and input values for modeling the effects of ethanol blends on nonroad engine fuel hose and tank permeation is also available in the docket for this final rulemaking.[8]

3.2.1.3.1 Fuel Ethanol Content

Currently, about 55 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 both exhaust and evaporative emissions from nonroad equipment. The oxygen content of the ethanol tends to make combustion mixtures leaner, which can decrease exhaust HC and CO emissions while increasing NOx. Also, 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 surpass 11 billion gallons per year by then. Based on these figures and projected gasoline sales from the Energy Information Administration,[10,11] we estimate that about three-fourths of gasoline sold in 2009 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 until switching to 10 percent in 2010.

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	12.5%
2001	132.0	1.8	13.4%
2002	135.6	2.1	15.7%
2003	137.0	2.8	22.2%
2004	140.1	3.5	27.3%
2005	140.2	4.0	31.0%
2006	142.2	5.5	41.5%
2007	141.7	6.1	46.3%
2008	142.5	7.6	57.5%
2009	144.1	10.0	75.1%
2010	145.4	10.9	78.8%
2011	147.1	11.0	*78.8%**
2012	149.0	11.2	*78.8%**

* ethanol fraction projected to be constant after 2010

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 nonroad 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.[12] 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 nonroadSI 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 fuel lines used in handheld equipment tested using E10 fuel. Based on this data, we estimate an average permeation rate at 23˚C, on fuel containing 10 percent ethanol of 255 g/m^2/day. 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).[13,14] 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 final 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 final 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 final 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.[15] Recently, we received comment from a boatbuilder using outboard motors that the hose lengths in our calculations were too short.[16] 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 nonroad 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.[17]

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 zero to 20 percent ethanol volume percent:

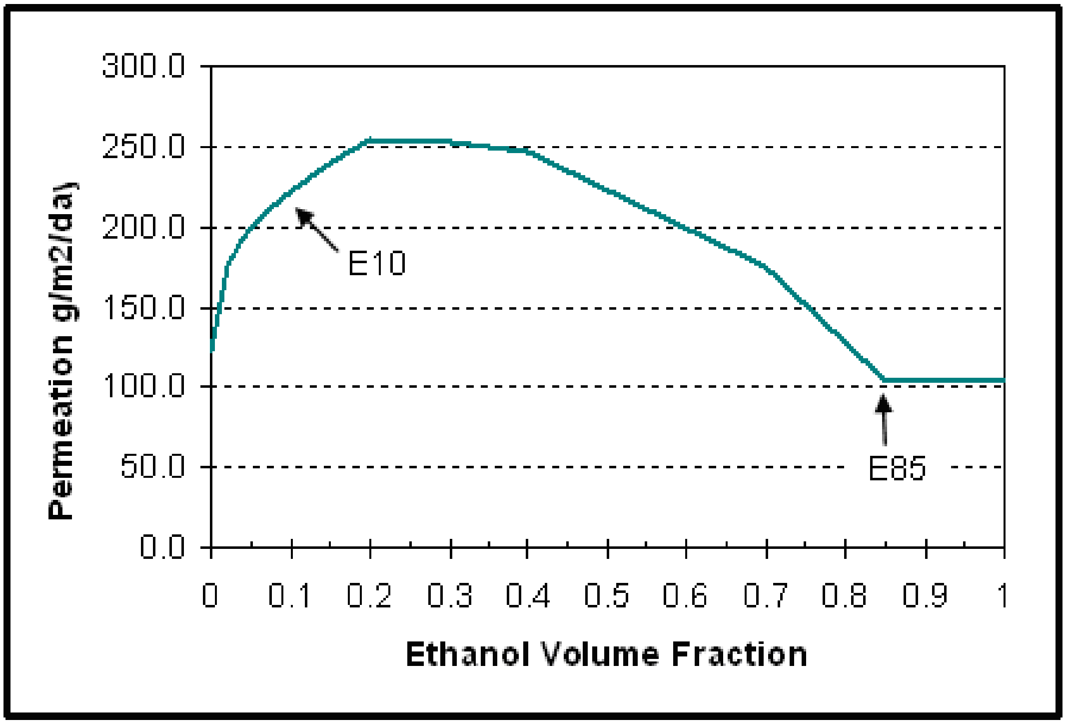
$$\text{Permeation EF} = \text{GasEF} + \text{GasEF} \times (\text{E10fac} - 1) \times [\,(\text{EthVfrac} / 0.10)\ \text{\textasciicircum}\ 0.4\,]$$

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

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

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



It should be noted that all ethanol blends currently modeled with the NONROAD model are less than or equal to E10, so no parts of this curve above E10 are used. Also, 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, VOC, 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	VOC	NOx	PM2.5	PM10	CO
2002	1,064,625	1,047,374	106,804	23,382	25,416	15,091,835
2003	1,026,922	1,009,822	106,852	23,480	25,522	14,351,829
2004	963,709	945,601	106,610	23,483	25,525	13,690,337
2005	886,524	867,081	106,847	23,417	25,453	12,923,819
2006	825,413	804,926	109,233	23,498	25,541	12,252,479
2007	768,239	747,552	109,439	23,804	25,874	11,711,607
2008	718,564	700,010	111,235	24,335	26,451	10,861,441
2009	682,088	665,890	116,329	24,882	27,045	9,992,801
2010	665,762	650,954	118,376	25,402	27,611	9,623,727
2011	663,620	649,358	119,424	25,888	28,139	9,568,610
2012	665,666	651,743	120,820	26,364	28,657	9,579,040
2013	671,328	657,539	122,506	26,832	29,165	9,644,512
2014	679,634	665,819	124,400	27,291	29,664	9,751,728
2015	689,045	675,131	126,395	27,747	30,160	9,879,027
2016	699,225	685,164	128,468	28,202	30,654	10,020,040
2017	709,899	695,658	130,573	28,655	31,146	10,169,185
2018	720,944	706,498	132,701	29,107	31,638	10,324,079
2019	732,284	717,615	134,846	29,558	32,128	10,483,706
2020	743,755	728,853	137,002	30,009	32,618	10,645,870
2021	755,254	740,118	139,160	30,460	33,109	10,808,929
2022	766,782	751,412	141,317	30,911	33,599	10,972,659
2023	778,333	762,727	143,475	31,362	34,089	11,136,954
2024	789,900	774,056	145,636	31,813	34,579	11,301,731
2025	801,493	785,411	147,806	32,265	35,070	11,467,292
2026	813,217	796,890	150,003	32,718	35,563	11,634,934
2027	824,971	808,397	152,209	33,173	36,057	11,803,402
2028	836,736	819,915	154,418	33,627	36,551	11,972,207
2029	848,508	831,439	156,628	34,081	37,045	12,141,251
2030	860,287	842,970	158,840	34,535	37,538	12,310,505
2031	872,069	854,504	161,053	34,990	38,032	12,479,899
2032	883,856	866,042	163,266	35,444	38,526	12,649,385
2033	895,645	877,583	165,479	35,898	39,020	12,818,940
2034	907,437	889,126	167,692	36,353	39,514	12,988,554
2035	919,232	900,672	169,906	36,807	40,008	13,158,228
2036	931,029	912,219	172,119	37,261	40,502	13,327,954
2037	942,828	923,769	174,332	37,716	40,995	13,497,732
2038	954,629	935,321	176,546	38,170	41,489	13,667,556
2039	966,431	946,874	178,759	38,625	41,983	13,837,424
2040	978,235	958,429	180,973	39,079	42,477	14,007,335

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

Year	THC	VOC	NOx	PM2.5	PM10	CO
2002	906,318	931,132	46,311	15,092	16,404	2,472,251
2003	873,287	896,969	49,694	14,417	15,670	2,407,992
2004	836,493	858,916	53,397	13,679	14,869	2,346,538
2005	796,279	817,340	57,862	12,886	14,007	2,266,733
2006	756,781	776,480	63,366	12,090	13,142	2,170,374
2007	717,924	736,303	67,730	11,311	12,295	2,103,059
2008	680,702	697,795	73,894	10,553	11,470	2,007,804
2009	645,730	661,588	82,123	9,824	10,678	1,885,970
2010	612,180	626,901	87,140	9,149	9,945	1,823,844
2011	580,750	594,415	90,516	8,525	9,266	1,788,830
2012	553,441	566,191	93,662	7,983	8,678	1,758,115
2013	530,682	542,671	96,528	7,534	8,189	1,732,653
2014	511,166	522,503	99,197	7,144	7,766	1,710,005
2015	495,178	505,981	101,703	6,823	7,416	1,690,755
2016	481,650	492,000	104,022	6,549	7,118	1,673,978
2017	470,667	480,648	106,158	6,324	6,874	1,660,415
2018	462,602	472,308	108,084	6,156	6,691	1,650,631
2019	455,864	465,336	109,885	6,012	6,535	1,642,841
2020	451,176	460,481	111,525	5,908	6,422	1,638,114
2021	447,624	456,799	113,063	5,826	6,333	1,635,047
2022	445,371	454,457	114,479	5,768	6,270	1,634,065
2023	443,951	452,972	115,802	5,726	6,224	1,634,672
2024	443,203	452,179	117,052	5,696	6,191	1,636,603
2025	443,196	452,151	118,228	5,680	6,174	1,639,914
2026	443,770	452,720	119,344	5,675	6,168	1,644,492
2027	444,806	453,764	120,401	5,678	6,172	1,650,159
2028	446,152	455,126	121,411	5,687	6,182	1,656,748
2029	447,768	456,766	122,387	5,701	6,197	1,663,933
2030	449,626	458,656	123,335	5,719	6,217	1,671,627
2031	451,666	460,733	124,260	5,741	6,240	1,679,753
2032	453,836	462,943	125,166	5,765	6,266	1,688,228
2033	456,159	465,310	126,052	5,792	6,296	1,697,074
2034	458,592	467,790	126,922	5,821	6,327	1,706,229
2035	461,115	470,363	127,777	5,851	6,360	1,715,675
2036	463,691	472,990	128,621	5,883	6,394	1,725,343
2037	466,323	475,674	129,454	5,915	6,429	1,735,210
2038	468,999	478,403	130,278	5,948	6,465	1,745,240
2039	471,706	481,164	131,095	5,982	6,502	1,755,400
2040	474,437	483,949	131,907	6,016	6,539	1,765,651

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.[c] 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)[18] 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 Chapter 2. Many of these compounds are also part of the THC and VOC 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 were developed using EPA's National Mobile Inventory Model (NMIM). This model is an analytical framework that links a county-level database to our NONROAD model 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 on a much finer scale than is possible when running the standalone NONROAD model. Emissions were modeled for all of the small nonroad and marine SI equipment categories in the continental United States, including California. Hence, the hazardous emission inventories presented here include the emissions from engines that are regulated by that State. As a result, the emission inventories are slightly overstated relative to the those from the small nonroad and marine SI engines subject to the federal Phase 3 requirements.

Table 3.2-10 presents the 50-state baseline inventories for toxic air emissions from small nonroad SI engines in 2002, 2020, 2030. Table 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	Naphthalene	POM
2002	35,086	5,561	8,664	2,900	505	447	97
2020	23,216	3,468	5,802	2,792	291	638	131
2030	26,776	3,999	6,691	3,217	336	739	152

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

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	Naphthalene	POM
2002	23,110	2,053	2,153	1,543	211	37	31
2020	8,417	763	535	818	27	42	16
2030	8,476	751	525	811	27	46	16

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 final 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.

The national inventories are presented for 2002, 2020, and 2030 for all 50-states and the District of Columbia.[19] The stationary, highway, and aircraft inventories were taken directly from EPA's National Emissions Inventory (NEI) modeling platform for 2002.[20] The emission inventories for locomotives, and Classes 1 and 2 commercial marine engines were taken from our recent final rule for these mobile source categories.[21] The inventories for Class 3 commercial marine engines was take from our recent advance notice of final rulemaking for that category of engines.[22] The emission estimates for portable fuel containers was taken from the recent final MSAT rule.[23] All of the land-based nonroad engine emission inventories was developed using the NONROAD2005d model, as previously described.[d] Finally, these inventories account for the future use of renewable fuels as required by the Energy Policy Act of 2005.

3.3.1 VOC Emissions Contribution

Table 3.3-1 provides the contribution of small nonroad SI engines, marine SI engines and other source categories to nationwide VOC emissions. The emissions from small nonroad (<19kW) and marine SI engines are 26 percent of the mobile source inventory and 12 percent of the total manmade VOC emissions in 2002. These percentages decrease slightly to 23 percent and 10 percent, respectively, by 2030.

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[d] The modeling inputs for diesel nonroad engines that were used in NONROAD2005d for this final rule are the same as those contained in the NONROAD2005a public.

3.3.2 NOx Emissions Contribution

Table 3.3-2 provides the contribution of nonroad small nonroad SI engines, marine SI engines and other source categories to nationwide NOx emissions. The emissions from small nonroad and marine SI engines are about 1 percent of the mobile source inventory and about 1 percent of the total manmade NOx emissions in 2002. These percentages increase to 6 percent and 3 percent, respectively, by 2030.

3.3.3 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 nationwide $PM_{2.5}$ and PM_{10} emissions, respectively. Both particle size categories from small nonroad and marine SI engines are about 8 percent of the mobile source inventory and approximately 1 percent of the total manmade $PM_{2.5}$ emissions in 2002. The mobile source percentage increases to about 12 percent and the total manmade percentage stay about the same at 1 percent by 2030.

3.3.4 CO Emissions Contribution

Table 3.3-5 provides the contribution of small nonroad SI engines, marine SI engines, and other source categories to nationwide CO emissions. The emissions from small nonroad and marine SI engines are 23 percent of the mobile source inventory and 10 percent of the total manmade CO emissions in 2002. These percentages decrease to 30 percent and increase to 25 percent, respectively, by 2030.

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

Category	2002			2020			2030		
	short tons	% of mobile	% of total	short tons	% of mobile	% of total	short tons	% of mobile	% of total
Small Nonroad SI total	*1,165,257*	*14.0%*	*6.6%*	*808,873*	*19.6%*	*6.3%*	*935,619*	*23.1%*	*7.3%*
NonHandheld Small SI	*675,311*	*8.1%*	*3.8%*	*590,186*	*14.3%*	*4.6%*	*684,057*	*16.9%*	*5.4%*
Handheld Small SI	*489,946*	*5.9%*	*2.8%*	*218,688*	*5.3%*	*1.7%*	*251,562*	*6.2%*	*2.0%*
Recreational Marine SI	*1,003,325*	*12.1%*	*5.7%*	*496,183*	*12.0%*	*3.9%*	*494,217*	*12.2%*	*3.9%*
Locomotive	50,665	0.6%	0.3%	27,974	0.7%	0.2%	17,722	0.4%	0.1%
Recreational Marine Diesel	1,538	0.0%	0.0%	2,485	0.1%	0.0%	2,912	0.1%	0.0%
Commercial Marine (C1 & C2)	17,229	0.2%	0.1%	11,478	0.3%	0.1%	6,911	0.2%	0.1%
Land-Based Nonroad Diesel	184,868	2.2%	1.0%	76,817	1.9%	0.6%	63,342	1.6%	0.5%
Commercial Marine (C3)	26,175	0.3%	0.1%	53,204	1.3%	0.4%	79,697	2.0%	0.6%
SI Recreational Vehicles	551,285	6.6%	3.1%	442,121	10.7%	3.4%	382,468	9.5%	3.0%
Large Nonroad SI (>25hp)	134,950	1.6%	0.8%	11,957	0.3%	0.1%	9,953	0.2%	0.1%
Portable Fuel Containers	243,994	2.9%	1.4%	38,185	0.9%	0.3%	43,375	1.1%	0.3%
Aircraft	52,651	0.6%	0.3%	63,251	1.5%	0.5%	67,730	1.7%	0.5%
Total Off Highway	3,431,938	41.3%	19.3%	2,032,530	49.2%	15.8%	2,103,947	52.0%	16.5%
Highway Diesel	191,514	2.3%	1.1%	129,321	3.1%	1.0%	140,959	3.5%	1.1%
Highway Non-Diesel	4,684,391	56.4%	26.4%	1,973,180	47.7%	15.3%	1,800,856	44.5%	14.1%
Total Highway	4,875,904	58.7%	27.5%	2,102,501	50.8%	16.3%	1,941,815	48.0%	15.2%
Total Diesel (distillate) Mobile	445,814	5.4%	2.5%	248,075	6.0%	1.9%	231,847	5.7%	1.8%
Total Mobile Sources	8,307,843	100%	46.8%	4,135,030	100%	32.1%	4,045,762	100%	31.6%
Stationary Point and Area Sources	9,433,356	-	53.2%	8,740,057	-	67.9%	8,740,057	-	68.4%
Total Man-Made Sources	17,741,198	-	100%	12,875,088	-	100%	12,785,819	-	100%

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

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Small Nonroad SI	*119,833*	*0.9%*	*0.6%*	*153,872*	*2.7%*	*1.3%*	*178,406*	*3.4%*	*1.6%*
NonHandheld Small SI	*116,743*	*0.9%*	*0.5%*	*148,004*	*2.6%*	*1.3%*	*171,650*	*3.2%*	*1.6%*
Handheld Small SI	*3,090*	*0.0%*	*0.0%*	*5,867*	*0.1%*	*0.1%*	*6,756*	*0.1%*	*0.1%*
Recreational Marine SI	*49,902*	*0.4%*	*0.2%*	*120,172*	*2.1%*	*1.0%*	*132,898*	*2.5%*	*1.2%*
Locomotive	1,118,786	8.8%	5.2%	669,405	11.7%	5.8%	437,245	8.3%	4.0%
Recreational Marine Diesel	40,437	0.3%	0.2%	43,579	0.76%	0.38%	43,665	0.8%	0.4%
Commercial Marine (C1 & C2)	834,025	6.5%	3.9%	499,798	8.77%	4.36%	308,614	5.8%	2.8%
Land-Based Nonroad Diesel	1,555,812	12.2%	7.3%	683,481	12.0%	5.96%	435,774	8.2%	3.9%
Commercial Marine (C3)	745,224	5.9%	3.5%	1,368,420	24.00%	11.93%	2,023,974	38.3%	18.3%
SI Recreational Vehicles	10,614	0.1%	0.0%	30,108	0.5%	0.3%	34,318	0.6%	0.3%
Large Nonroad SI (>25hp)	336,292	2.6%	1.6%	48,270	0.8%	0.42%	47,766	0.9%	0.4%
Aircraft	103,591	0.8%	0.5%	132,278	2.32%	1.15%	143,986	2.7%	1.3%
Total Off Highway	4,914,515	38.6%	23.0%	3,749,382	65.8%	32.7%	3,786,645	71.6%	34.2%
Highway Diesel	3,529,046	27.7%	16.5%	681,142	11.9%	5.9%	355,817	6.7%	3.2%
Highway Non-Diesel	4,293,733	33.7%	20.1%	1,270,269	22.3%	11.1%	1,144,199	21.6%	10.3%
Total Highway	7,822,779	61.4%	36.6%	1,951,411	34.2%	17.0%	1,500,016	28.4%	13.6%
Total Diesel (distillate) Mobile	7,078,105	55.6%	33.2%	2,577,404	45.2%	22.5%	1,581,115	29.9%	14.3%
Total Mobile Sources	12,737,294	100%	59.7%	5,700,793	100%	49.7%	5,286,661	100%	47.8%
Stationary Point and Area Sources	8,613,718	-	40.3%	5,773,927	-	50.3%	5,773,927	-	52.2%
Total Man-Made Sources	21,351,012	-	100%	11,474,721	-	100%	11,060,589	-	100%

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

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Small Nonroad SI	*25,700*	*5.2%*	*0.7%*	*32,905*	*10.0%*	*1.0%*	*37,878*	*10.7%*	*1.1%*
NonHandheld Small SI	*4,841*	*1.0%*	*0.1%*	*6,957*	*2.1%*	*0.2%*	*8,065*	*2.3%*	*0.2%*
Handheld Small SI	*20,859*	*4.2%*	*0.6%*	*25,947*	*7.9%*	*0.8%*	*29,813*	*8.4%*	*0.9%*
Recreational Marine SI	*16,262*	*3.3%*	*0.5%*	*6,367*	*1.9%*	*0.2%*	*6,163*	*1.7%*	*0.2%*
Locomotive	29,660	5.99%	0.84%	15,145	4.59%	0.45%	8,584	2.42%	0.25%
Recreational Marine Diesel	1,096	0.22%	0.03%	973	0.29%	0.03%	1,053	0.30%	0.03%
Commercial Marine (C1 & C2)	28,730	5.80%	0.82%	15,787	4.78%	0.47%	10,017	2.82%	0.29%
Land-Based Nonroad Diesel	159,111	32.1%	4.52%	46,056	13.9%	1.36%	17,902	5.0%	0.53%
Commercial Marine (C3)	54,667	11.04%	1.55%	110,993	33.61%	3.29%	166,161	46.78%	4.88%
SI Recreational Vehicles	13,710	2.8%	0.4%	11,901	3.6%	0.4%	10,090	2.8%	0.3%
Large Nonroad SI (>25hp)	1,652	0.3%	0.05%	2,421	0.7%	0.07%	2,844	0.8%	0.08%
Aircraft	17,979	3.63%	0.51%	22,176	6.72%	0.66%	24,058	6.77%	0.71%
Total Off Highway	348,568	70.4%	9.9%	264,722	80.2%	7.8%	284,749	80.2%	8.4%
Highway Diesel	94,982	19.2%	2.7%	20,145	6.1%	0.6%	18,802	5.3%	0.6%
Highway non-diesel	51,694	10.4%	1.5%	45,329	13.7%	1.3%	51,621	14.5%	1.5%
Total Highway	146,676	29.6%	4.2%	65,474	19.8%	1.9%	70,423	19.8%	2.1%
Total Diesel (distillate) Mobile	313,581	63.3%	8.9%	98,106	29.7%	2.9%	56,358	15.9%	1.7%
Total Mobile Sources	495,245	100%	14.1%	330,196	100%	9.8%	355,172	100%	10.4%
Stationary Point and Area Sources	3,025,244	-	85.9%	3,047,714	-	90.2%	3,047,714	-	89.6%
Total Man-Made Sources	3,520,488	-	100%	3,377,911	-	100%	3,402,887	-	100%

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

	2002			2020			2030		
Category	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Small Nonroad SI	*27,935*	*4.9%*	*0.7%*	*35,766*	*8.5%*	*1.0%*	*41,172*	*9.0%*	*1.1%*
NonHandheld Small SI	*5,262*	*0.9%*	*0.1%*	*7,562*	*1.8%*	*0.2%*	*8,767*	*1.9%*	*0.2%*
Handheld Small SI	*22,673*	*4.0%*	*0.6%*	*28,204*	*6.7%*	*0.8%*	*32,406*	*7.1%*	*0.9%*
Recreational Marine SI	*17,676*	*3.1%*	*0.5%*	*6,920*	*1.7%*	*0.2%*	*6,699*	*1.5%*	*0.2%*
Locomotive	30,578	5.33%	0.82%	15,613	3.73%	0.43%	8,849	1.93%	0.24%
Recreational Marine Diesel	1,130	0.20%	0.03%	1,003	0.24%	0.03%	1,086	0.24%	0.03%
Commercial Marine (C1 & C2)	29,619	5.17%	0.79%	16,275	3.89%	0.45%	10,327	2.25%	0.28%
Land-Based Nonroad Diesel	164,032	28.6%	4.40%	47,480	11.3%	1.31%	18,455	4.0%	0.51%
Commercial Marine (C3)	59,409	10.36%	1.59%	120,617	28.83%	3.34%	180,566	39.32%	4.94%
SI Recreational Vehicles	14,902	2.6%	0.4%	12,936	3.1%	0.4%	10,967	2.4%	0.3%
Large Nonroad SI (>25hp)	1,672	0.3%	0.04%	2,441	0.6%	0.07%	2,866	0.6%	0.08%
Aircraft	24,622	4.30%	0.66%	30,211	7.22%	0.84%	32,714	7.12%	0.90%
Total Off Highway	371,575	64.8%	10.0%	289,263	69.1%	8.0%	313,702	68.3%	8.6%
Highway Diesel	109,097	19.0%	2.9%	32,733	7.8%	0.9%	34,746	7.6%	1.0%
Highway non-diesel	92,531	16.1%	2.5%	96,380	23.0%	2.7%	110,796	24.1%	3.0%
Total Highway	201,628	35.2%	5.4%	129,113	30.9%	3.6%	145,542	31.7%	4.0%
Total Diesel (distillate) Mobile	334,456	58.3%	9.0%	113,105	27.0%	3.1%	73,464	16.0%	2.0%
Total Mobile Sources	573,203	100%	15.4%	418,376	100%	11.6%	459,244	100%	12.6%
Stationary Point and Area Sources	3,158,011	-	84.6%	3,194,610	-	88.4%	3,194,610	-	87.4%
Total Man-Made Sources	3,731,215	-	100%	3,612,986	-	100%	3,653,854	-	100%

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

	2002			2020			2030		
Category	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Small Nonroad SI	*16,943,267*	*19.9%*	*17.6%*	*11,934,654*	*25.5%*	*20.6%*	*13,803,668*	*26.8%*	*22.1%*
NonHandheld Small SI	*15,884,854*	*18.7%*	*16.5%*	*11,084,472*	*23.7%*	*19.2%*	*12,826,965*	*24.9%*	*20.5%*
Handheld Small SI	*1,058,413*	*1.2%*	*1.1%*	*850,181*	*1.8%*	*1.5%*	*976,703*	*1.9%*	*1.6%*
Recreational Marine SI	*2,663,932*	*3.1%*	*2.8%*	*1,765,122*	*3.8%*	*3.1%*	*1,801,234*	*3.5%*	*2.9%*
Locomotive	123,210	0.1%	0.1%	167,488	0.4%	0.3%	195,882	0.4%	0.3%
Recreational Marine Diesel	6,467	0.0%	0.0%	9,374	0.0%	0.0%	10,930	0.0%	0.0%
Commercial Marine (C1 & C2)	151,331	0.2%	0.2%	139,712	0.3%	0.2%	143,791	0.3%	0.2%
Land-Based Nonroad Diesel	860,257	1.0%	0.9%	310,250	0.7%	0.5%	155,576	0.3%	0.2%
Commercial Marine (C3)	59,515	0.1%	0.1%	120,889	0.3%	0.2%	181,032	0.4%	0.3%
SI Recreational Vehicles	1,741,702	2.0%	1.8%	1,910,030	4.1%	3.3%	1,916,102	3.7%	3.1%
Large Nonroad SI (>25hp)	1,801,104	2.1%	1.9%	289,382	0.6%	0.5%	270,827	0.5%	0.4%
Aircraft	557,820	0.7%	0.6%	677,930	1.4%	1.2%	723,842	1.4%	1.2%
Total Off Highway	24,908,605	29.3%	25.8%	17,324,829	37.0%	29.9%	19,202,883	37.3%	30.7%
Highway Diesel	940,898	1.1%	1.0%	260,238	0.6%	0.4%	219,594	0.4%	0.4%
Highway non-diesel	59,178,847	69.6%	61.4%	29,211,716	62.4%	50.5%	32,038,635	62.3%	51.3%
Total Highway	60,119,745	70.7%	62.4%	29,471,955	63.0%	50.9%	32,258,229	62.7%	51.6%
Total Diesel (distillate) Mobile	2,082,164	2.4%	2.2%	887,061	1.9%	1.5%	725,772	1.4%	1.2%
Total Mobile Sources	85,028,351	100%	88.2%	46,796,783	100%	80.9%	51,461,112	100%	82.3%
Stationary Point and Area Sources	11,354,201	-	11.8%	11,049,239	-	19.1%	11,049,239	-	17.7%
Total Man-Made Sources	96,382,552	-	100%	57,846,022	-	100%	62,510,350	-	100%

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 Phase 3 standards. 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 final 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 final 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, VOC, NOx, $PM_{2.5}$, PM_{10}, and CO

The controlled exhaust and evaporative emission inventories for small nonroad and marine SI engines were generated by modifying the input files for NONROAD2005d to account for the engine and equipment controls associated with the Phase 3 standards. (See the baseline emission inventory discussion in Section 3.2 for the changes we made to the publically available NONROAD2005a model to develop NONROAD2005d.) 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 final Phase 3 emission standards and implementation schedule are shown in Table 3.4-1. While the new standards take effect in 2011 for Class II engines and 2012 for Class I engines, we providing a number of flexibilities for engine and equipment manufacturers that will allow the continued production and use of Class II 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 these flexibilities.

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 compliance flexibilities by engine and equipment manufacturers. Used for modeling purposes only.

The modeled emission factors corresponding to the final 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	431.72	0.080	0.08	1.095

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 0.735 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 final 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 final 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 establishing 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 final 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	20.9	4.8	542	640	563	563
2.3-4.5 kW	22.1	3.6	357	538	560	560
4.6-8.2 kW	15.5	5.6	292	243	555	555
8.3-11.9 kW	11.6	6.8	248	231	552	552
12.0-18.6 kW	12.5	4.3	205	218	543	543
18.7-29.8 kW	10.2	5.7	189	206	528	528
29.9-37.3 kW	9.3	5.9	167	206	507	507
37.4-55.9 kW	9.2	5.4	169	206	471	486
55.9-74.6 kW	9.2	5.4	169	206	471	486
74.7-130.5 kW	9.2	5.0	173	202	415	394
130.6+ kW	10.2	3.7	137	178	387	380

For sterndrive and inboards, we developed a new engine classification similar to the OB/PWC discussion above. SD/I engines at or below 373 kW are modeled to meet the final 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. High performance engines have two tiers of standards that can be achieved through the use of engine-based technology. Although the standards distinguish between two power ranges for high-performance, a single weighted EF is used here. CO emission factors are based on meeting the final 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	
kW ≤373 kW	1.80	1.64	1.60	1.15	55.0	1.36	345
> 373 kW, Tier 1	11.80	1.69	6.70	1.38	207	1.81	362
> 373 kW, Tier 2	8.58	1.69	6.80	1.38	207	1.81	362

3.4.1.2 Controlled Evaporative Emission Rates

Below, we present the effect of the final Phase 3 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 final 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 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. The same correction factors used to account for the effect of ethanol on permeation are used in the control and baseline cases.

Fill neck and vent hose containing vapor rather than liquid fuel are not subject to the final standards. No emission reductions are modeled for these hose types. In addition, no emission reductions are modeled for hose on handheld equipment used in cold weather applications (e.g. Class V chainsaws).

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 final 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 0.75 g/gal/day at 29°C on gasoline. 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. The same correction factors used to account for the effect of ethanol on permeation are used in the control and baseline cases.

One exception to the above discussion is metal tanks. For these fuel tanks, we do not include any emissions reductions from baseline.

3.4.1.2.3 Diurnal

We are not establishing a diurnal emission requirement for small nonroad SI equipment. Therefore, we do not model direct reductions in diurnal emissions. However, we are placing 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 SI engines, 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 final 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 final 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, VOC, NOx, $PM_{2.5}$, PM_{10}, CO and SO_2

Tables 3.4-5 presents the 50-state controlled emission inventories 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	VOC	NOx	PM2.5	PM10	CO
2002	1,064,625	1,047,374	106,804	23,382	25,416	15,091,835
2003	1,026,922	1,009,822	106,852	23,480	25,522	14,351,829
2004	963,709	945,601	106,610	23,483	25,525	13,690,337
2005	886,524	867,081	106,847	23,417	25,453	12,923,819
2006	825,413	804,926	109,233	23,498	25,541	12,252,479
2007	768,239	747,552	109,439	23,804	25,874	11,711,607
2008	713,266	694,712	111,235	24,335	26,451	10,861,441
2009	669,782	653,584	116,329	24,882	27,045	9,992,801
2010	646,659	631,851	118,376	25,402	27,611	9,623,727
2011	618,463	604,977	107,135	25,888	28,139	9,427,359
2012	573,611	562,317	96,222	26,364	28,445	9,240,448
2013	535,035	525,722	86,623	26,832	28,747	9,125,886
2014	509,895	501,985	81,011	27,291	29,071	9,107,104
2015	495,565	488,517	76,412	27,747	29,473	9,135,515
2016	486,951	480,492	73,517	28,202	29,896	9,201,411
2017	484,102	477,989	72,202	28,655	30,336	9,298,167
2018	485,460	479,510	71,768	29,107	30,795	9,415,010
2019	488,969	483,092	71,822	29,558	31,259	9,543,762
2020	493,763	487,905	72,175	30,009	31,727	9,679,462
2021	499,618	493,736	72,848	30,460	32,198	9,820,562
2022	506,071	500,141	73,667	30,911	32,671	9,964,572
2023	512,988	506,990	74,592	31,362	33,146	10,110,794
2024	520,130	514,054	75,564	31,813	33,622	10,258,216
2025	527,386	521,227	76,578	32,265	34,098	10,406,862
2026	534,763	528,516	77,629	32,718	34,576	10,557,631
2027	542,202	535,864	78,700	33,173	35,055	10,709,373
2028	549,676	543,246	79,782	33,627	35,534	10,861,555
2029	557,179	550,657	80,875	34,081	36,013	11,014,081
2030	564,711	558,094	81,977	34,535	36,492	11,166,921
2031	572,261	565,549	83,086	34,990	36,971	11,319,980
2032	579,823	573,015	84,197	35,444	37,450	11,473,166
2033	587,396	580,492	85,312	35,898	37,929	11,626,453
2034	594,978	587,978	86,429	36,353	38,408	11,779,824
2035	602,567	595,471	87,547	36,807	38,887	11,933,276
2036	610,167	602,974	88,669	37,261	39,366	12,086,826
2037	617,776	610,486	89,795	37,716	39,845	12,240,473
2038	625,391	618,003	90,922	38,170	40,324	12,394,188
2039	633,010	625,525	92,051	38,625	40,803	12,547,962
2040	640,633	633,050	93,181	39,079	41,282	12,701,792

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

Year	THC	VOC	NOx	PM2.5	PM10	CO
2002	906,318	931,132	46,311	15,092	16,404	2,472,251
2003	873,287	896,969	49,694	14,417	15,670	2,407,992
2004	836,493	858,916	53,397	13,679	14,869	2,346,538
2005	796,279	817,340	57,862	12,886	14,007	2,266,733
2006	756,781	776,480	63,366	12,090	13,142	2,170,374
2007	717,924	736,303	67,730	11,311	12,295	2,103,059
2008	680,702	697,795	73,894	10,553	11,470	2,007,804
2009	644,330	660,187	82,123	9,824	10,678	1,885,970
2010	593,432	607,656	84,822	8,832	9,600	1,808,304
2011	543,080	555,760	85,353	7,891	8,577	1,755,638
2012	495,189	506,468	85,673	7,035	7,647	1,707,370
2013	452,028	462,066	85,732	6,275	6,820	1,664,442
2014	412,280	421,190	85,609	5,577	6,062	1,624,423
2015	376,203	384,108	85,334	4,951	5,381	1,587,889
2016	342,807	349,793	84,890	4,376	4,756	1,553,983
2017	312,281	318,441	84,279	3,856	4,191	1,523,443
2018	285,067	290,507	83,468	3,399	3,695	1,496,863
2019	259,742	264,519	82,546	2,978	3,237	1,472,528
2020	238,704	242,957	81,398	2,640	2,869	1,452,196
2021	219,826	223,621	80,081	2,341	2,545	1,433,655
2022	203,027	206,427	78,657	2,081	2,262	1,417,440
2023	188,065	191,121	77,197	1,851	2,012	1,403,195
2024	175,954	178,752	75,802	1,673	1,818	1,391,146
2025	166,147	168,751	74,424	1,534	1,668	1,380,739
2026	157,943	160,391	73,057	1,419	1,542	1,371,913
2027	151,063	153,384	71,713	1,323	1,438	1,364,592
2028	145,397	147,624	70,421	1,247	1,355	1,358,936
2029	140,670	142,822	69,236	1,185	1,288	1,354,638
2030	136,990	139,083	68,639	1,137	1,236	1,353,989
2031	134,079	136,124	68,339	1,099	1,194	1,355,439
2032	131,797	133,803	68,148	1,067	1,160	1,357,905
2033	130,067	132,045	68,038	1,043	1,134	1,361,273
2034	128,766	130,723	67,985	1,024	1,113	1,365,343
2035	127,853	129,798	67,975	1,010	1,098	1,370,010
2036	127,275	129,212	68,009	1,001	1,088	1,375,199
2037	126,952	128,888	68,077	995	1,081	1,380,822
2038	126,816	128,753	68,174	991	1,077	1,386,805
2039	126,828	128,769	68,302	989	1,075	1,393,116
2040	126,959	128,906	68,461	989	1,075	1,399,715

3.4.2 Controlled Hazardous Air Pollutant Estimates

The final 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 multiplied the baseline hazardous air pollutant estimates (Section 3.2.2) by the ratio of control and baseline emission inventories (Section 3.2.1.4 and 3.4.1.3, respectively) for VOC or PM, as appropriate. More specifically, we used the VOC ratio for all toxic pollutant species that are found in the gas phase. The gas phase pollutants are all the species described below, except for naphthalene and the polycyclic organic matter (POM) compounds that are found in both the gas and particulate phase. In these cases, we used the PM ratio to estimate the controlled inventories.

Controlled inventories were calculated for the seven major types of air toxic emissions: benzene, formaldeyde, acetaldehyde, 1,3-butadiene, acrolein, naphthalene, and 15 other compounds grouped together as POM for this analysis.[e] Table 3.4-7 presents the 50-state controlled inventories, respectively, small nonroad SI engines. Table 3.4-8 provides 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	Naphthalene	POM
2002	35,086	5,561	8,664	2,900	505	447	97
2020	15,413	2,504	4,189	2,015	210	620	128
2030	17,577	2,859	4,784	2,300	240	718	147

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	Naphthalene	POM
2002	23,110	2,053	2,153	1,543	211	37	31
2020	4,453	390	273	418	14	19	7
2030	2,582	216	151	234	8	9	3

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

3.5 Projected Emissions Reductions from the Final Rule

This section presents the projected total emission reductions associated with the final Phase 3 standards. We calculated the reductions by subtracting the baseline inventories from Section 3.2 by the controlled inventories from Section 3.4.

3.5.1 Results for THC, VOC, 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 final rule. The earliest Phase 3 evaporative standards for small nonroad SI engines begin in 2008. Similar final evaporative 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 3.5-5 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 Spark-Ignition Engines (short tons)

	THC		VOC		NOx		PM2.5		PM10		CO	
Year	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2008	5,298	1	5,298	1	0	0	0	0	0	0	0	0
2009	12,306	2	12,306	2	0	0	0	0	0	0	0	0
2010	19,103	3	19,103	3	0	0	0	0	0	0	0	0
2011	45,157	7	44,381	7	12,289	10	0	0	0	0	141,251	1
2012	92,055	14	89,426	14	24,598	20	195	1	212	1	338,592	4
2013	136,293	20	131,817	20	35,882	29	385	1	419	1	518,625	5
2014	169,739	25	163,834	25	43,389	35	546	2	594	2	644,624	7
2015	193,479	28	186,614	28	49,983	40	632	2	687	2	743,512	8
2016	212,274	30	204,672	30	54,951	43	697	2	758	2	818,628	8
2017	225,797	32	217,669	32	58,371	45	745	3	810	3	871,019	9
2018	235,483	33	226,988	33	60,933	46	776	3	843	3	909,068	9
2019	243,315	33	234,523	33	63,024	47	800	3	870	3	939,944	9
2020	249,991	34	240,948	34	64,827	47	820	3	892	3	966,407	9
2021	255,636	34	246,382	34	66,312	48	838	3	911	3	988,367	9
2022	260,711	34	251,271	34	67,650	48	854	3	928	3	1,008,088	9
2023	265,345	34	255,737	34	68,883	48	868	3	943	3	1,026,161	9
2024	269,770	34	260,002	34	70,072	48	881	3	958	3	1,043,515	9
2025	274,107	34	264,185	34	71,228	48	894	3	972	3	1,060,430	9
2026	278,455	34	268,375	34	72,374	48	908	3	987	3	1,077,303	9
2027	282,769	34	272,533	34	73,509	48	922	3	1,002	3	1,094,028	9
2028	287,060	34	276,668	34	74,635	48	936	3	1,017	3	1,110,652	9
2029	291,328	34	280,782	34	75,753	48	949	3	1,032	3	1,127,170	9
2030	295,576	34	284,876	34	76,863	48	963	3	1,047	3	1,143,584	9
2031	299,808	34	288,955	34	77,967	48	977	3	1,062	3	1,159,920	9
2032	304,033	34	293,027	34	79,068	48	990	3	1,076	3	1,176,219	9
2033	308,250	34	297,091	34	80,167	48	1,004	3	1,091	3	1,192,487	9
2034	312,460	34	301,148	34	81,264	48	1,018	3	1,106	3	1,208,730	9
2035	316,665	34	305,201	34	82,359	48	1,031	3	1,121	3	1,224,953	9
2036	320,862	34	309,246	34	83,450	48	1,045	3	1,136	3	1,241,128	9
2037	325,052	34	313,284	34	84,537	48	1,059	3	1,151	3	1,257,259	9
2038	329,238	34	317,318	34	85,623	48	1,072	3	1,166	3	1,273,368	9
2039	333,421	35	321,349	35	86,708	49	1,086	3	1,181	3	1,289,462	9
2040	337,602	35	325,379	35	87,792	49	1,100	3	1,195	3	1,305,543	9

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

	THC		VOC		NOx		PM2.5		PM10		CO	
Year	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2009	1,400	0	1,400	0	0	0	0	0	0	0	0	0
2010	18,748	3	19,245	3	2,318	3	317	3	344	3	15,540	1
2011	37,670	6	38,656	7	5,163	6	634	7	689	7	33,192	2
2012	58,252	11	59,723	11	7,989	9	948	12	1,031	12	50,745	3
2013	78,654	15	80,605	15	10,796	11	1,259	17	1,369	17	68,211	4
2014	98,886	19	101,313	19	13,588	14	1,567	22	1,703	22	85,582	5
2015	118,974	24	121,873	24	16,369	16	1,872	27	2,035	27	102,867	6
2016	138,843	29	142,207	29	19,131	18	2,173	33	2,362	33	119,995	7
2017	158,386	34	162,207	34	21,879	21	2,468	39	2,683	39	136,972	8
2018	177,535	38	181,801	38	24,617	23	2,756	45	2,996	45	153,767	9
2019	196,122	43	200,818	43	27,340	25	3,034	50	3,298	50	170,313	10
2020	212,471	47	217,524	47	30,128	27	3,269	55	3,553	55	185,917	11
2021	227,798	51	233,178	51	32,981	29	3,485	60	3,788	60	201,392	12
2022	242,345	54	248,030	55	35,822	31	3,688	64	4,008	64	216,625	13
2023	255,886	58	261,851	58	38,605	33	3,875	68	4,212	68	231,477	14
2024	267,248	60	273,428	60	41,250	35	4,023	71	4,373	71	245,457	15
2025	277,049	63	283,400	63	43,803	37	4,146	73	4,506	73	259,174	16
2026	285,828	64	292,329	65	46,286	39	4,256	75	4,626	75	272,579	17
2027	293,743	66	300,379	66	48,689	40	4,355	77	4,734	77	285,568	17
2028	300,755	67	307,503	68	50,990	42	4,440	78	4,826	78	297,811	18
2029	307,097	69	313,944	69	53,151	43	4,516	79	4,909	79	309,295	19
2030	312,636	70	319,573	70	54,696	44	4,582	80	4,981	80	317,638	19
2031	317,588	70	324,609	70	55,921	45	4,642	81	5,046	81	324,313	19
2032	322,039	71	329,140	71	57,018	46	4,698	81	5,107	81	330,323	20
2033	326,092	71	333,265	72	58,015	46	4,749	82	5,162	82	335,801	20
2034	329,826	72	337,067	72	58,937	46	4,797	82	5,214	82	340,886	20
2035	333,261	72	340,565	72	59,802	47	4,841	83	5,262	83	345,665	20
2036	336,417	73	343,778	73	60,611	47	4,882	83	5,306	83	350,145	20
2037	339,371	73	346,786	73	61,377	47	4,920	83	5,348	83	354,388	20
2038	342,183	73	349,649	73	62,104	48	4,957	83	5,388	83	358,435	21
2039	344,878	73	352,395	73	62,793	48	4,993	83	5,427	83	362,283	21
2040	347,477	73	355,043	73	63,445	48	5,027	84	5,464	84	365,936	21

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

	THC		VOC		NOx		PM2.5		PM10		CO	
Year	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
2008	5,298	0	5,298	0	0	0	0	0	0	0	0	0
2009	13,706	1	13,706	1	0	0	0	0	0	0	0	0
2010	37,851	3	38,348	3	2,318	1	317	1	344	1	15,540	0
2011	82,827	7	83,037	7	17,451	8	634	2	689	2	174,444	2
2012	150,307	12	149,149	12	32,587	15	1,143	3	1,243	3	389,337	3
2013	214,947	18	212,422	18	46,679	21	1,644	5	1,787	5	586,836	5
2014	268,625	23	265,147	22	56,977	25	2,113	6	2,297	6	730,206	6
2015	312,454	26	308,487	26	66,353	29	2,504	7	2,722	7	846,379	7
2016	351,117	30	346,879	29	74,082	32	2,870	8	3,120	8	938,623	8
2017	384,183	33	379,875	32	80,250	34	3,213	9	3,493	9	1,007,991	9
2018	413,019	35	408,789	35	85,550	36	3,532	10	3,839	10	1,062,836	9
2019	439,437	37	435,340	37	90,363	37	3,834	11	4,168	11	1,110,258	9
2020	462,463	39	458,472	39	94,954	38	4,089	11	4,444	11	1,152,325	9
2021	483,433	40	479,560	40	99,293	39	4,323	12	4,698	12	1,189,759	10
2022	503,056	42	499,301	41	103,472	40	4,541	12	4,936	12	1,224,712	10
2023	521,231	43	517,588	43	107,488	41	4,743	13	5,155	13	1,257,637	10
2024	537,018	44	533,430	44	111,322	42	4,905	13	5,331	13	1,288,972	10
2025	551,156	44	547,584	44	115,031	43	5,040	13	5,479	13	1,319,604	10
2026	564,282	45	560,704	45	118,660	44	5,164	13	5,613	13	1,349,882	10
2027	576,512	45	572,913	45	122,198	45	5,277	14	5,736	14	1,379,596	10
2028	587,814	46	584,171	46	125,625	46	5,376	14	5,843	14	1,408,463	10
2029	598,426	46	594,726	46	128,904	46	5,465	14	5,940	14	1,436,465	10
2030	608,211	46	604,449	46	131,559	47	5,545	14	6,027	14	1,461,222	10
2031	617,396	47	613,565	47	133,888	47	5,619	14	6,107	14	1,484,233	10
2032	626,072	47	622,167	47	136,087	47	5,688	14	6,183	14	1,506,542	11
2033	634,342	47	630,356	47	138,182	47	5,753	14	6,253	14	1,528,288	11
2034	642,286	47	638,215	47	140,201	48	5,814	14	6,320	14	1,549,616	11
2035	649,926	47	645,766	47	142,161	48	5,872	14	6,383	14	1,570,618	11
2036	657,279	47	653,024	47	144,061	48	5,927	14	6,442	14	1,591,273	11
2037	664,423	47	660,069	47	145,914	48	5,979	14	6,499	14	1,611,647	11
2038	671,421	47	666,967	47	147,727	48	6,029	14	6,554	14	1,631,803	11
2039	678,299	47	673,744	47	149,501	48	6,079	14	6,607	14	1,651,746	11
2040	685,079	47	680,422	47	151,237	48	6,127	14	6,660	14	1,671,479	11

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

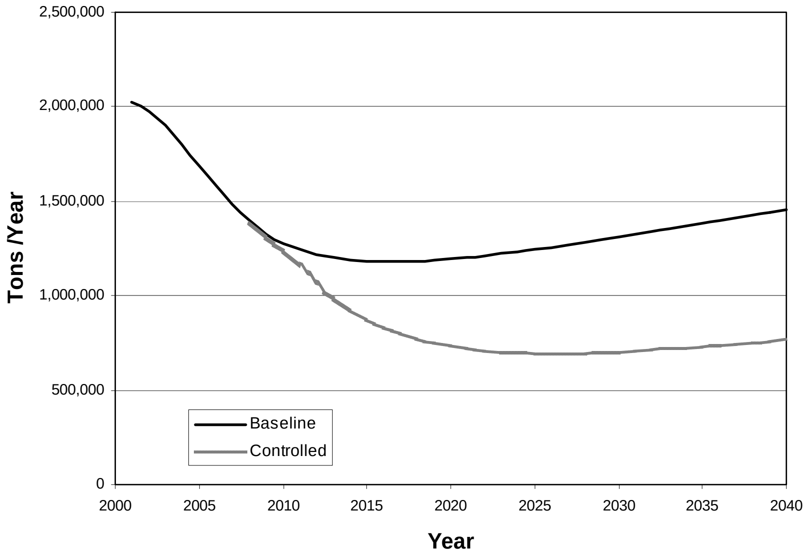


Figure 3.5-2: 50-State Annual VOC Exhaust and Evaporative Emissions for Small SI and Marine SI Engines

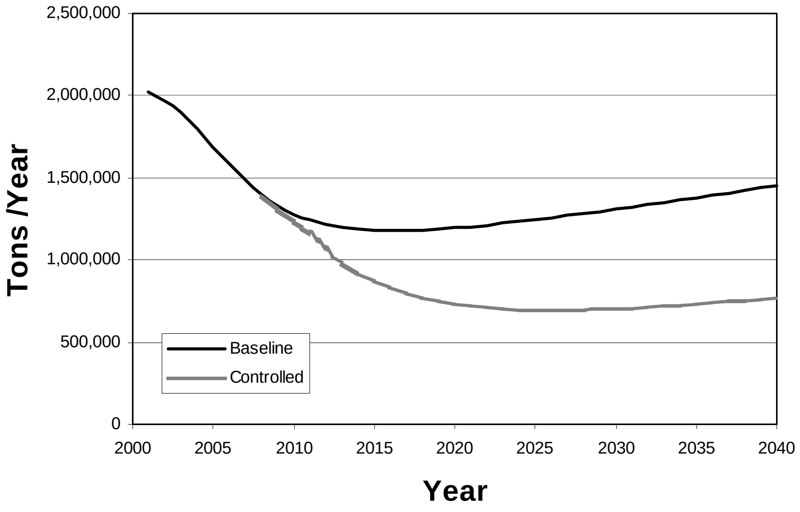


Figure 3.5-2: 50-State Annual NOx Exhaust Emissions for Small SI and Marine SI Engines

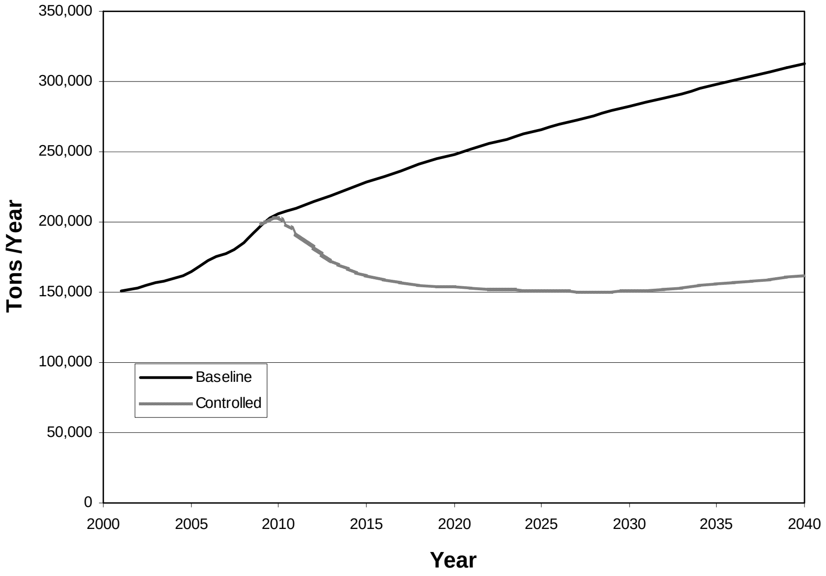


Figure 3.5-3: 50-State Annual PM2.5 Exhaust Emissions for Small SI and Marine SI Engines

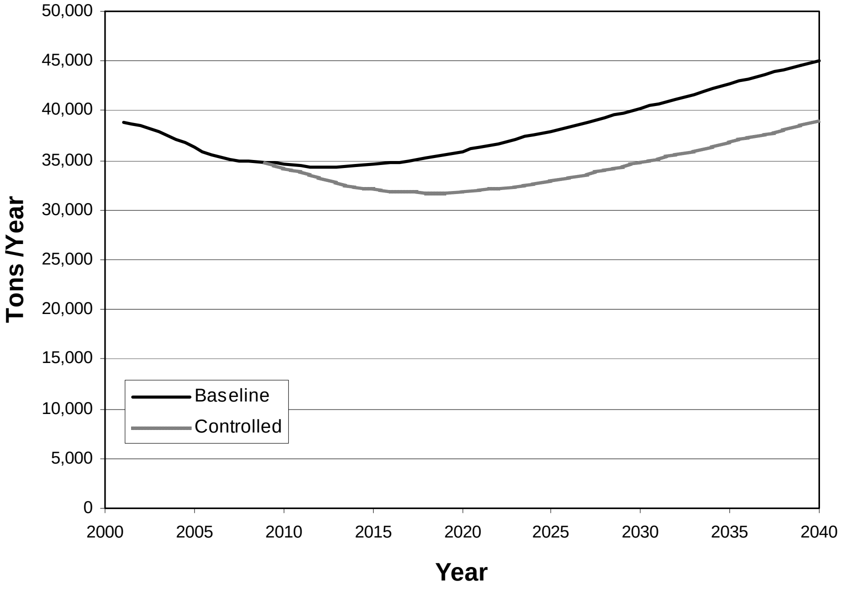
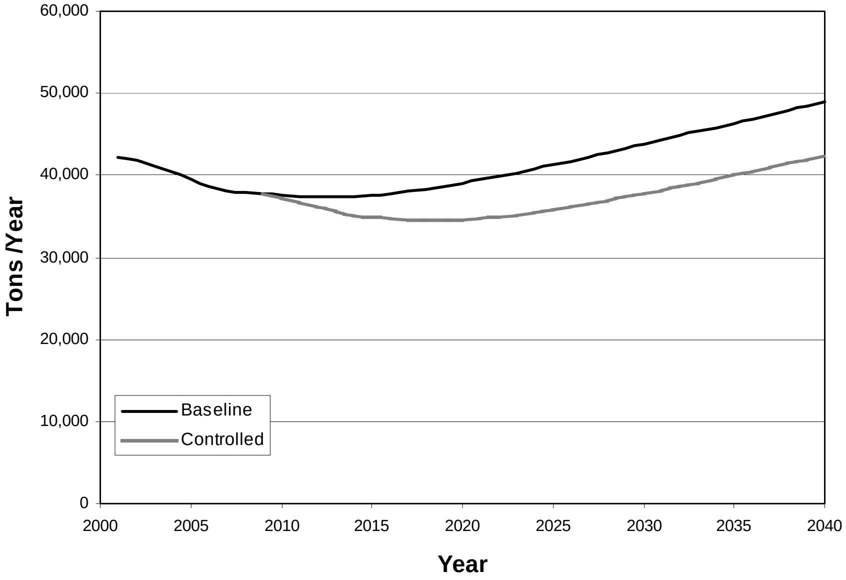
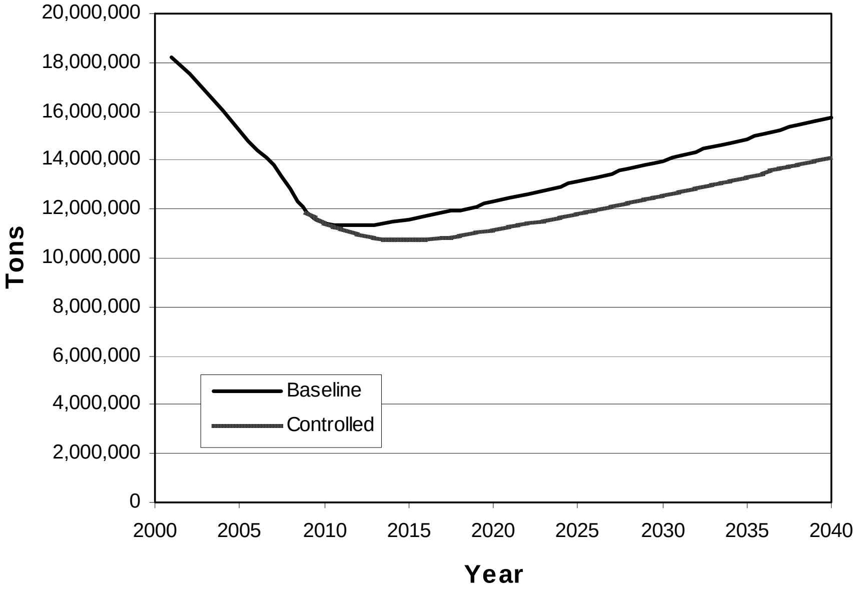


Figure 3.5-4: 50-State Annual PM10 Emissions for Small SI and Marine SI Engines



Figire 3.5-5: 50-State CO Exhaust Emission for Small SI and Marine SI Engines



3.5.2 Results for Hazardous Air Pollutants

Table 3.5-4 presents the 50-state exhaust and evaporative hazardous air pollutant emission reductions for small nonroad SI engines that are expected as a result of the final standards. Table 3.5-5 provides the same information for marine SI engines. Table 3.5-6 summarizes the combined hazardous air pollutant reductions for the final rule. These results are displayed for 2020 and 2030, when most or all of the engines subject to the 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	7,803	34	965	28	1,614	28	777	28	81	28	17	3	4	3
2030	9,200	34	1,140	29	1,907	29	917	29	96	29	21	29	4	3

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	3,964	47	373	49	261	49	400	49	13	49	23	55	9	55
2030	5,893	70	535	71	374	71	577	71	19	71	37	80	13	80

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	11,767	37	1,338	32	1,875	30	1,176	33	94	30	41	6	9	11
2030	15,093	43	1,675	35	2,281	32	1,494	37	115	32	57	7	57	10

3.6 Emission Inventories Used for Air Quality Modeling

This section briefly summaries the methodology we used for air quality modeling purposes and to develop the emission inventories for that modeling. It also describes the changes to our emission inventory modeling inputs and resulting emission inventories that were made between the preliminary baseline and control scenarios used for the air quality modeling, and the updated final baseline and control scenarios for the final Phase 3 rule. These differences often occur because 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. Given that lead time requirement, air quality modeling is often based on analytical methods and inputs that may be superceded, or on a control scenario that does not specifically match the final set of emission standards.

3.6.1 General Description of the Air Quality Modeling

Air quality modeling was performed for the 48 contiguous states and the District of Columbia to estimate the effect of the final rule on future annual fine particulate matter ($PM_{2.5}$) concentrations, 8-hour ozone concentrations, and visibility levels. The analysis was performed for calendar years 2002, 2020, and 2030 using the Community Multiscale Air Quality (CMAQ) model. The model simulates the multiple physical and chemical processes involved in the formation, transport, and destruction of fine particulate and ozone.

The air quality modeling for the final rule was predominately taken directly from the work performed for EPA's recent final rulemaking to control air emissions from locomotive engines and marine compression-ignition engines less than 20 liters per cylinder (the locomotive/marine rule). This approach was adopted to ensure that the air quality modeling for this rule included the effects all EPA's most recent air pollution control regulations and to conserve resources by taking advantage of the existing inventory preparation (i.e., input files), analytical methods, and results.

More specifically, we used the locomotive/marine rule's "control" scenario as our starting point. The resulting baseline for the Phase 3 final rule was then modified to include more recent modeling updates for small nonroad and marine SI engines based on the NONROAD2005d core model and a set of input files that closely matches those used in this final rule. (The differences in the input files used in the preliminary inventories and those for the final rule, which also used NONROAD 2005d core model, are specifically described later in this section.) For air quality modeling purposes, the nonroad model was executed within the framework of EPA's National Mobile Inventory Model (NMIM) that links a county-level database to the model and collates the output into a single database table. The resulting NMIM inventory estimates for nonroad and marine SI engines account for local differences in fuel characteristics and temperatures. By contrast, if NONROAD2005d is run as a stand alone model, results are based on a somewhat less accurate, but much less resource intensive approach that uses national average daily temperatures and fuel characteristics.

The NMIM emissions inventory methodology and results for the highway vehicles and all nonroad sources (including those for small nonroad and marine SI engines) that were used in the air quality assessment are in the docket for this final rule.[24]

3.6.2 Methodology for Comparing the Preliminary Air Quality Emission Inventories and the Final Inventories

The simplest method for comparing the preliminary emission inventories and the inventories represented in the final rule is to compare the emission results from using the NONROAD2005d core model with the national average inputs for temperature and fuel that reflect the modeling assumptions for the preliminary and final rule inventories. This is possible because of the similarities in the underlying use of the NONROAD2005d model. More specifically, even though the two modeling approaches, i.e., NMIM and the stand alone NONROAD2005 model, use different temperature and fuel characteristics, the computational method is the same.[f] This consistency means that the results of the two modeling approaches will be proportional in nature, i.e., the relative changes in the inventories will be similar. Also, as is explained in more detail later, the other basic modeling scenario inputs, e.g., emission factors and deterioration rates, are nearly identical. Taken together, the modeling results from using the NONROAD2005d model with national average inputs for temperature and fuels will closely mirror the differences in inventories produced with NMIM. This avoids the more time and resource intensive approach of rerunning the NMIM model for the final rule scenarios, while still providing a good comparison of the differences in the absolute inventories, i.e., tons, and more importantly for air quality considerations, the percent reduction between the baseline and control cases. Therefore, the comparisons of the preliminary and final emission scenarios that are presented in the following sections are based on comparing 50-state inventories using the nonroad model with national average inputs.

3.6.3 Comparison of the Baseline Scenario Emission Inventories

As described in Section 3.2., the final emission inventories for the Phase 3 rule are based on the use of a special version of the nonroad model, i.e., NONROAD2005d. Similarly, the preliminary emission inventories for air quality modeling were also constructed using the same version NONROAD2005d core model. Therefore, the only difference between the preliminary and final baseline scenarios are the modeling inputs. These differences and a comparison of the respective inventory results are presented below.

3.6.3.1 Differences Between the Preliminary and Final Baseline Scenarios

The modeling inputs for the final baseline scenario are described in Section 3.2.1. The only difference in the inputs for small nonroad SI engines between the preliminary and the final baseline scenarios is that the preliminary results did not include correction of the running loss

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[f] The difference between the preliminary emission inventories using NMIM and final rule emission inventories using NONROAD2005d is that the NMIM results, which use county-level data for temperatures and fuel characteristics, are generally 10-15 percent greater depending on the pollutant.

emission factors for Class 1 snowblowers to account for cold weather applications as described in Section 3.2.1.1.1, number 8. There were no differences in the inputs for marine SI engines.

3.6.3.2 Comparison of Preliminary and Final Baseline Emission Inventories

Table 3.6-1 compares the preliminary and final 50-state baseline scenario inventories for small nonroad and marine SI engines. As shown, the differences in the baseline scenarios are insignificant.

Table 3.6-1: Comparison of 50-State Baseline Scenario Emissions for Preliminary Air Quality Modeling and Final Rule

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 Final rule	2020	728,853	729,235	(382)	137,002	137,002	0	30,009	30,009	0
	2030	842,970	843,410	(440)	158,840	158,840	0	34,535	34,535	0
Marine SI	2020	460,481	460,481	0	111,525	111,525	0	5,908	5,908	0
	2030	458,656	458,656	0	123,335	123,335	0	5,719	5,719	0
Total	2020	1,189,334	1,189,716	(382)	248,527	248,527	0	35,917	35,917	0
	2030	1,301,626	1,302,066	(440)	282,175	282,175	0	40,254	40,255	0

Table 3.6-1 (Cont'd)
Comparison of 50-State Baseline Scenario Emissions for Preliminary Air Quality Modeling and Final Rule

Applications	Year	PM_{10} [short tons]			CO [short tons]		
		Final	Preliminary	Difference	Final	Preliminary	Difference
Small Nonroad SI Subject to the Final rule	2020	32,618	32,618	0	10,645,870	10,645,870	0
	2030	37,538	37,538	0	12,310,505	12,310,505	0
Marine SI	2020	6,422	6,422	0	1,638,114	1,638,114	0
	2030	6,217	6,217	0	1,671,627	1,671,627	0
Total	2020	39,041	39,041	0	12,283,983	12,283,983	0
	2030	43,755	43,755	0	13,982,132	13,982,132	0

3.6.4 Comparison of the Control Scenario Emission Inventories

As noted above, the preliminary and final emission inventories for the Phase 3 rule are based on the same version of the nonroad model, i.e., NONROAD2005d. Therefore, the only difference between the scenarios are the modeling inputs. These differences and a comparison of the respective inventory results are presented below.

3.6.4.1 Differences Between the Preliminary and Final Control Scenarios

The modeling inputs for the final control scenario are described in Section 3.4.1. The only difference in the inputs for small nonroad SI engines between the preliminary and the final control scenarios is that the preliminary results excluded the following:

1. Update of the Phase 3 Class II zero-hour emission factor for CO from 391.13 to 431.72 g/kW-hr (321.9 g/hp-hr); and
2. Update of the Phase 3 Class II brake specific fuel consumption values from 0.666 to 0.735 lb/hp-hr to reflect a lower use of electronic fuel injection systems.

For marine SI engines, the only difference in the inputs between the preliminary and the final control scenarios is that the preliminary results excluded the following:

1. Revised several of the HC and NOx emission factors for outboards, personal watercraft, and sterndrive/inboards;
2. Revised the Phase 3 standard phase-in dates for high performance sterndrive/inboards (>600 hp);
3. Delayed by one year the implementation dates for outboards, personal watercraft, and stern drive/inboards; and

4. Delayed by one year the implementation of diurnal Phase 3 controls for portable fuel tanks to 2010 and installed fuel tanks to 2011.

3.6.4.2 Comparison of Preliminary and Final Control Emission Inventories

Table 3.6-2 compares the preliminary and final 50-state control scenario inventories for small nonroad and marine SI engines. As shown, the difference in the control scenarios are insignificant.

Table 3.6-2: Comparison of 50-State Control Scenario Emissions for Preliminary Air Quality Modeling Scenario and Final Rule (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 Final rule	2020	487,905	487,663	242	72,175	72,175	0	29,189	29,189	0
	2030	558,094	557,805	289	81,977	81,977	0	33,572	33,572	0
Marine SI	2020	242,957	241,216	1,741	81,398	81,162	236	2,640	2,640	0
	2030	139,083	136,650	2,433	68,639	68,538	101	1,137	1,137	0
Total	2020	730,862	728,879	1,983	153,573	153,336	237	31,829	31,829	0
	2030	697,177	694,455	2,722	150,616	150,515	101	34,709	34,709	0

Table 3.6-2 (Cont'd)
Comparison of 50-State Control Scenario Emissions for
Preliminary Air Quality Modeling and Final Rule

Applications	Year	PM_{10} [short tons]			CO [short tons]		
		Final	Preliminary	Difference	Final	Preliminary	Difference
Small Nonroad SI Subject to the Final rule	2020	31,727	31,727	0	9,679,462	9,029,001	650,461
	2030	36,492	36,492	0	11,166,921	10,393,508	773,413
Marine SI	2020	2,869	2,869	0	1,452,196	1,447,553	4,643
	2030	1,236	1,236	0	1,353,989	1,345,079	8,910
Total	2020	34,596	34,596	0	11,131,658	10,476,554	655,104
	2030	37,728	37,728	0	12,520,910	11,738,587	782,323

3.6.5 Comparison of the Emission Reduction Inventories

Table 3.6-3 compares the emission reductions for preliminary and final 50-state inventories for small nonroad and marine SI engines. As shown, the differences are insignificant.

Table 3.6-3: Comparison of 50-State Emissions Reductions for Preliminary Air Quality Modeling Scenario and Final Rule (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 Final rule	2020	240,948	241,572	(624)	64,827	64,827	0	820	820	0
	2030	284,876	285,605	(729)	76,863	76,863	0	963	963	0
Marine SI	2020	217,524	219,265	(1,741)	30,128	30,364	(236)	1,287	3,269	(1,982)
	2030	319,573	322,006	(2,433)	54,696	54,797	(101)	3,269	4,582	(1,313)
Total	2020	458,472	460,837	(2,365)	94,955	95,191	(236)	4,082	4,089	(7)
	2030	604,449	607,611	(3,162)	131,559	131,660	(101)	5,545	5,545	0

Table 3.6-3 (Cont'd)
Comparison of 50-State Emission Reductions for Preliminary Air Quality Modeling and Final Rule

Applications	Year	PM_{10} [short tons]			CO [short tons]		
		Final	Preliminary	Difference	Final	Preliminary	Difference
Small Nonroad SI Subject to the Final rule	2020	892	892	0	966,407	1,616,868	(650,461)
	2030	1,047	1,047	0	1,143,584	1,916,997	(773,413)
Marine SI	2020	3,553	3,553	0	185,917	190,560	(4,643)
	2030	4,981	4,981	0	317,638	326,548	(8,910)
Total	2020	4,445	4,445	0	1,152,325	1,807,428	(655,103)
	2030	6,028	6,028	0	1,461,222	2,243,545	(782,323)

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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 exhaust emission standards are technically achievable accounting for all the above factors.

The 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 of new 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 its 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.

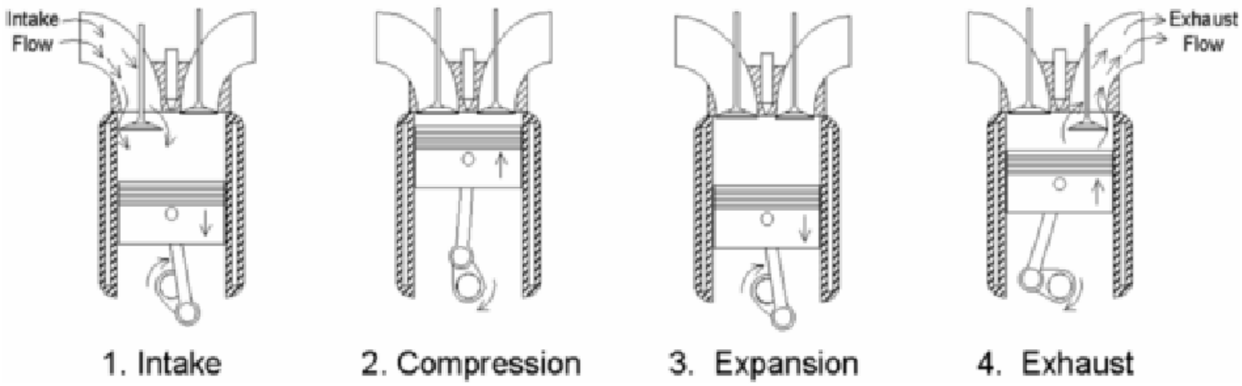
An emerging technology for reducing emissions and scavenging losses from two-stroke engines is direct-injection. This is used primarily on larger outboard and personal watercraft engines (37 kW and up) to meet exhaust emission standards. In a direct-injected engine, charge air is used to scavenge the 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 gasoline-powered highway motorcycles, automobiles, trucks and buses are powered by four-stroke 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 its name from the fact that the piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, 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 carbon monoxide (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 through external exhaust gas recirculation or inefficient 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

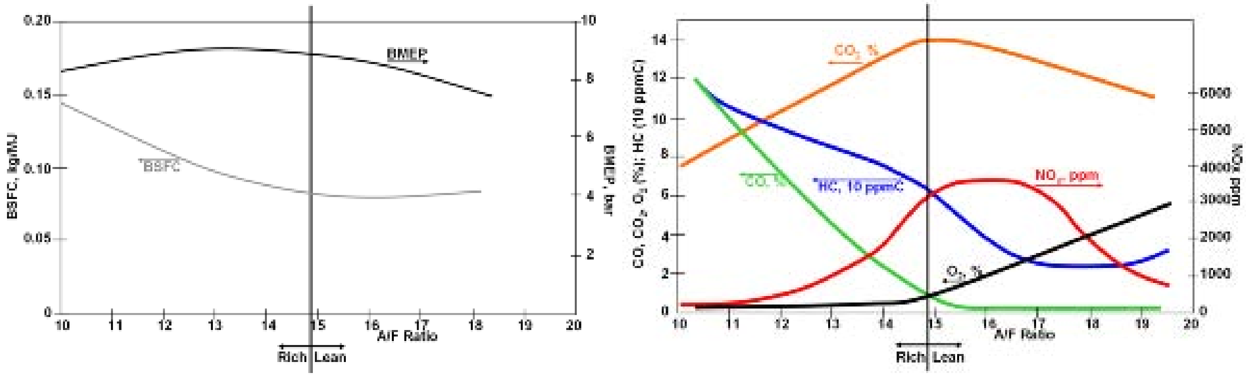
The calibration of engine air-to-fuel ratio affects torque and power output, fuel consumption (often indicated as Brake Specific Fuel Consumption or BSFC), engine temperatures, and emissions for SI engines. The effects of changing the air-to-fuel ratio on emissions, fuel consumption and torque (indicated 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 L 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 provide 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 camshafts 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 rule. 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 do 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 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

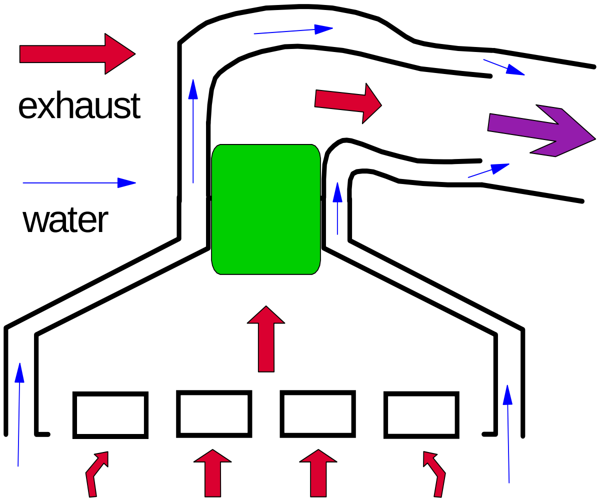
actuation could be actively controlled using an electric solenoid or solenoid valve. The use of active systems is an option but seems unlikely. The most likely control scenario for Class II would be a combination of engine out emission control, use of a small catalyst, and no use of secondary air.

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.

Figure 4.2-1: Placement of Marine Catalyst



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.

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, offers 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 establishing new, more stringent HC+NOx standards for Small SI engines (<19kW) used in nonhandheld, terrestrial applications (we are also setting 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 making 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 existing Phase 2 exhaust emission standards for Class I and II small spark ignition engines as well as the new Phase 3 standards. The Phase 3 standards represent a nominal 35-40 percent reduction from current standards.

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

Engine Class	Phase 2 Standards (HC+NOx g/kW-hr)	Phase 3 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 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 Phase 3 standards and conclude with a more in depth assessment of the technical feasibility of the 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 2008 Certification Test Data

In the 2008 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	66%	2%
Overhead Valve	34%	98%
With Catalyst	0.003%	0.4%
With Other (Electronic Fuel Injection and/or water cooled)	0	1%

Looking at the industry from an engine family rather than a sales perspective, shows that 68 and 212 engine families were emission certified in Class I and II, respectively for 2008. The range of technology types is shown in Table 4.3-3. The majority of engine families in Class I are overhead-valve, carbureted engines, with only 14 families using side-valve, carbureted designs (the side-valve engines still account for the bulk of Class I sales). Five families utilized catalytic exhaust aftertreatment.

Table 4.3-3: 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 Carburetor w. Catalyst	Multi-Cylinder Fuel Injection	Multi-Cylinder Fuel Injection w. Catalyst
I	yes (14)	no	yes (48)	yes (4)	no	no	no	no
II	yes (2)	yes (0)	yes (43)	no	yes (105)	yes (6)	yes (6)	yes (8)

In Class II, the majority of the engine families use multi-cylinder (predominately v-twins) designs incorporating overhead-valve technology. Most of these multi-cylinder families utilized carburetors, with a few using catalytic exhaust aftertreatment, fuel injection, or electronic engine controls. There are relatively fewer single-cylinder engine families using the older, less sophisticated side-valve technology. None of these engines were certified with catalytic aftertreatment.

Figures 4.3-1 and 4.3-2 present the 2008 certification results at full life for Class I and II engine families, respectively, by technology type.[1] One striking feature of these figures, especially Figure 4.3-2, is that there are a number of engine families displaying emission levels well above the existing, i.e., Phase 2, standards. Generally, these families represent somewhat older technology, low production engines that have been certified using preexisting emission credits. Under the conditions of the final Phase 3 rules, these engine families will be unable to be certified using existing credits. As a consequence, we expect these families will be eliminated in favor of newer designs when the Phase 3 standards become effective.

Looking at the remaining engine families, several families were certified at levels necessary to comply with the Phase 3 standards. Also, 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 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 new standards.

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[1] The data presented in Figure 4.3-1 and Figure 4.3-2 are consistent with the 2008 certification data used for the cost analysis in Chapter 6. This data does not include certification data from the nearly 90 Chinese manufacturers that have started certifying nonhandheld engines with EPA in the last few years. (As noted in Chapter 6, EPA has chosen not include data from Chinese manufacturers because we have no information on actual sales of their engines in the United States. Based on discussions with nonhandheld engine manufacturers that have been certifying with EPA for over ten years now, it is our understanding that sales of nonhandheld engines from Chinese manufacturers are relatively small at this time.) The certification levels of the engines certified by Chinese manufacturers generally fall within the same range as the engines presented in Figure 4.3-1 and Figure 4.3-2.

Figure 4.3-1:Class I HC+NOx Full Life Certification Results for 2008

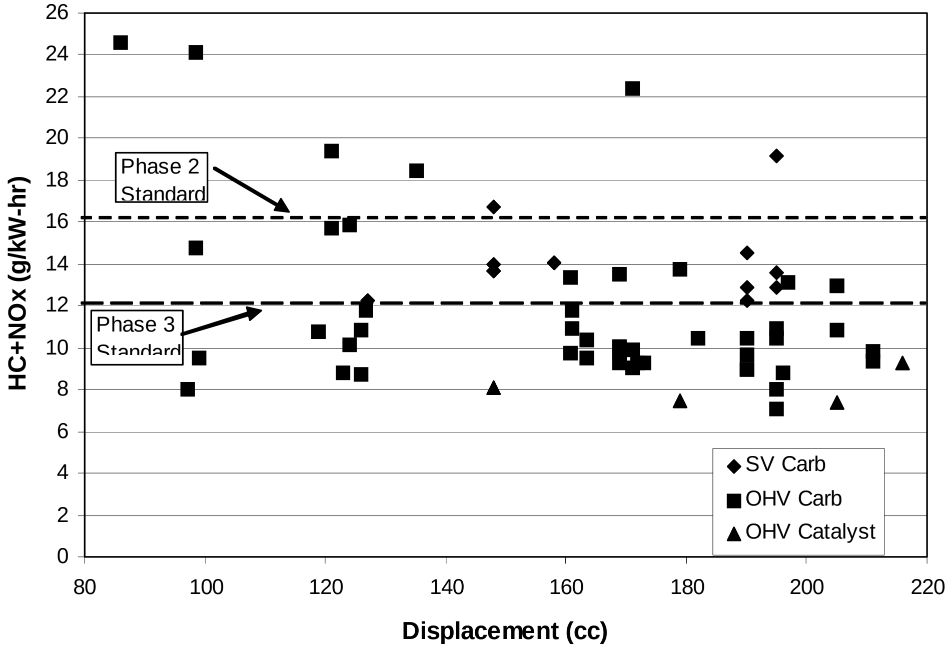
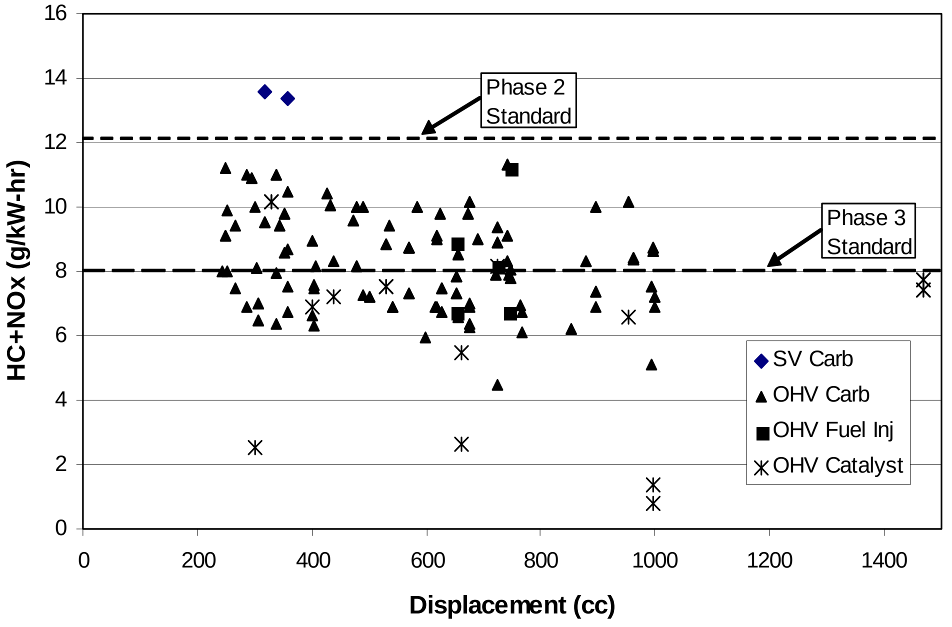


Figure 4.3-2: Class II HC+NOx Full Life Certification Results for 2008



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 Phase 3 standards. However, many engine families clearly will have to do more to improve emission performance. Generally, we believe the new 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 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.[2] 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 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-hour 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. [3] 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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[2] 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.

[3] These results were taken from the 2005 certification results.

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

Engine ID	Displace-ment (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	Over-head	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.[4] Our approach also did not explicitly account for the fact that manufacturers 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-hour 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 degradation 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 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;
4. Improving design and manufacturing processes for carburetors to reduce the production variability in air-fuel mixtures; and

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[4] 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.

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 2008, only 2 out of 107 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 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 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 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)	Useful Life	Fuel Metering	Catalyst Type	Catalyst Volume	Catalyst Cell Density	Catalyst Loading
142	0.40	500 hour	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1[1]
231	0.50	250 hour	Electronic Fuel Injection	Metal monolith	280 cc	200 cpsi	70 g/ft^3, 0:5:1
251	0.50	250 hour	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1
253	0.50	250 hour	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1
254	0.59	250 hour	Carburetor	Cordierite Ceramic Monolith	250 cc	400 cpsi	40 g/ft^3, 5:0:1
232	0.49	1,000 hour	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:palladium:rhodium.

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.[5] As shown, each of the engines achieved the requisite emission limit of 8 g/kW-hr HC+NOx.

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[5] These results were taken from the 2005 certification results.

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 (w/ EFI)	10-40	1.8 ± 0.4[2]
	Projected High	**2.2**
232 (w/ EFI)	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**
254	10-40	4.0 ± 0.3
	Projected High	**4.5**
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 2005 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.[35363738] 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 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 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 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 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 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 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 new 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 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 Configuration	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 cpsi	60 g/ft^3,
catalyst		**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:palladium:rhodium.

Finally, the combination of electronic fuel injection and catalytic exhaust aftertreatment clearly has the potential to reduce emissions well below the Phase 3 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 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 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 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 new 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 include 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 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.[4344] 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 2008 Certification Database lists 6 multi-cylinder engine families in the Class II 1000 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 finalizing 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 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 new 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

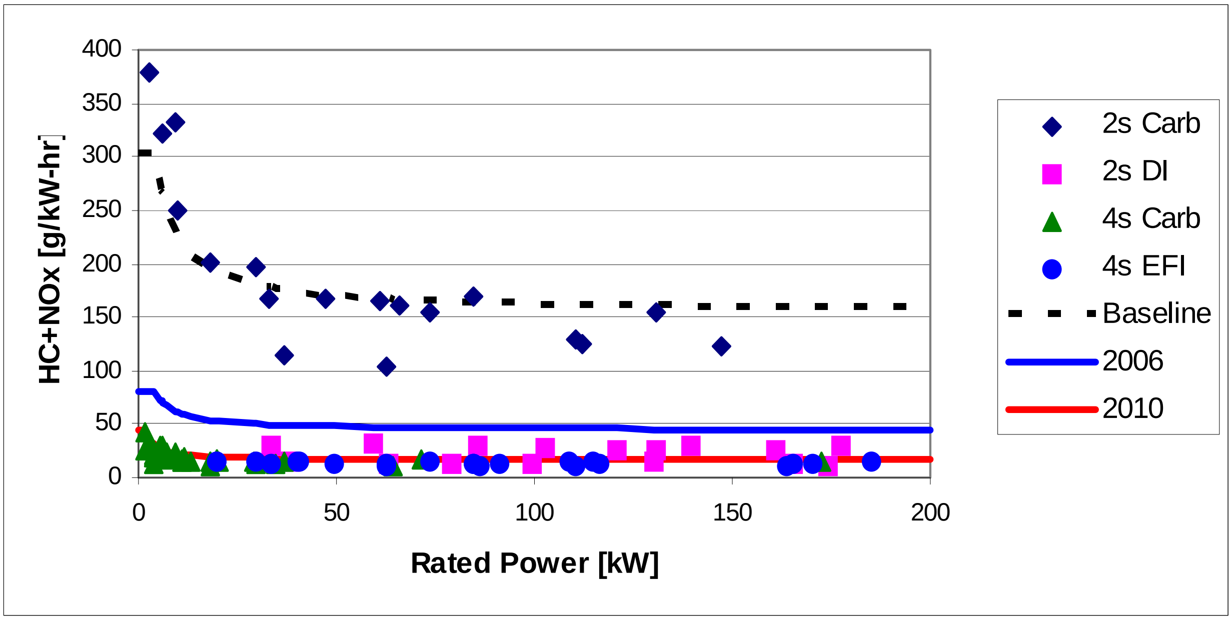
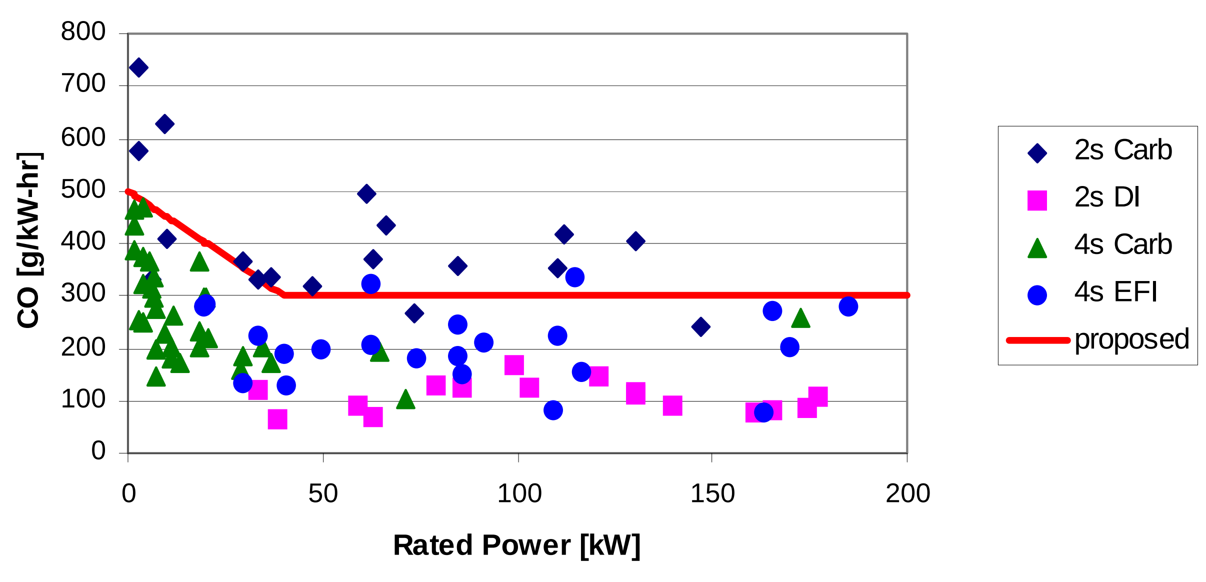


Figure 4.4-2: 2006 MY New Technology Outboard HC+NOx Certification Levels



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 new HC+NOx standards.

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

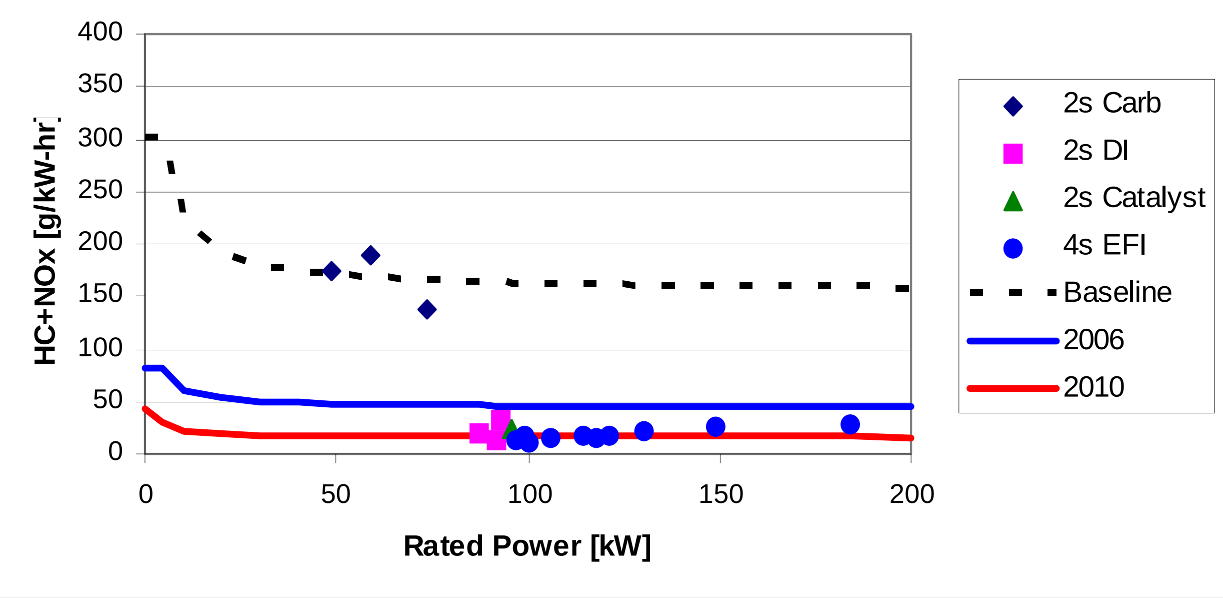
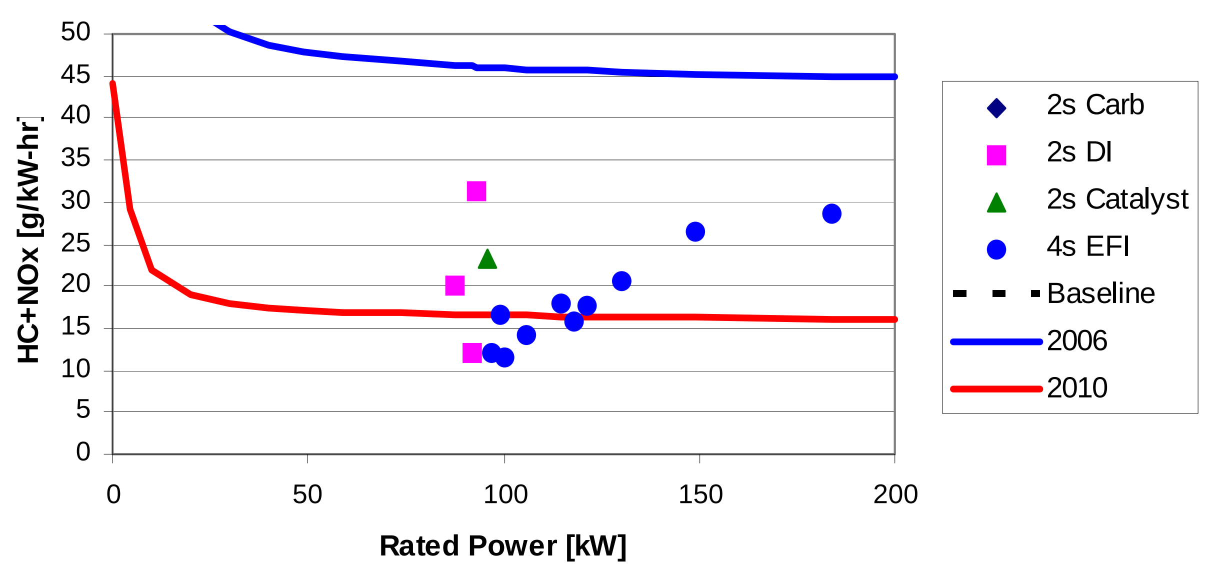


Figure 4.4-4: 2006 MY New Technology PWC HC+NOx Certification Levels



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

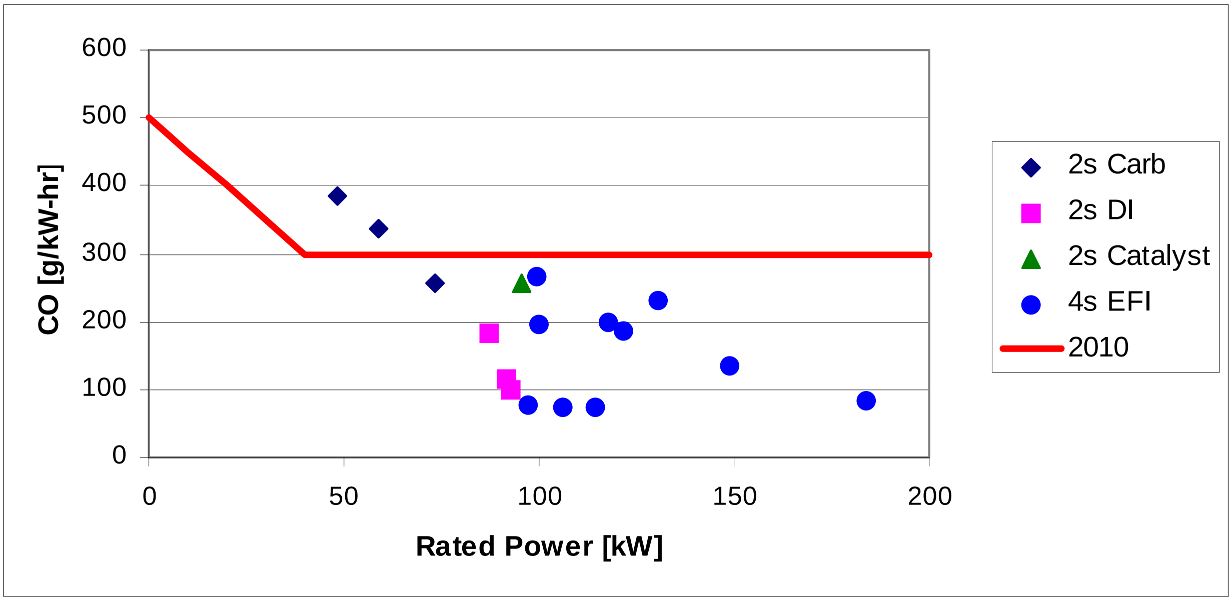
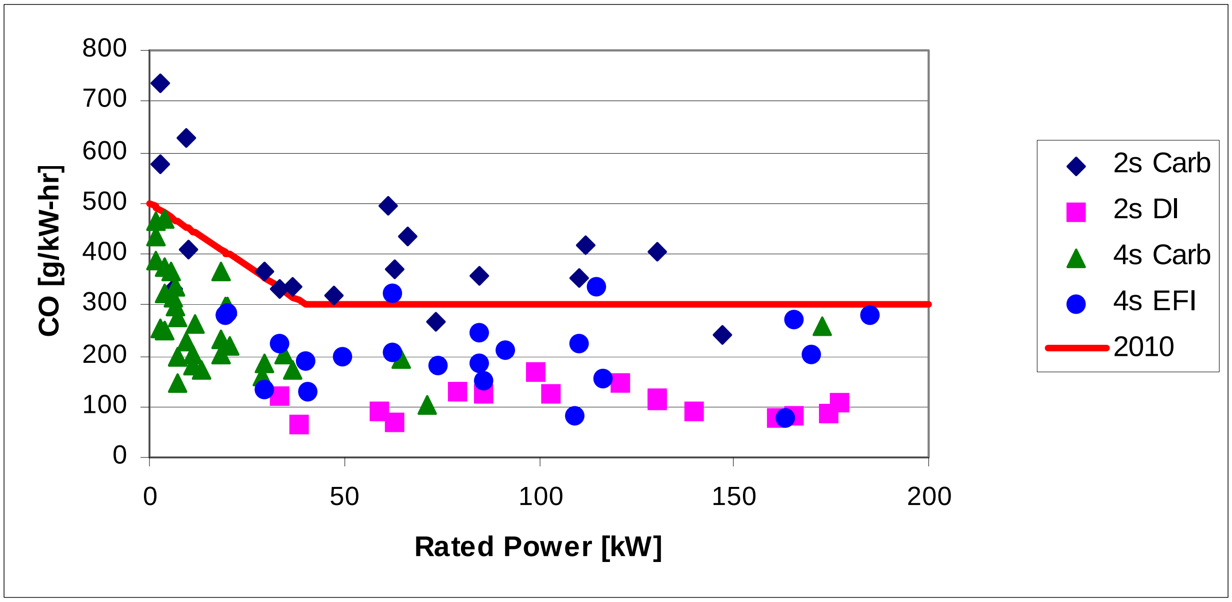


Figure 4.4-6: Reported CO Emission Levels for 2006 MY PWC Engines



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.

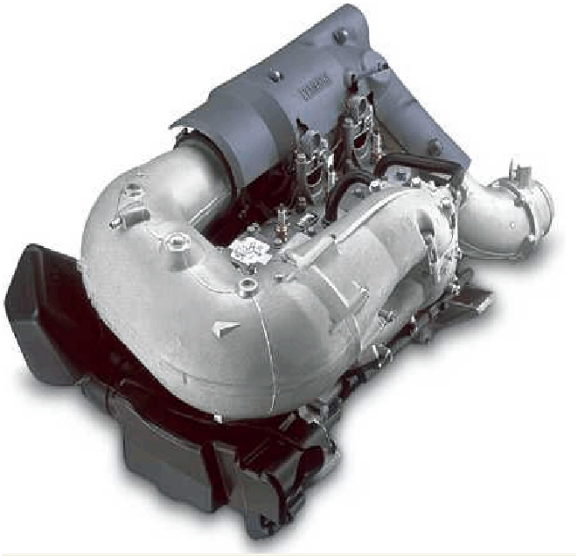
4.4.2.3 Four Stroke Engines

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). Manufacturers have recently begun efforts to develop a three-way catalyst system for PWC engines used in jet boats.

Figure 4.4-7: PWC Engine with Catalyst



Catalysts have not yet been packaged into the exhaust system of production outboard marine engines. 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 establishing exhaust emission standards for spark-ignition sterndrive and inboard (SD/I) engines. These new 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 by EPA on five high-performance engines.[55,56,57] This data also includes data submitted by a high performance engine manufacturer in its public comments on the proposed rule.[58]

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

Power [kW]	Fuel Delivery System	HC	NOx	CO	BSFC
391	multi-port electronic fuel injection	14.7	3.8	243	354
550	carburetor	13.2[a]	8.4	253	376
634	multi-port electronic fuel injection, supercharger	16.9	9.1	135	348
778	throttle-body fuel-injection, supercharger, intercooler	7.6	4.9	349	448
802	multi-port electronic fuel injection, supercharger	16.1	9.4	102	299
466	electronic fuel injection	15.4[a]	3.2	257	--
410	electronic fuel injection	14.8[a]	3.9	325	--
466	electronic fuel injection, low emission calibration[b]	4.3	10.8	104	--

[a] HC concentration at idle was out of measurement range

[b] 15% load factor at idle

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).[59,60,61] 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 program 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.[62] 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

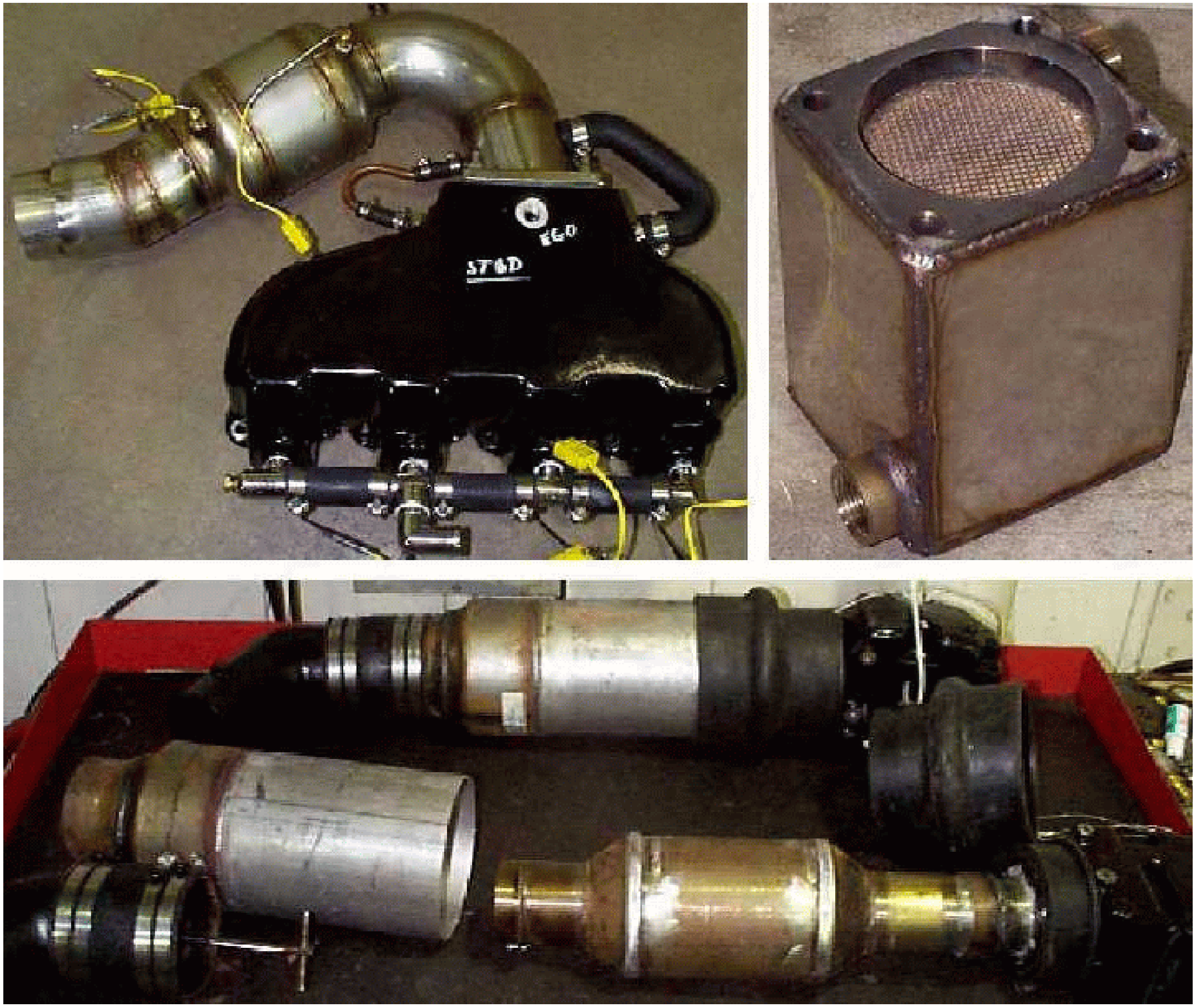


Table 4.5-4 presents the exhaust emission results for the baseline test and three catalyst packaging configurations. In each case a pair of catalysts were used, one for each exhaust manifold. For the riser catalyst configuration, we tested the engine with two cell densities, 60 and 300 cells per square 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 compared 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 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.[63,64] 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.[65] No significant deterioration was observed on any of the catalysts. In fact, all of the 5.7 L engines were below the 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 HC+NOx standard, the final emissions for the 4.3 L engine were 15 percent above the 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.[66] 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

At the time of proposal, only one manufacturer was selling inboard Marine SI engines equipped with catalysts. These engines 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.[67] 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

At this time, three manufacturers have certified engines, equipped with catalysts, to the 5 g/kW-hr HC+NOx California standards for SD/I engines. Table 4.5-11 presents the certification data available from the California Air Resources Board's Off-Road Certification Database.[68]

Table 4.5-11: Catalyst-Equipped SD/I Engines Certified in California

Manufacturer	Engine Disp. [liters]	Rated Power [kW]	HC+NOx [g/kW-hr]
Indmar	5.7	230	3.7
	5.7	230	4.6
Mercury Marine	1.6	75	4.2
	3.0	101	2.7
	5.0	194	1.8
	5.7	246	3.4
	8.1	280	2.8
	8.1	317	4.6
Volvo Penta	5.0	239	3.3
	8.1	298	2.6

4.5.3.5 CO Emissions Reductions at Low versus High Power

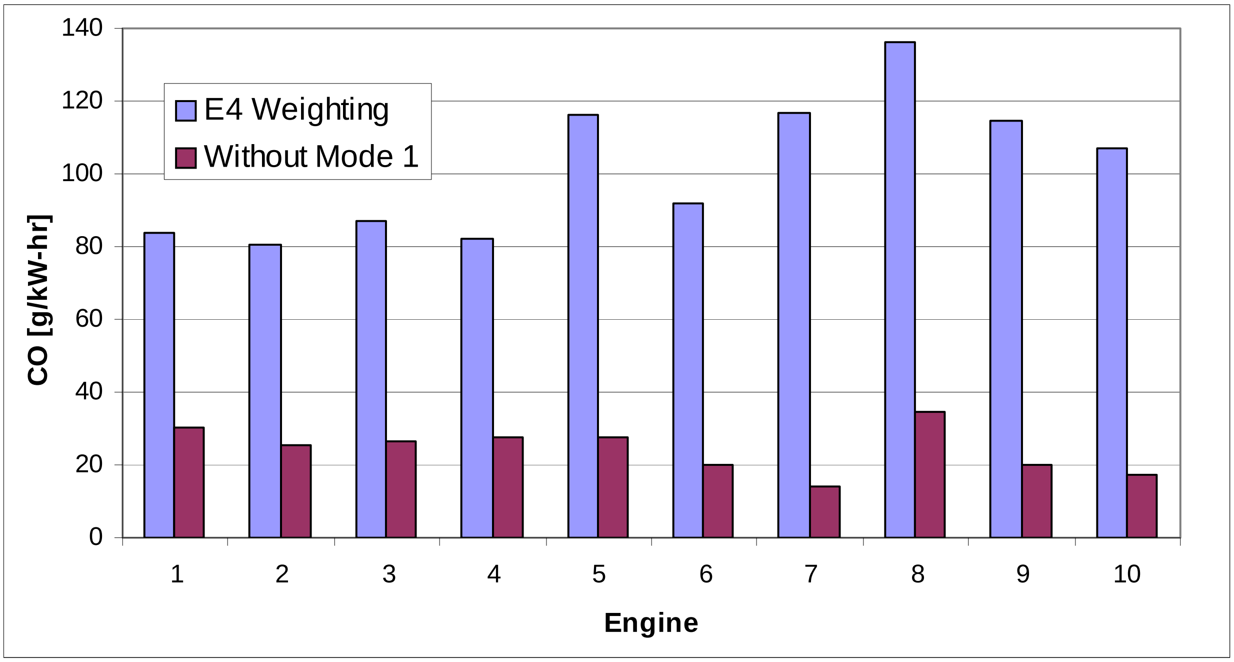
Under stoichiometric or lean conditions, catalysts are effective at oxidizing CO in the exhaust. However, under very rich conditions, catalysts are not effective for reducing CO emissions. SD/I engines often run at high power modes for extended periods of time. At these temperatures, engine marinizers must calibrate the engine to run rich as an engine protection strategy. If the engine were calibrated for a stoichiometric air-fuel ratio at high power, high temperatures could lead to failures in exhaust valves and cylinder 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 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 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[69] 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 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.[70] 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.[71,72] 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.[73,74] 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	throttle-body injection, O_2 sensor, catalyst	2.0	0.01
	17.9	throttle-body injection, O_2 sensor, catalyst	4.4	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.[75] 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 making 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 including SD/I engines in these test procedures. In addition we are establishing 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 using the same certification duty cycle and test procedures for all Marine SI engines, including sterndrives and inboards. Table 4.5-6 presents the 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.[76] 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.[77] 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[a] 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[b]	--	0.40

[a] % power = (% speed) × (% torque)

[b] 15% of maximum torque at MES for high-performance engines

For high-performance engines, the above test procedure is modified slightly. These engines typically have substantial auxiliary loads and parasitic losses even when the vessel does not need propulsion power. In addition, these engines are not designed to operate at a low load idle and survey data suggests that operators do not spend significant time at zero power idle.[78] To account for this, for high-performance engines, we revised the test torque at idle speed to be 15 percent of maximum torque at maximum test speed.

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 have requirements that extend to typical in-use operation. We are establishing 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 new 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 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.

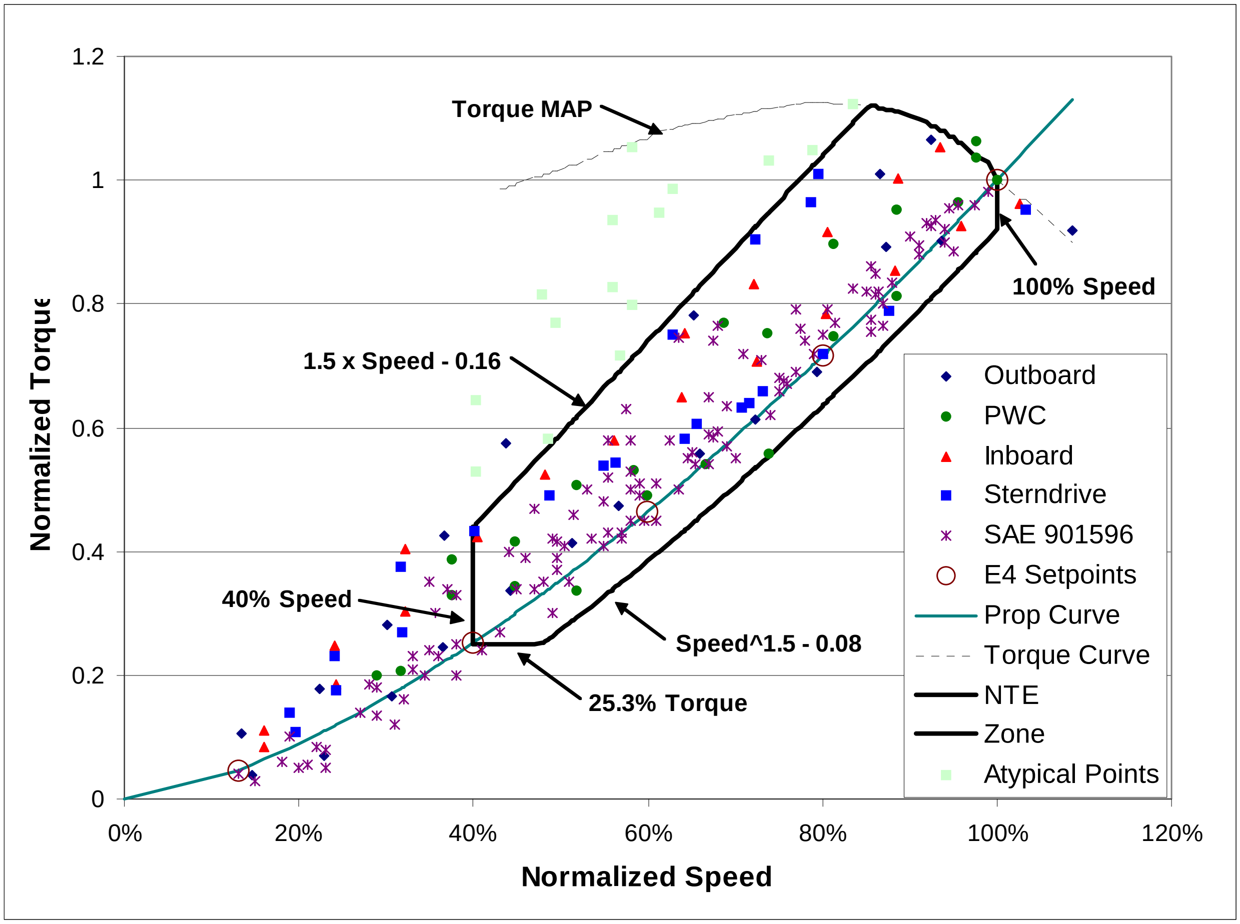
4.7.2.1 Shape of the NTE Zone

The 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.[79] 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.[80] 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 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: 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 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 NTE zone would be steady-state. When bringing a boat to plane, marine engine operation would be transient and would likely be above the 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 Modal Emission Test Data within the NTE Zone

The NTE zone has emissions caps 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 the 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,[81,82,83] 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.[84,85,86,87] Our analysis focuses only on engines using technology that could be used to meet the new 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 and 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

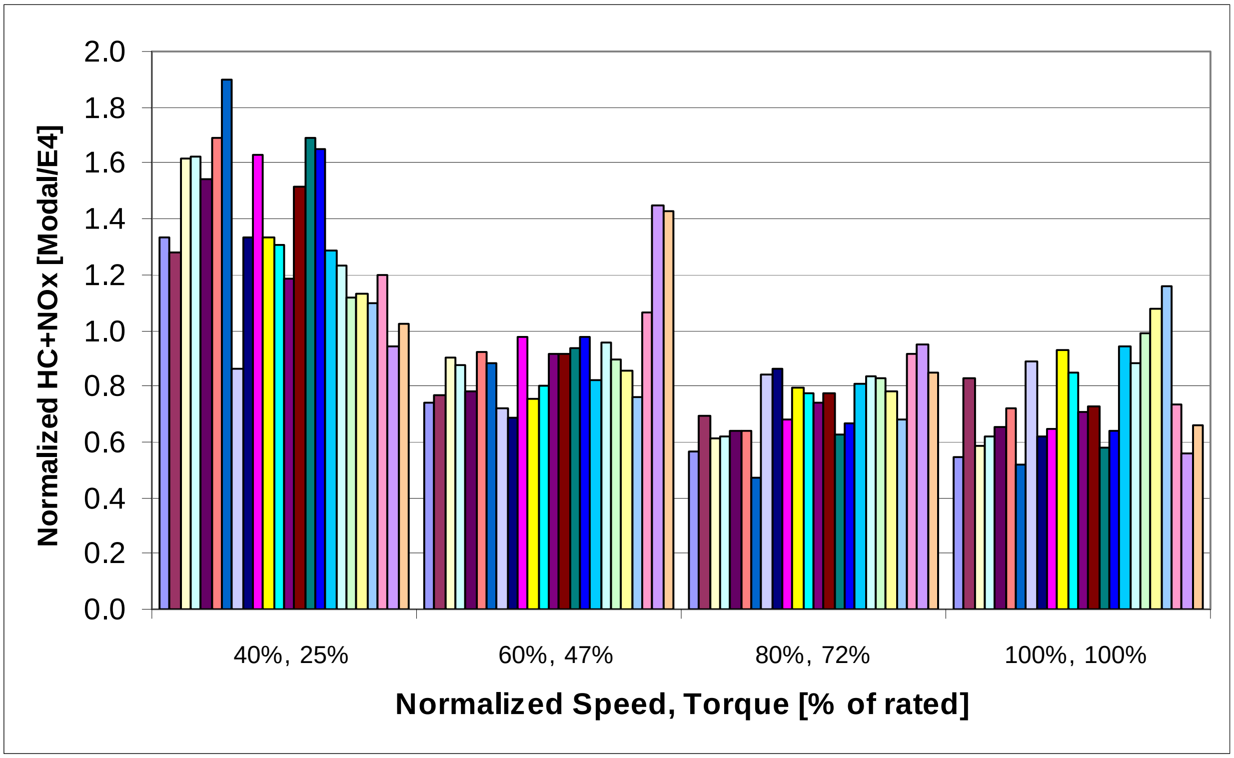


Figure 4.7-3: Normalized Modal CO for Carbureted 4-Stroke OB/PWC

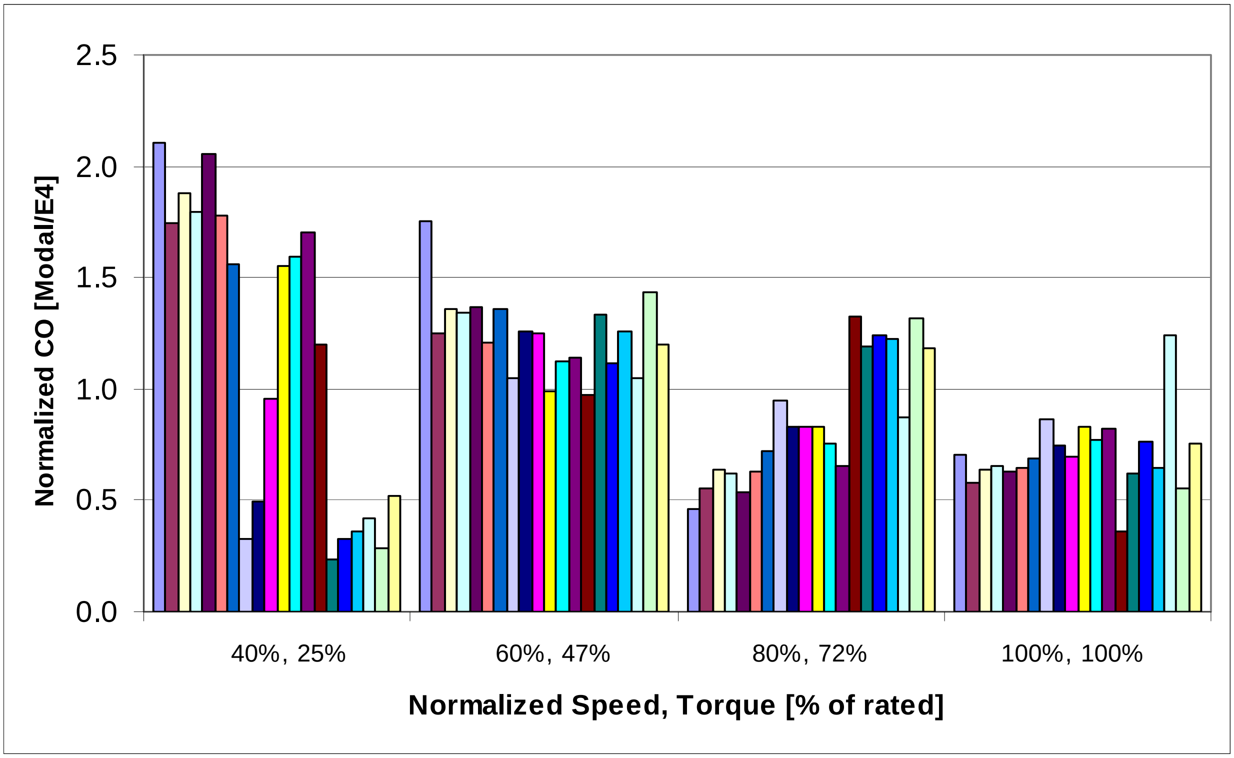


Figure 4.7-4: Normalized Modal HC+NOx for EFI 4-Stroke OB/PWC

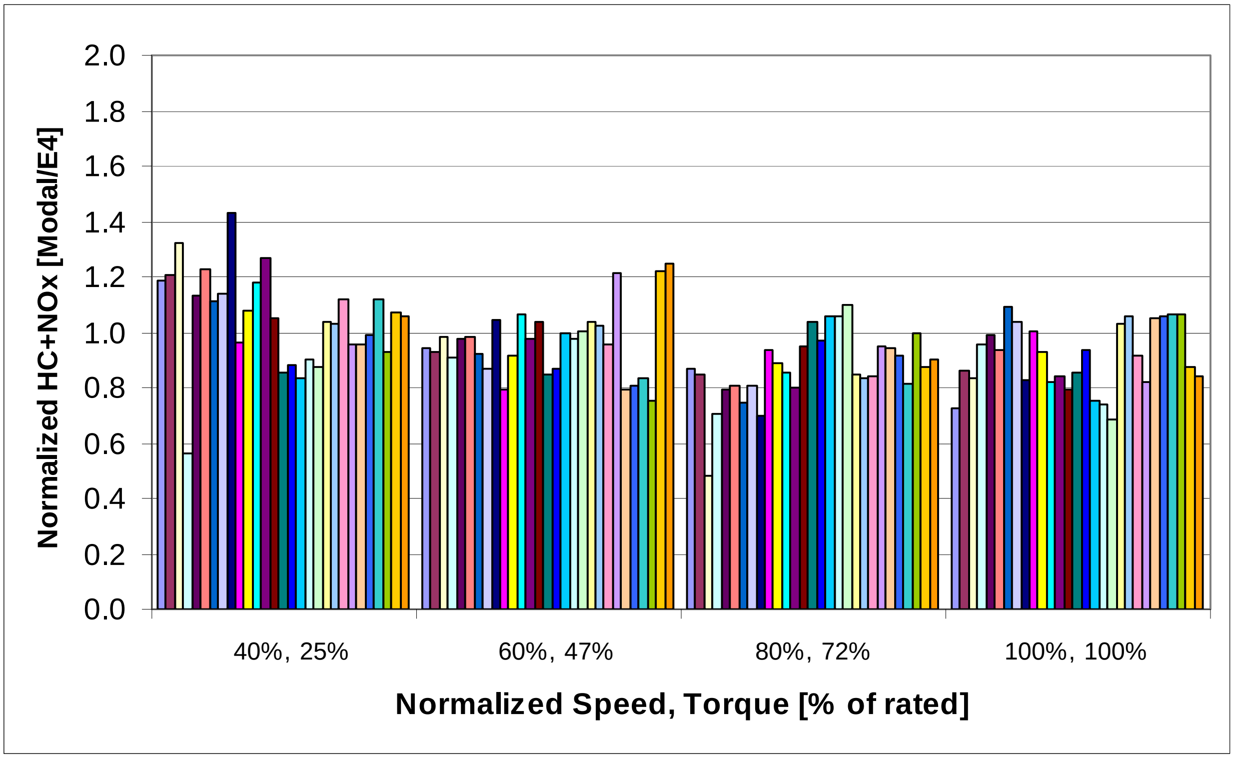
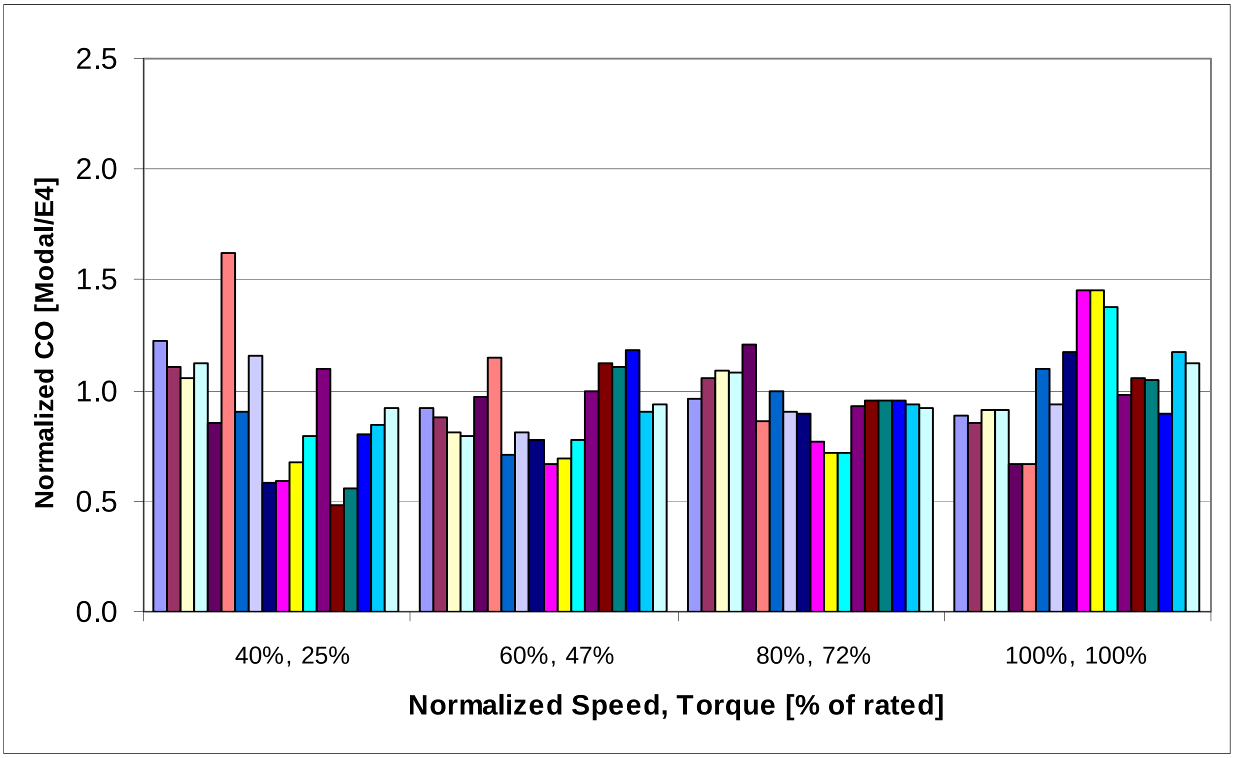


Figure 4.7-5: Normalized Modal CO for EFI 4-Stroke OB/PWC



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

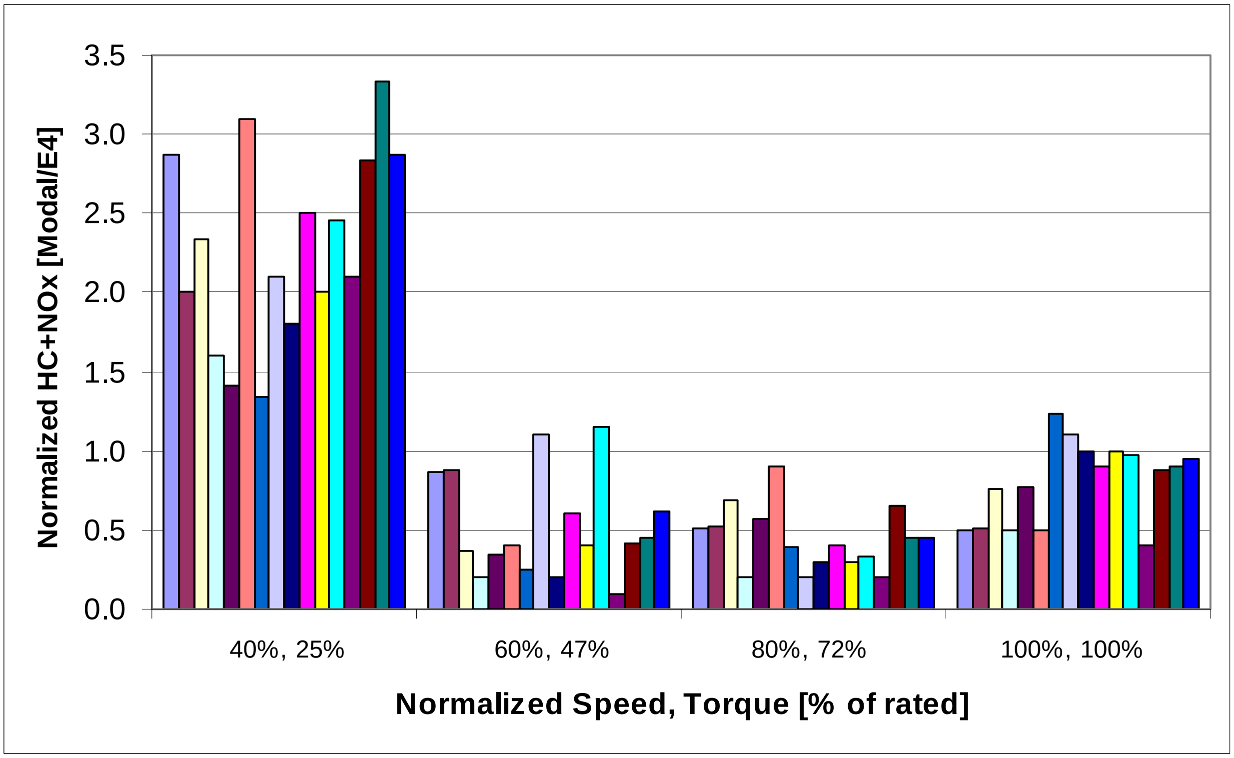


Figure 4.7-7: Normalized Modal CO for Type 1 DI 2-Stroke OB/PWC

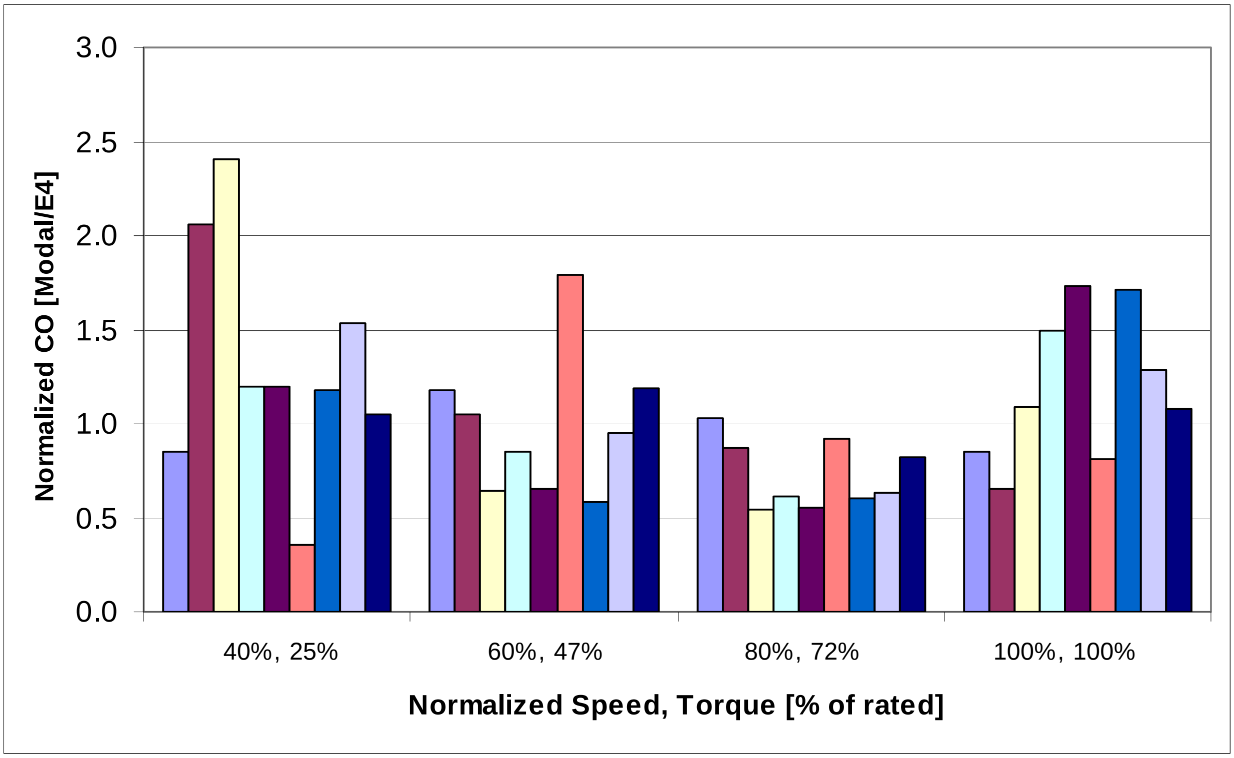


Figure 4.7-8: Normalized Modal HC+NOx for Type 2 DI 2-Stroke OB/PWC

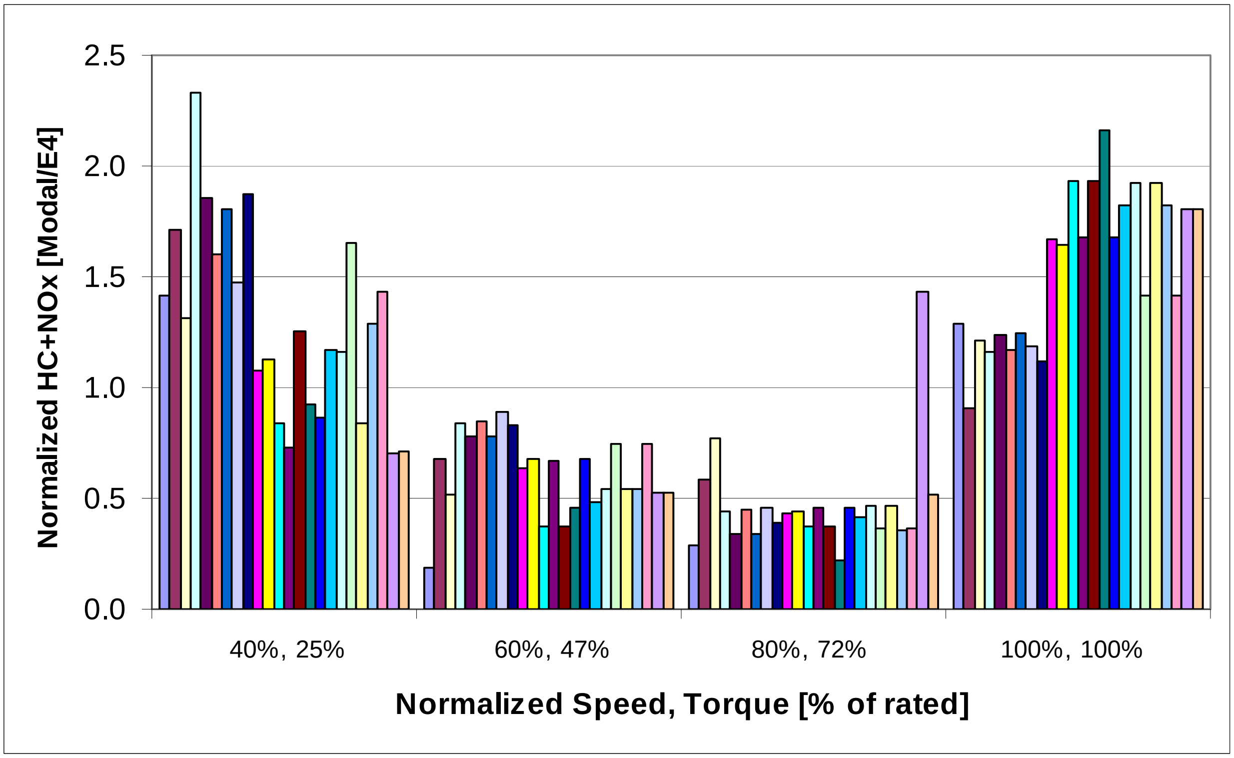
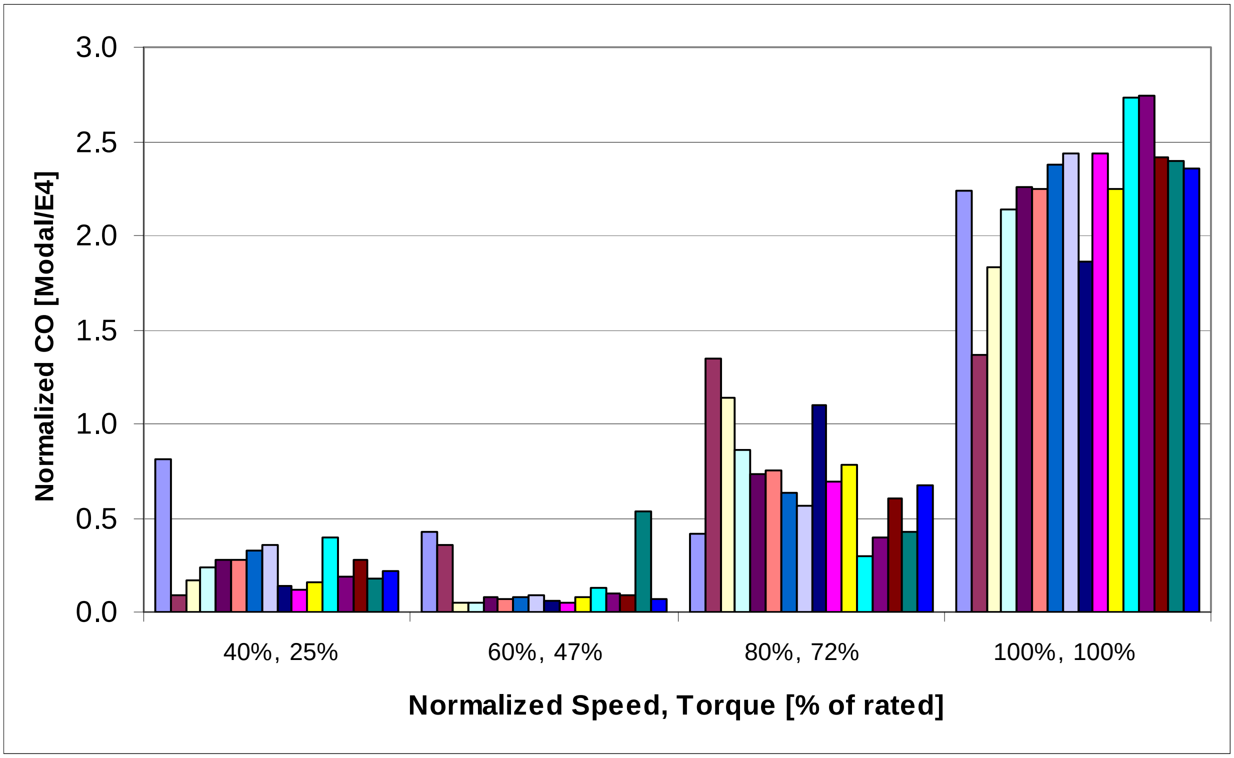


Figure 4.7-9: Normalized Modal CO for Type 2 DI 2-Stroke OB/PWC



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 NTE zone.[88] 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 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

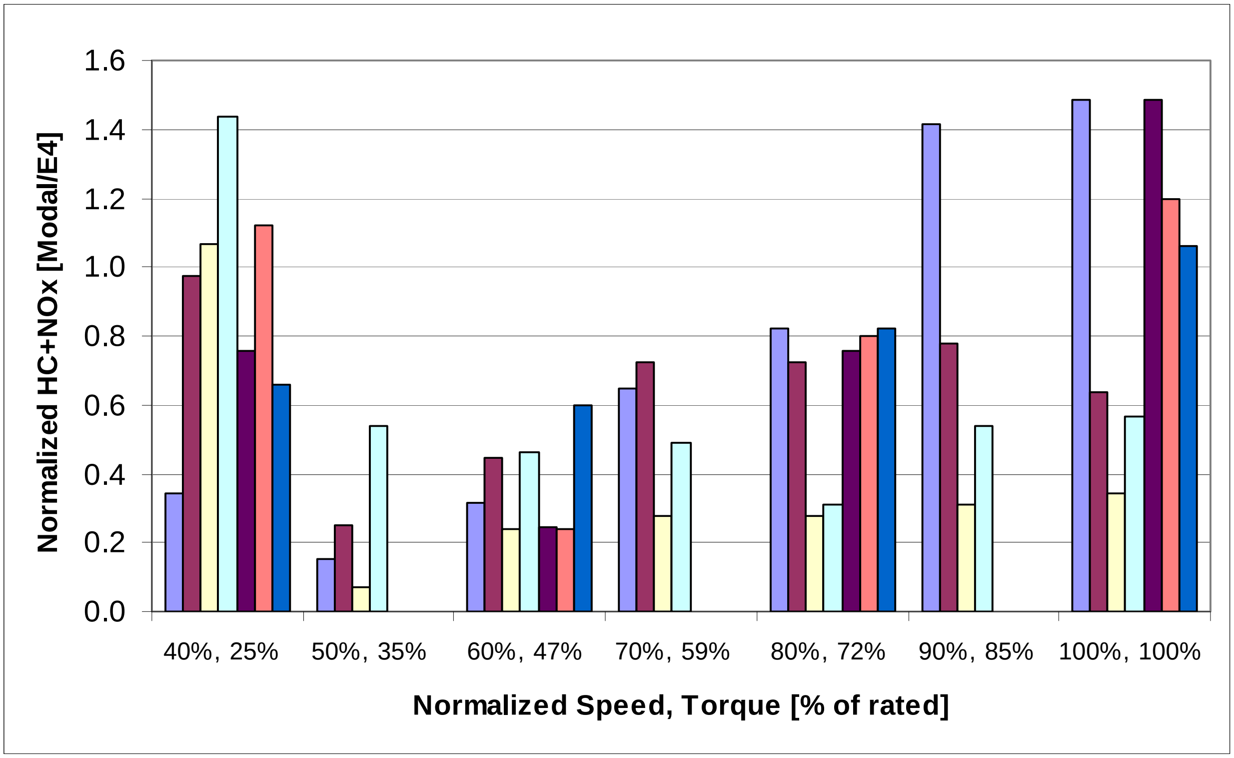
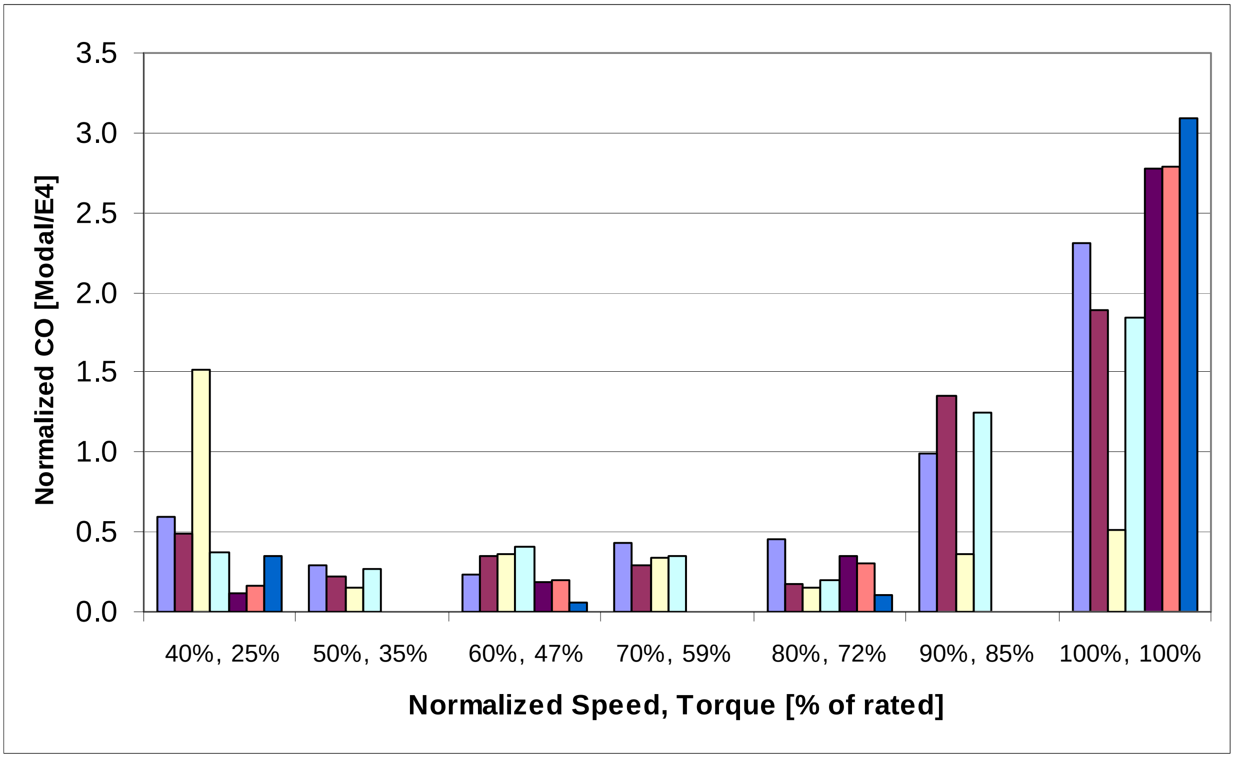


Figure 4.7-11: Normalized Modal CO for SD/I with Catalysts



4.7.2.3 NTE Zones and Standards

As described above, the emissions characteristics of marine engines are largely dependent on technology type. Four-stroke engines tend to have relatively constant emission levels throughout the NTE zone. In contrast, two-stroke engine tend to have high variability in emissions, not only within the NTE zone but between different engine designs as well. Catalyst-equipped engines tend to have relatively flat emissions profiles, in the NTE zone, when operating in closed-loop engine control mode. However, at higher engine power, the engines are calibrated to operate with a rich fuel-air ratio, in open-loop control, to protect the exhaust valves and catalyst from high exhaust temperatures. This reduces the catalyst efficiency at high power for oxidizing HC and CO.

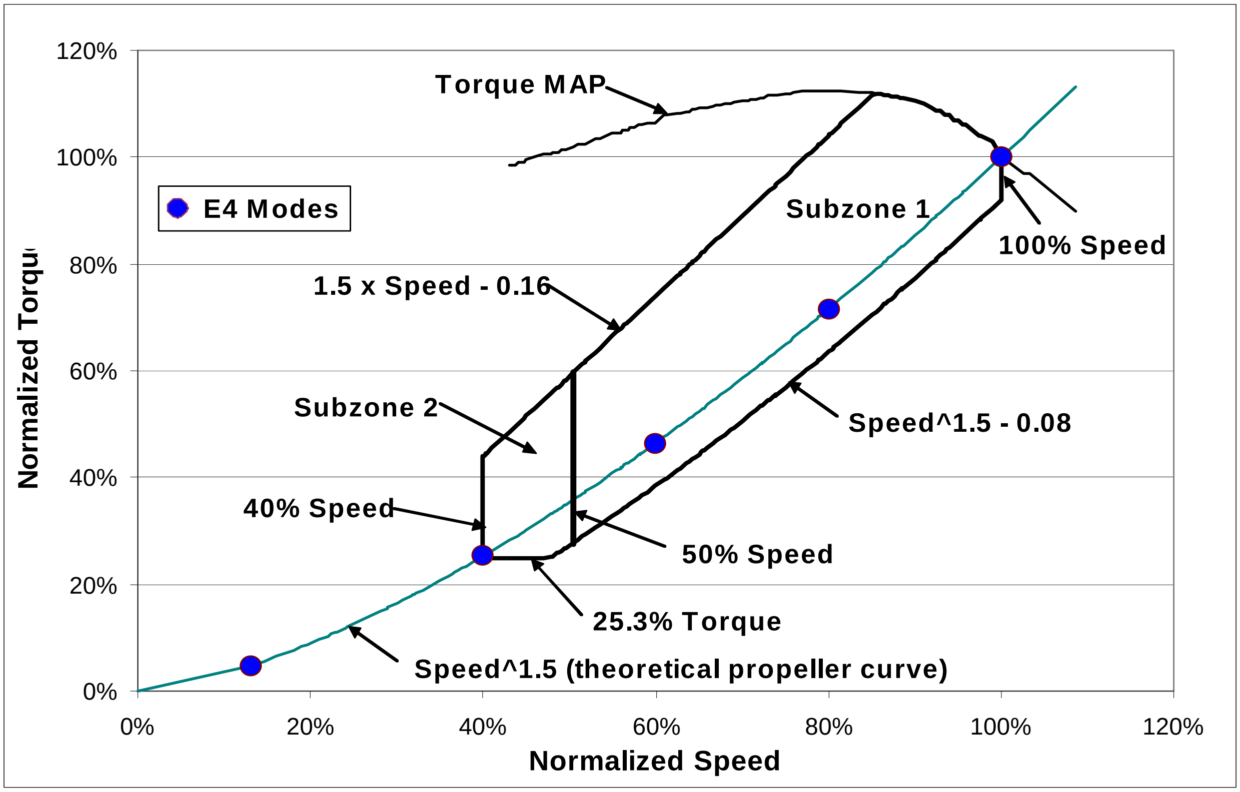
Since the NPRM was published, we have worked with engine manufacturers to better understand the design constraints, operation, and emissions characteristics of marine engines. Based on this understanding, and the emission data presented above, we decided to develop different NTE standards for three distinct types of engines; 4-stroke, 2-stroke, and catalyst-equipped. These standards are discussed below.

We used the modal data presented above and the data on additional operation points presented in Appendix 4A to develop NTE limits. These limits are presented as a multiplier times the Family Emission Limit (FEL) developed using the 5-mode test procedure. The 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 NTE limits, we believe that these engines can be calibrated to meet these limits. In addition, the limits are based on the FELs 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 NTE limits.

4.7.2.3.1 4-Stroke Engines

The emissions data, presented above, for 4-stroke marine engines suggests that brake-specific emissions rates are relatively constant throughout the NTE zone. One exception is slightly higher HC+NOx emissions at low power. To account for this, we are subdividing the NTE zone to have a low power subzone below 50 percent of maximum test speed. In this low power subzone, the HC+NOx NTE limit is 1.6, while it is 1.4 for the remainder of the NTE zone. The CO NTE limit is 1.5 throughout the NTE zone. Figure 4.7-12 presents the NTE zone and subzones. These limits would apply to all non-catalyzed four-stroke marine engines.

Figure 4.7-12: 4-Stroke Engine NTE Zone and Subzones



4.7.2.3.2 2-Stroke Engines

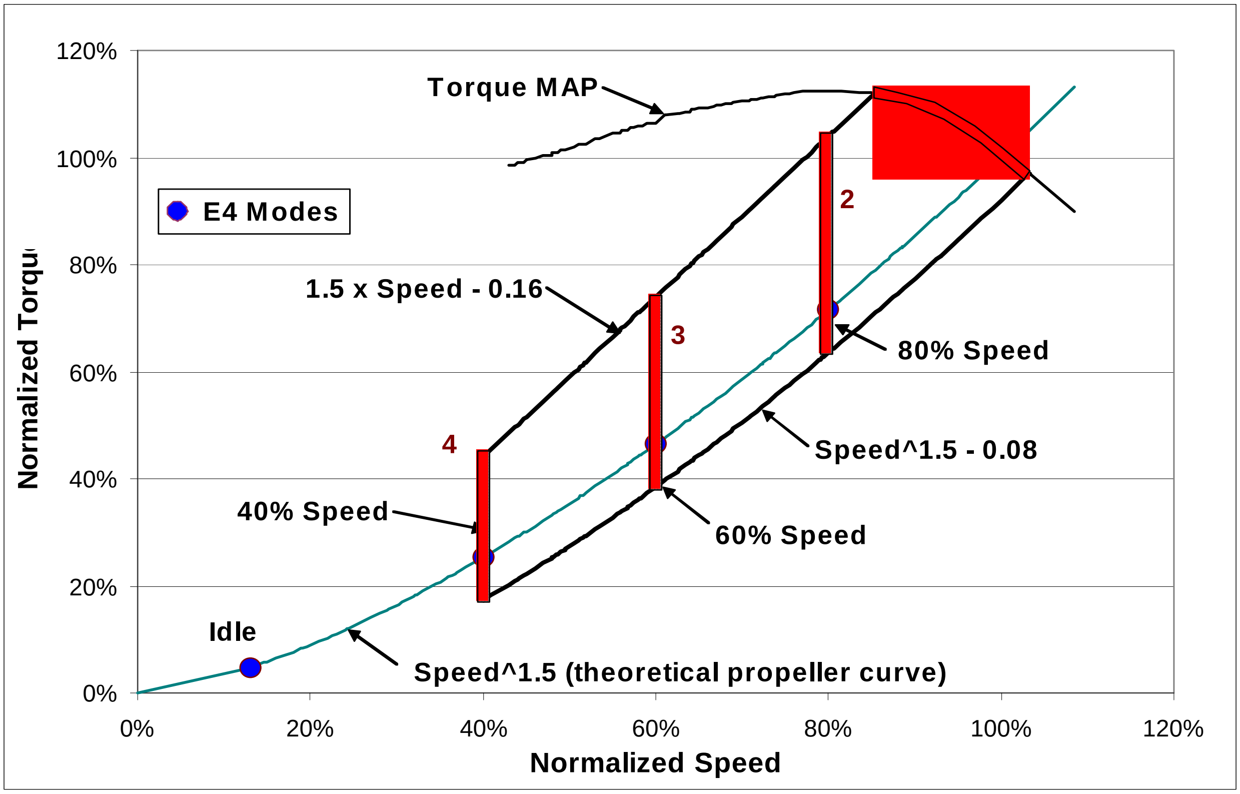
The emissions data presented above, for 2-stroke direct-injection marine engines suggests that these engines have high variability in emissions, not only within the NTE zone but between different engine designs as well. Due to this variability, we do not believe that a flat (or stepped) limit in the NTE zone could be effectively used to establish meaningful standards for these engines. At the same time, we believe that NTE standards are valuable for facilitating in-use testing. Therefore, we developed a weighted NTE approach specifically for these engines. In the long term, we may consider further emission reduction based on catalytic control applied to OB/PWC engines. In this case, we would revisit the appropriateness of the weighted NTE approach in the context of those standards.

Under the weighted NTE approach, emissions data is collected at five test points. These test points are idle, full power, and the speeds specified in modes 2-4 of the 5-mode duty cycle. Similar to the 5-mode duty cycle, the five test points are weighted to achieve a composite value. This composite value must be no higher than 1.2 times the FEL for that engine.

The difference in this approach, from the 5-mode duty cycle, is that the test torque is not specified. During an in-use test, the engine would be set to the target speed and the torque value would be allowed to float. In addition, at wide open throttle, the engine speed would be based on actual performance on the boat. Because in-use engines installed in boats do not generally operate on the theoretical propeller curve used to define the 5-mode duty cycle, this NTE approach helps facilitate NTE testing.

At each test mode, limits are placed on allowable engine operation. These limits are generally based on the NTE zone presented above for 4-stroke engines, but there are two exceptions. First, the lower torque limit at 40 percent speed is lowered slightly to better ensure that an engine on an in-use boat is capable of operating within the NTE zone. Second, the speed range is extended at wide-open throttle for the same reason. Figure 4.7-13 presents this approach.

Figure 4.7-13: 2-Stroke Engine Weighted NTE Concept



During laboratory testing, any point within each of the four non-idle subzones may be chosen as test points. These test points do not necessarily need to lie on a propeller curve. It should be noted that the actual power measured would be used in the calculation of the weighted brake-specific emissions.

4.7.2.3.3 Catalyst-Equipped Engines

SD/I engines are anticipated to make use of three-way catalysts to meet the new exhaust emission standards. These catalysts are most effective when the fuel-air ratio in the exhaust is near stoichiometry. Engine manufacturers use closed-loop control to monitor and maintain the proper fuel-air ratio in the exhaust for optimum catalyst efficiency. However, at high power, engine manufacturers must increase the fueling rate to reduce the temperature of the exhaust. Otherwise, if the exhaust temperature becomes too high, exhaust valves and catalysts may be damaged. During rich, open-loop operation at high power, the catalyst is oxygen-limited and less effective at oxidizing HC and CO. To address the issue of open-loop catalyst efficiency, we created a high power subzone in the NTE zone for catalyst-equipped engines.

The majority of SD/I engines are based on engine blocks produced by General Motors. To determine the appropriate threshold for the high power-subzone, we used temperature data supplied by General Motors.[89] This data was consistent with confidential data supplied by engine marinizers on engine control strategies for catalyst-equipped SD/I engines. Figure 4.7-14 presents the stoichiometric limits for engine protection, based on the General Motors study, for three different engine designs.

Figure 4.7-14: GM Study-Stoichiometric Limits for Engine Protection

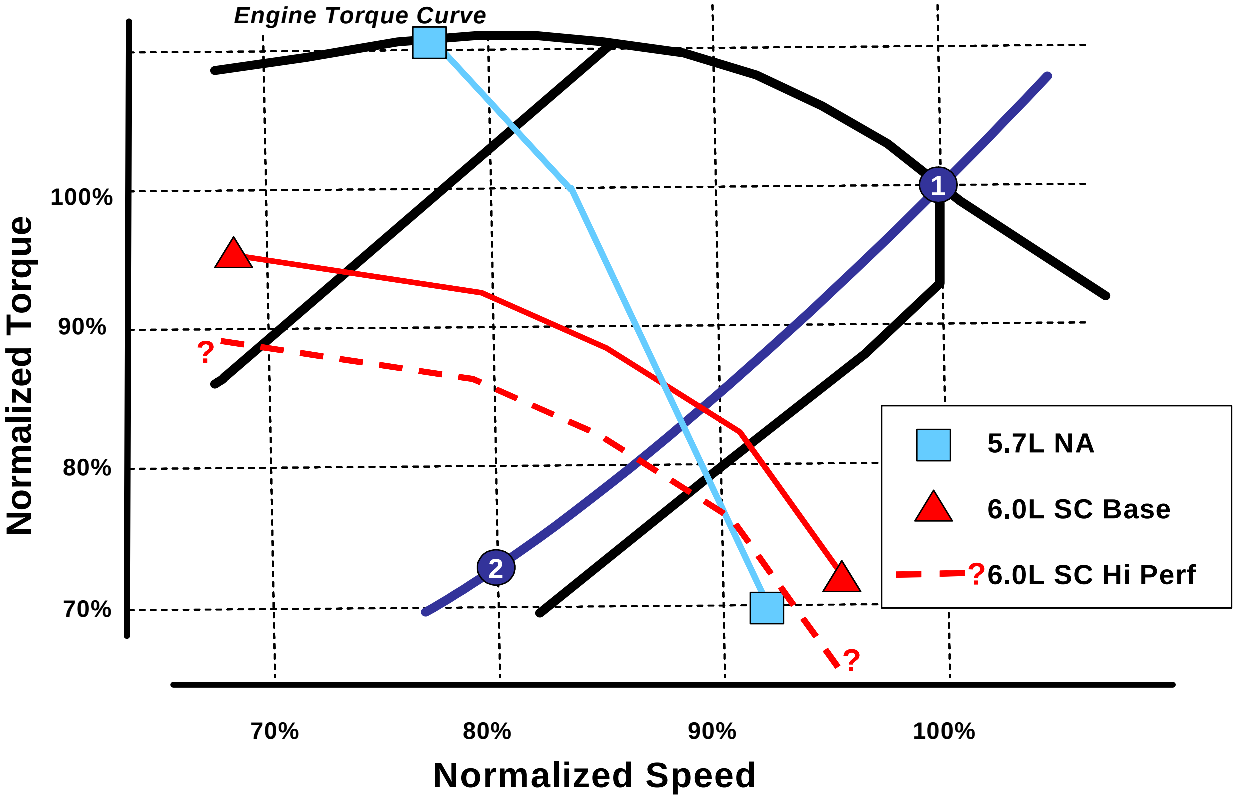


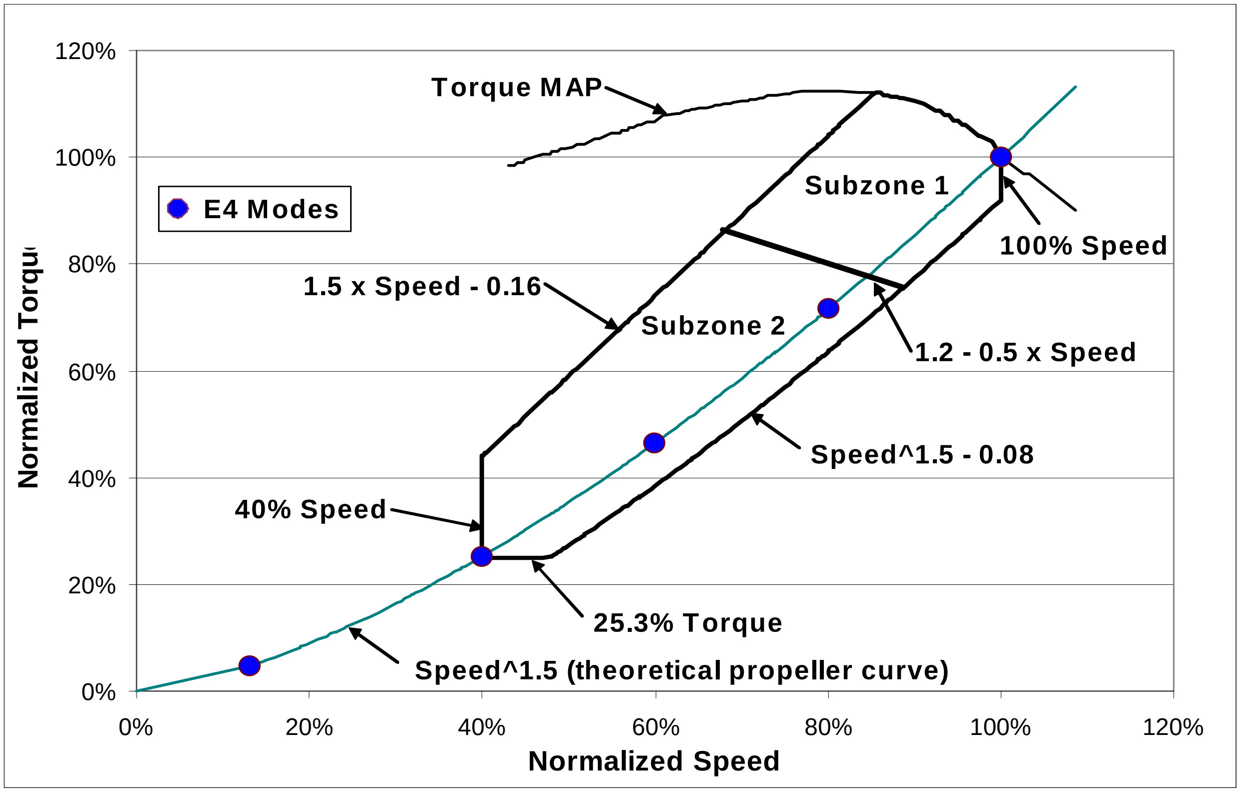
Figure 4.7-15 presents the NTE zone and high power subzone for catalyst-equipped marine engines. The shape of the high power subzone is based on the General Motors engine protection data. The emission limits are based on data discussed above on SD/I engines, with catalysts, operating in open-loop versus closed-loop engine control.

For catalyst-equipped engines, the largest contribution of emissions over the 5-mode duty cycle comes from open-loop operation at Mode 1. In addition, the idle point (Mode 5) is weighted

40 percent in the 5-mode duty cycle, but not included in the NTE zone. For this reason, brake-specific emissions throughout most of the NTE zone are less than the weighted average from the steady-state testing. For most of the NTE zone, we are therefore requiring a limit equal to the duty-cycle standard (i.e., NTE multiplier = 1.0).

Emission data on catalyst-equipped engines also show higher emissions near full-power operation. As discussed above, this is due to the need for richer fuel-air ratios under high-power operation to protect the engines from overheating. We are therefore establishing higher NTE limits for subzone 1 based on emissions performance during open-loop operation. Specifically, we are establishing an HC+NOx limit of 1.5 times the duty-cycle standard. Some HC+NOx control is expected in subzone 1 because a three-way catalyst will effectively reduce NOx emissions under rich conditions. However, for subzone 1, we are not setting a CO limit. Under rich conditions, a three-way catalyst is not at all effective for oxidizing HC or CO emissions. In addition, the cycle weighted emission level for CO is primarily driven by Mode 1.

Figure 4.7-15: Catalyst-Equipped Engine NTE Zone and Subzones



4.7.2.4 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 applying 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.[90] 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 specified range, we require 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 requiring that the NTE testing include a range of ambient water temperatures from 5 to 27°C (41 to 80°F). The 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 emission standards for nonroad spark-ignition engines under 50 horsepower. As further detailed in the following sections, we expect that the 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 finalizing new exhaust standards.[91] 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 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 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).[92] 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.

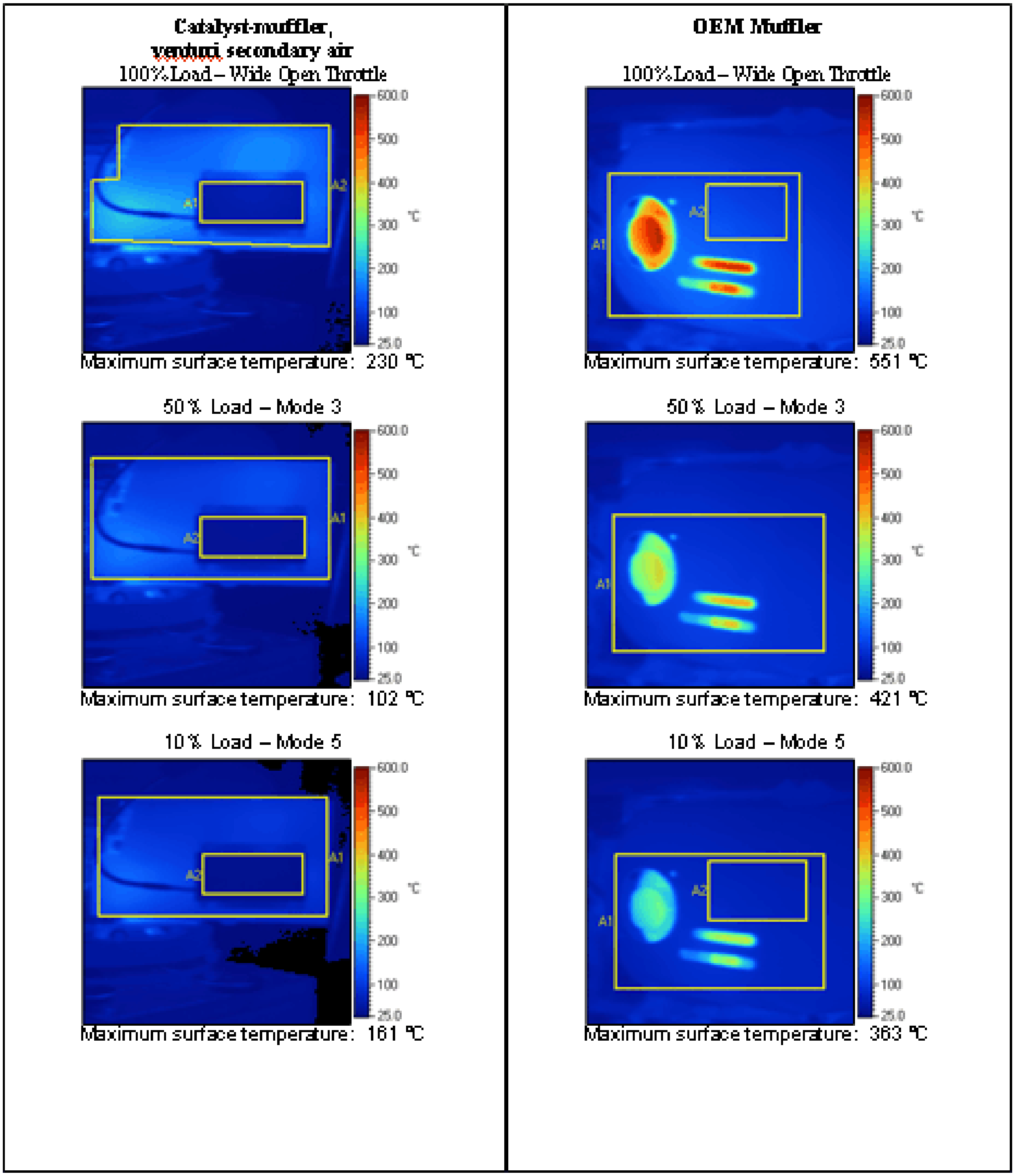


Figure 4.8-2: Hot Soak Surface Temperature Infrared Thermal Images of Exhaust System Components for Class 1 Engine 244 After Sustained Wide Open Throttle and 100 Percent Load.

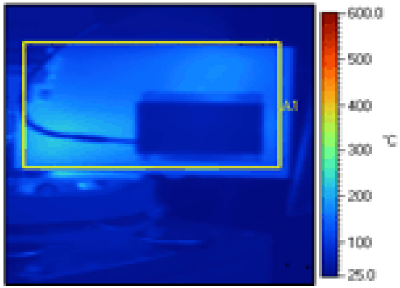
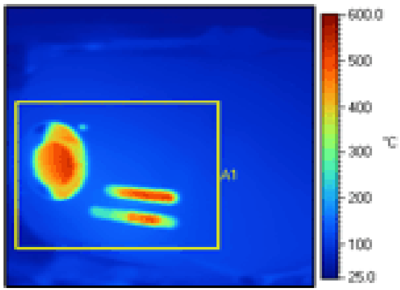
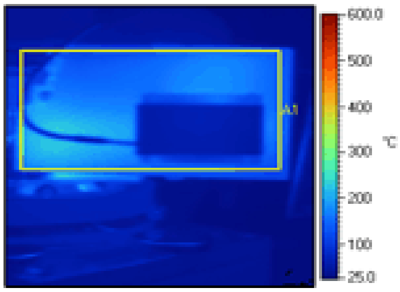
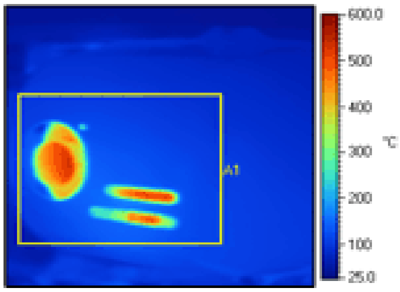
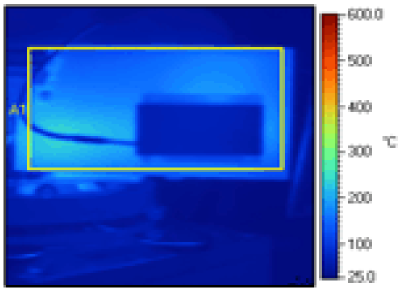
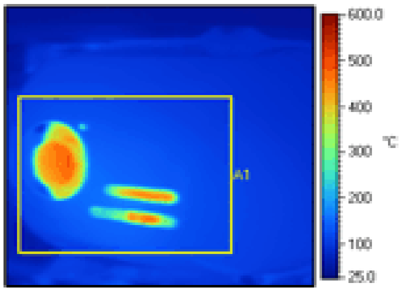
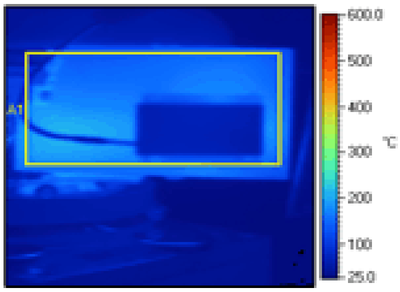
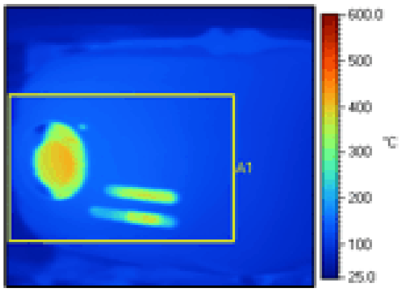
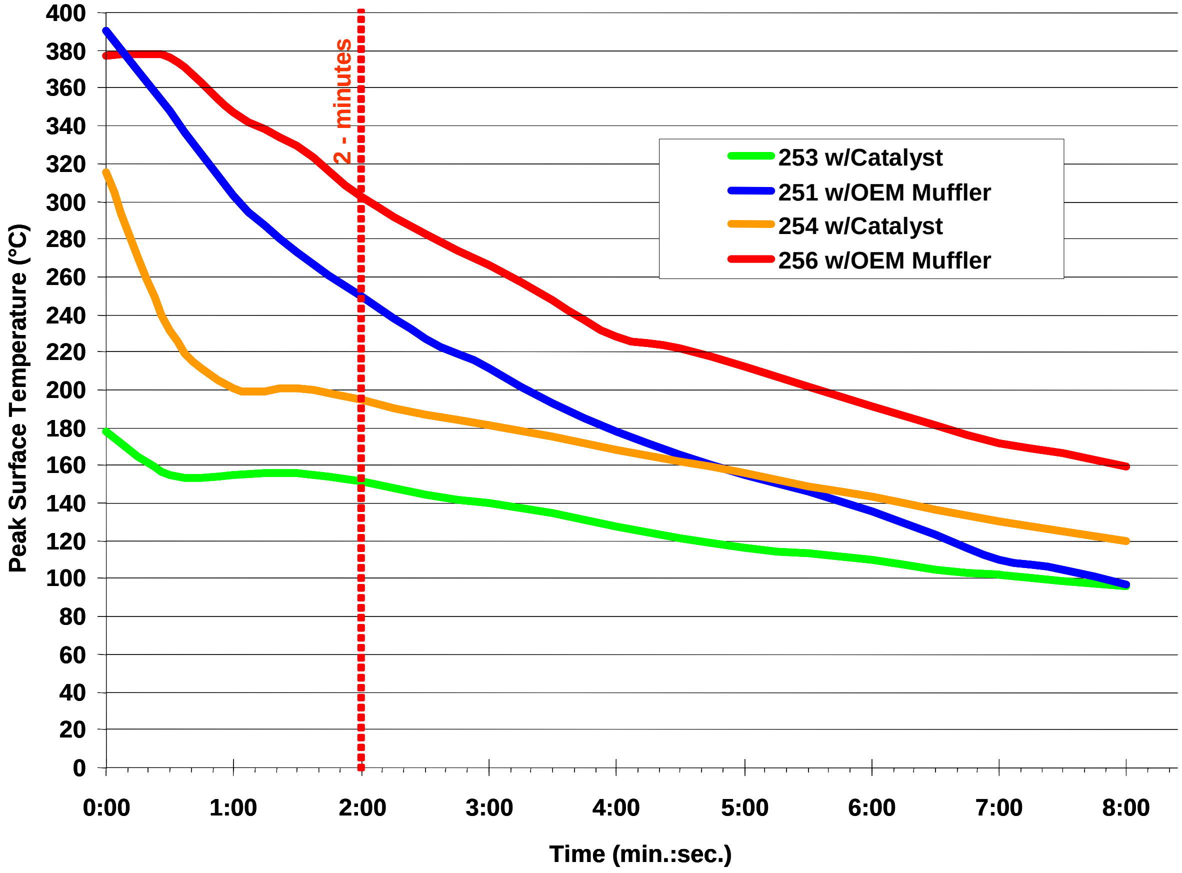
Modified Catalyst-muffler		OEM Muffler
 Maximum surface temperature: 228 °C	0-seconds	 Maximum surface temperature: 526 °C
 Maximum surface temperature: 234 °C	30-seconds	 Maximum surface temperature: 527 °C
 Maximum surface temperature: 240 °C	1-minute	 Maximum surface temperature: 483 °C
 Maximum surface temperature: 215 °C	2-minutes	 Maximum surface temperature: 418 °C

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 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 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 standard.

The conversion of some carbureted Small SI engines to fuel injection technologies is also expected to improve fuel economy. We estimate approximately 7 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 22 million gallons of gasoline in 2030 when all of the Class II engines used in the U.S. will comply with the 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

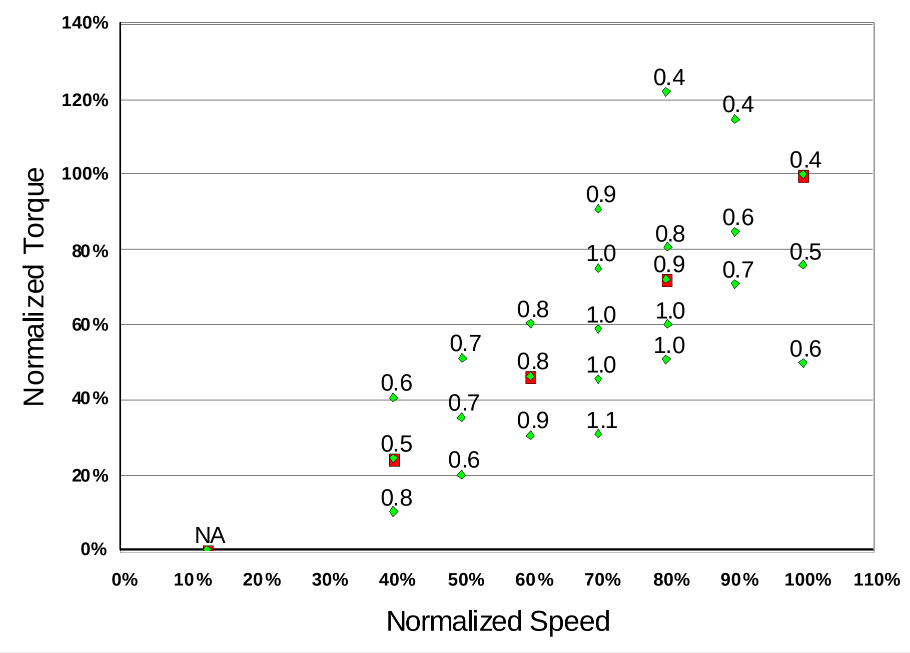


Figure 4A-2: CO Ratios for 7.4L MPI Engine, Baseline

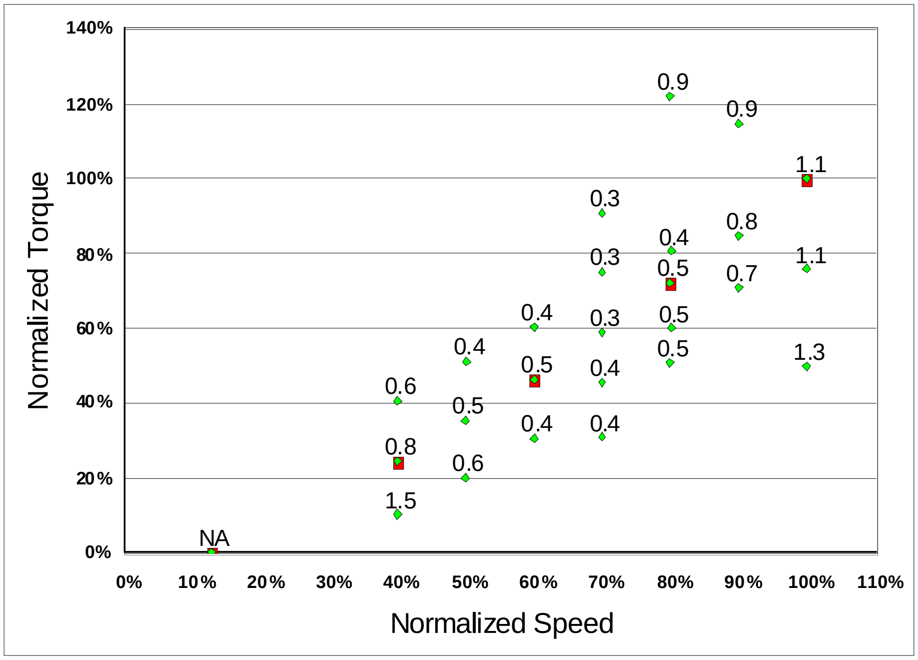


Figure 4A-3: HC+NOx Ratios for 7.4L MPI Engine, Riser Catalysts

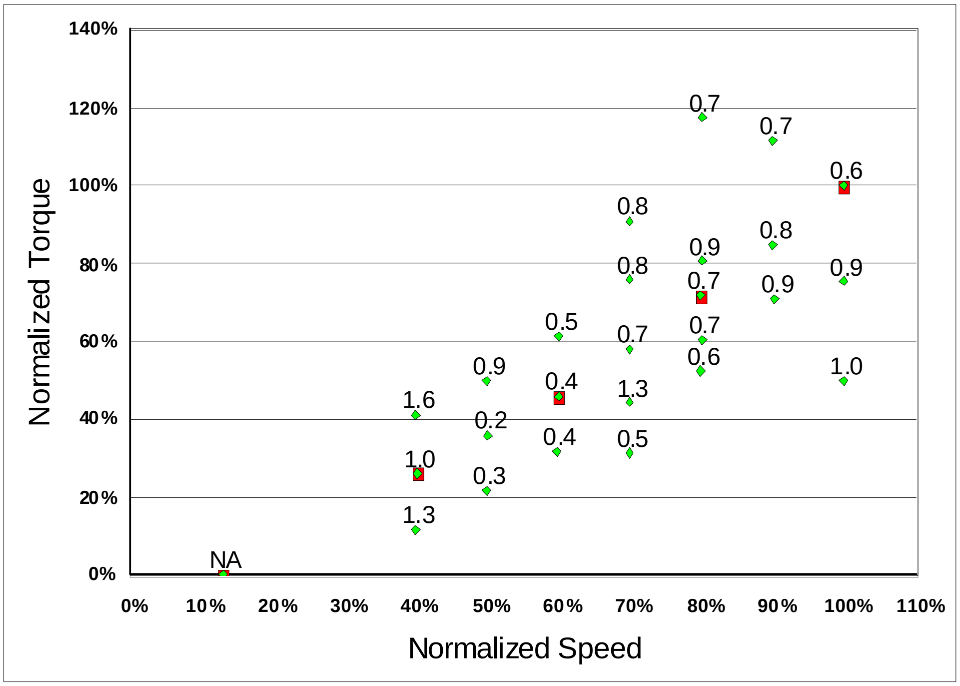


Figure 4A-4: CO Ratios for 7.4L MPI Engine, Riser Catalysts

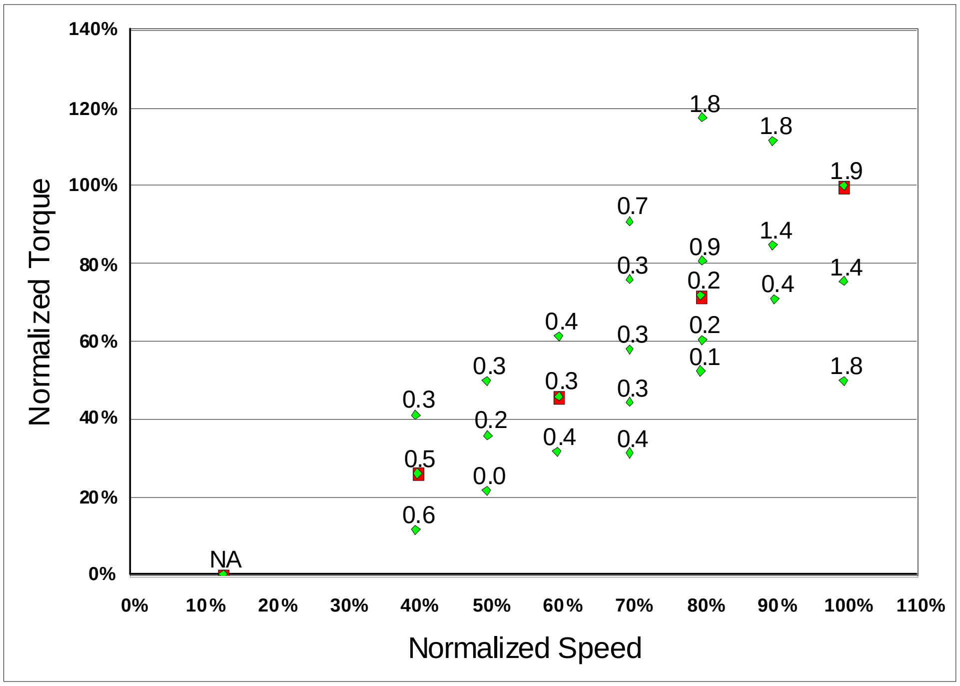


Figure 4A-5: HC+NOx Ratios for 7.4L MPI Engine, Elbow Catalysts

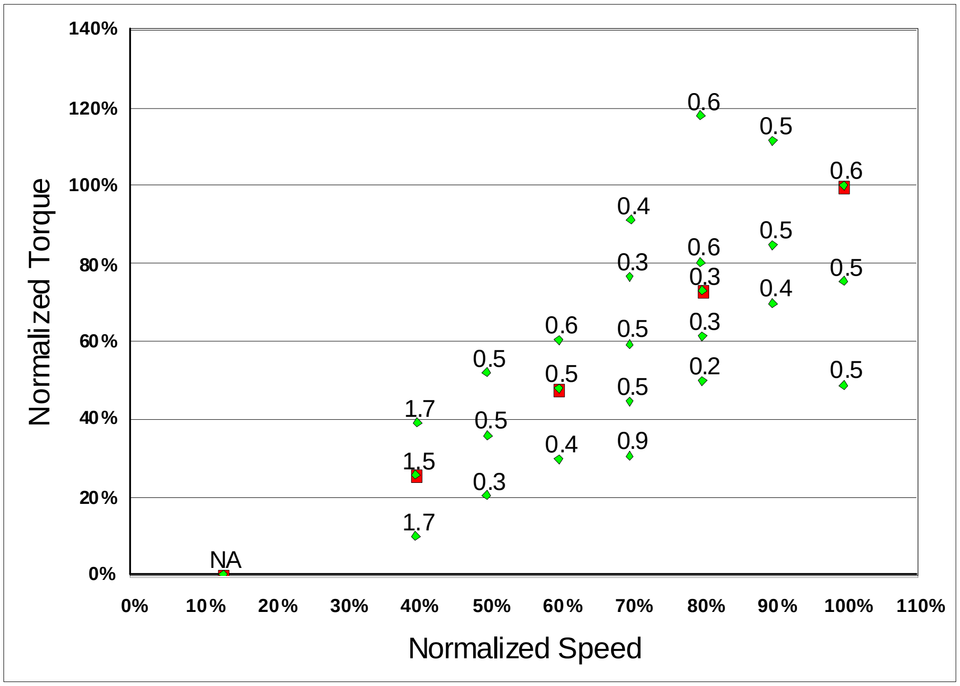


Figure 4A-6: CO Ratios for 7.4L MPI Engine, Elbow Catalysts

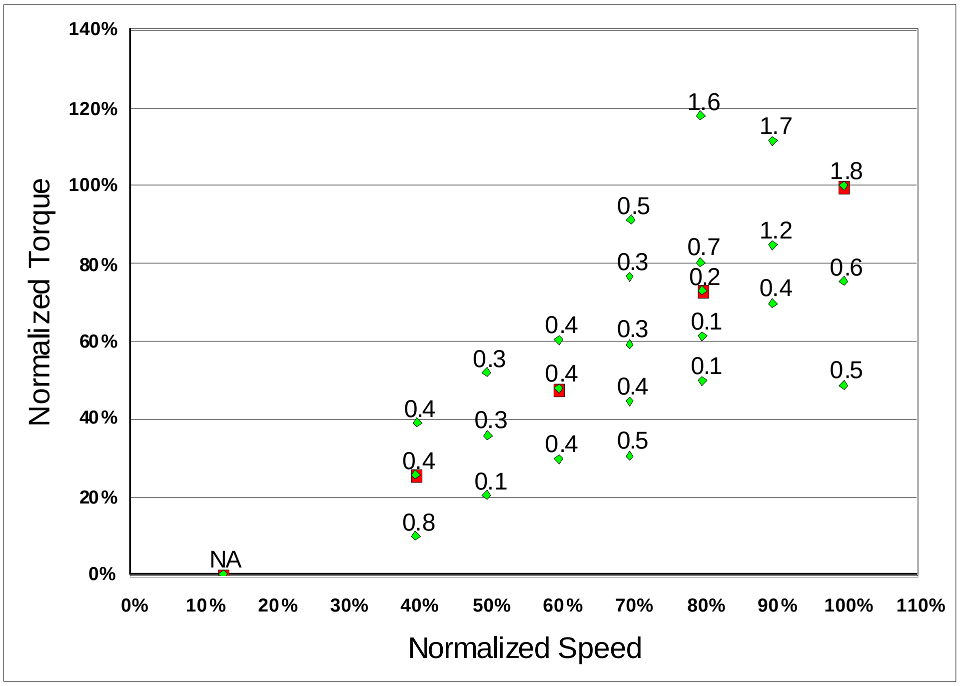


Figure 4A-7: **HC+NOx Ratios for 7.4L MPI Engine, External Catalysts**

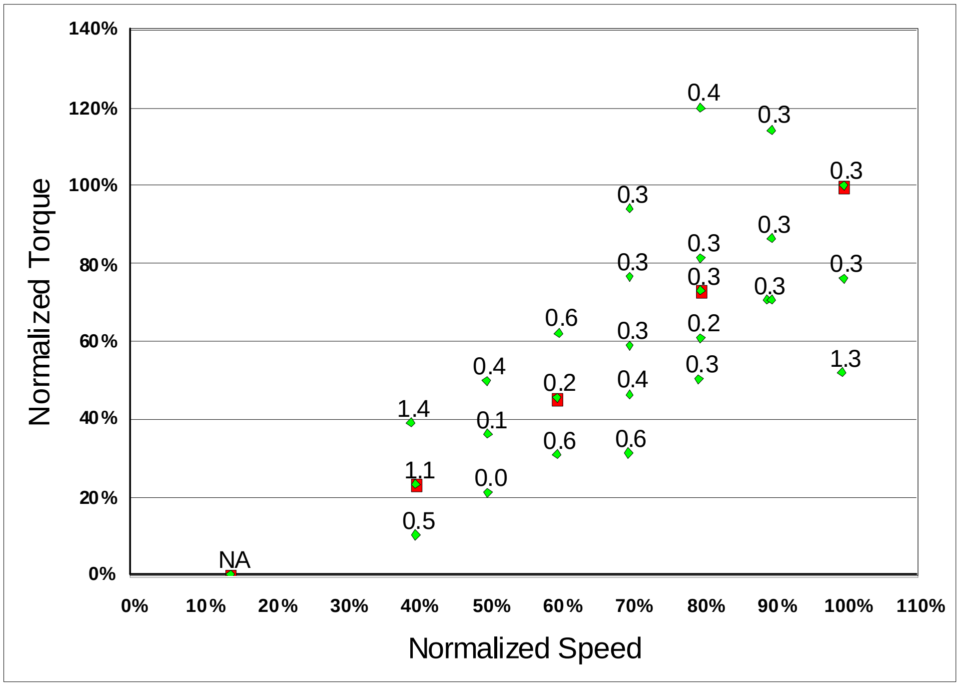
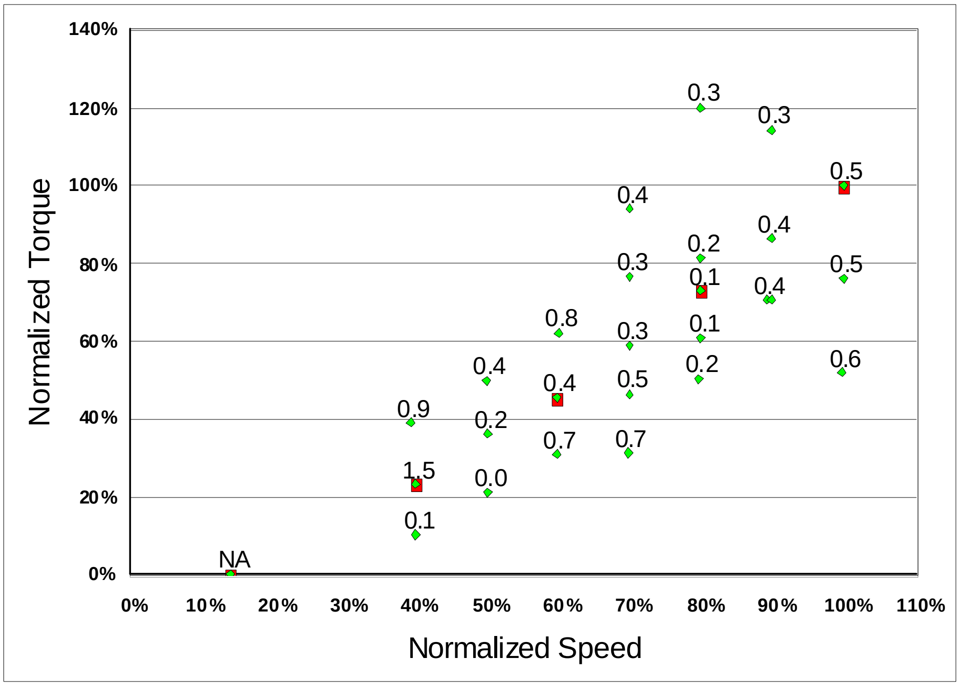


Figure 4A-8: **CO Ratios for 7.4L MPI Engine, External Catalysts**



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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 new evaporative emission standards are technically achievable accounting for all the above factors.

The 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 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 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 is about 4.5 psi. In this example, the partial pressure of the air is 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 is 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 is 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 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 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 due to increases in permeation caused by the ethanol or due to differences in fuel volatility. 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 profile of the fuel in the tank. 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 2002 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 corrected 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 open sites available 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%

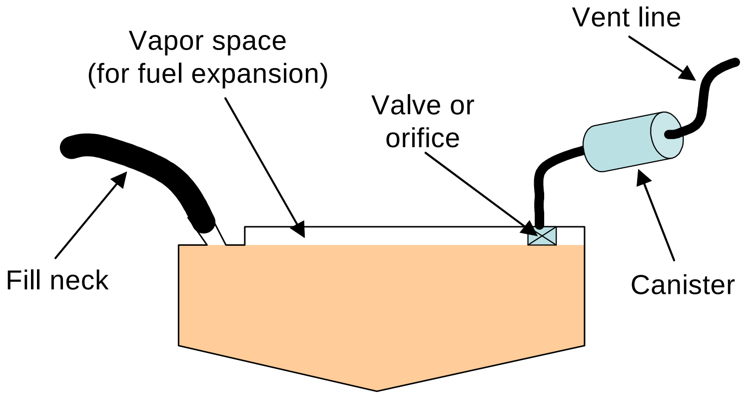
Marine manufacturers raised the concern that the high humidity in the areas where boats are used would be detrimental to this technology. They stated that the carbon could become saturated with water vapor, thereby reducing the available sites for hydrocarbon capture. These manufacturers also commented 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 performed a test program has to demonstrate the durability of carbon canisters in marine applications. This test program included installing carbon canisters on a total of fourteen boats made by four boat builders.[24] These boat types included 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 liquid 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 proper performance.[25]

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. In any case, as with the vent line, if the carbon canister is self-draining, then the canister would not likely hold the five ounces of fuel, specified in 33 CFR 183.558, to trigger the need for flame protection.

Manufacturers have raised the concern that it is common for liquid fuel to pass out the vent line during refueling. If there were a canister in the vent line it would become saturated with fuel. While this would not likely cause permanent damage to the canister, we believe marine fuel systems should prevent liquid fuel from exiting the vent line for both environmental and safety reasons. A float valve or small orifice in the entrance to the vent line from the fuel tank would prevent liquid fuel from reaching the canister or escaping from the tank. Any pressure build-up from such a valve would cause fuel to back up the fill neck and shut off the fuel dispensing nozzle. In addition, a vapor space should be included to account for fuel expansion. These fuel system design considerations are straight-forward, long used in other applications,[27] are applicable to boats,[28] and would have the added benefit of minimizing fuel spillage, from boats, into the water. One possible design for preventing fuel from reaching the canister, due to refueling, sloshing, or expansion, is shown in Figure 5.1-1.

Figure 5.1-1: Canister Installation Example



Recently, the California Air Resources Board (ARB) performed diurnal emission testing on a commercial mower and a generator with 6 gallon fuel tanks and 0.65 liter canisters.[29] 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.[30] 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.[31] 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 Yacht Council makes the additional recommendation that the vent line should have a minimum inner diameter of 7/16 inch.[32] 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 diurnal 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

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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.

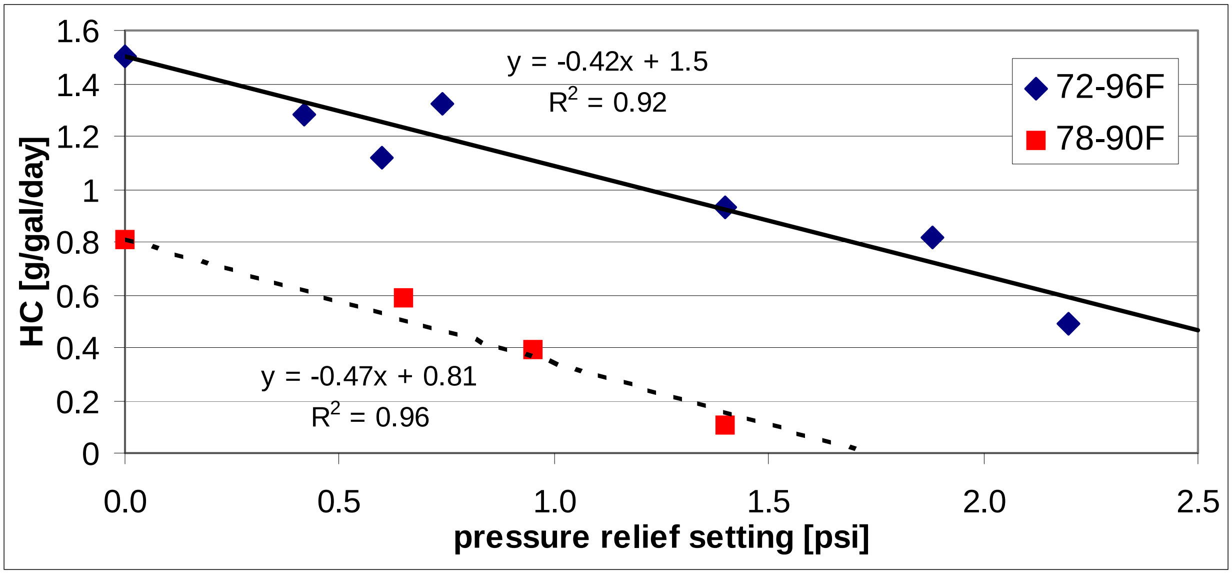
or valves used today may not work properly under 2 psi of pressure. Finally, they commented that backup pressure-relief valves would be necessary for safety. For smaller fuel tanks, such as used in personal watercraft, portable fuel tanks, and Small SI equipment, pressure is less of an issue because 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 5.1-2, there was a fairly linear relationship between the pressure setting of the valve and the emissions measured over the variable-temperature 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 5.1-2: Effect of Pressure Cap on Diurnal Emissions



Portable marine fuel tanks are generally equipped with a valve that allows the tank to be sealed when not in use. The valve must be opened during engine operation or the draw of fuel from the fuel tank can create a vacuum in the fuel tank. If the vacuum becomes too great, the engine will not be able to draw sufficient fuel from the tank and therefore stall. During storage, the valve may be closed to prevent fuel vapors from escaping. These fuel tanks are designed to withstand pressurization much greater than would be experienced when a fuel tank is heated by ambient temperature changes. However, this vapor control strategy relies heavily on user behavior. According to one survey, the majority of boat owners store their portable marine fuel tanks with fuel in them, and many do not close the vent during storage.[33] Therefore, significant emission reductions may be achieved with a sealed fuel tank with an automatic vacuum relief valve. This is discussed further in section 5.1.5.3 below.

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.[34] 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 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.[35] 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.[36] One of these uses is to act as a vapor processor to prevent hydrocarbon vapor from escaping from retail gasoline stations in California.[37] Another membrane used for similar applications allows hydrocarbons to permeate but blocks smaller gases. This membrane is used in hydrocarbon recovery applications.[38] 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 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 g/gal/day	72-96°F psi	78-90°F g/gal/day	78-90°F psi	81.6-86.4°F g/gal/day	81.6-86.4°F 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.[39] 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 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.

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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.

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.[40]

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.[41] In addition, THV is resistant to ethanol. Permeation rates for these materials are presented in Appendix 5D.

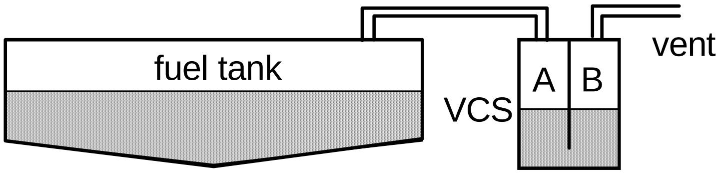
5.1.9 Floating Fuel and Vapor Separator

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

One company has developed a liquid vapor trap that it refers to as a fuel vapor containment system (VCS).[42] The VCS behaves similar to a liquid trap used in sink drains in that trapped

Figure 5.1-3: Liquid Vapor Trap



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 5.1-3 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.[43] 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.[44] 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.[45] 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.[46] 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	1.7	19.5	30.3	1.4
front tank near engine	1.1	15.7	28.4	1.0
Riding mower	6.5	24.3	33.2	7.8
rear tank away from engine	3.0	26.6	28.4	0.7
	2.5	27.0	35.0	3.2
Zero-turn riding mower	6.5 x 2	20.5	23.9	3.4
2 saddle tanks near engine	1.4 x 2	21.9	29.7	2.5
Walk-behind mower (plastic)	0.34	23.3	33.0	0.3
	0.25	28.7	46.7	1.2
Walk-behind mower (metal)	0.22	28.7	59.7	8.1
Generator set	8.5	20.6	25.8	1.8
	7.0	25.8	50.0	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.[47] 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.[48]

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.[49] 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[50] 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.[51,52,53,54,55] Table 5.3-3 presents a summary of this data which was collected using the ARB Test Method 513.[56] 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 standards using their current materials. In the cases where the permeation rates were higher than the 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 5.3-4a 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 5.3-4a: Permeation Rates for Handheld Fuel Tanks Tested by EPA at 29°C

Tank ID	Application	Material	Test Fuel	Permeation Loss [g/m^2/day]
R1 R2 R3	clearing saw (0.24 gallons)	nylon 6	gasoline E10 E10	0.34 0.42 0.48
B1 B2 B3 B4	hedge clipper (0.05 gallons)	nylon 6, 33% glass	gasoline E10 E10 E10	0.62 1.01 1.12 0.93
W1 W2 W3	chainsaw (0.06 gallons)	nylon 6, 30% glass	gasoline E10 E10	1.45 2.18 2.46
G1 G2 G3	chainsaw (0.06 gallons)	nylon 6, 30% glass	gasoline E10 E10	1.30 1.41 2.14

The handheld industry also tested a number of fuel tanks for their products.[57] In this testing, they investigated the effect of fuel type and gasket material on the permeation results. These test results suggested that permeation can be reduced significantly by using a low permeation material, such as FKM, for the seal on the fuel cap. In addition, data on aged tanks suggested that NBR o-rings may deteriorate in-use such that the permeation rate (or vapor leak rate) through the seal increases greatly. This test data is presented in Table 5.3-4b.

Table 5.3-4b: Permeation Rates for Handheld Fuel Tanks Tested by Industry

Tank Capacity	Tank Material	O-ring Material	Test Temp.	Test Fuel	Permeation Loss [g/m^2/day]
350cc	nylon 6, 30% glass	NBR NBR Aged NBR* New NBR*	28˚C	CE10	1.00 0.64 45.2 0.92
260cc	nylon 6, 30% glass	NBR	28˚C	CE10	1.31 0.64
773cc	nylon 6, 30% glass	NBR	40˚C	CE10 CE10 gasoline	3.58 2.60 1.10
400cc	nylon 6, 30% glass	FKM	40˚C	CE10	0.40
1538cc	nylon 6, 33% glass	NBR	40˚C	CE10	1.11
1538cc	nylon 6, 30% glass	NBR FKM	40˚C	CE10	1.42 0.37
530cc	nylon 6, 30% glass	NBR	40˚C	gasoline	1.55
400cc	HDPE	NBR (gasket)	40˚C	gasoline	17.5

* these units were used in the field prior to testing

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.[58,59] 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.[60] 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

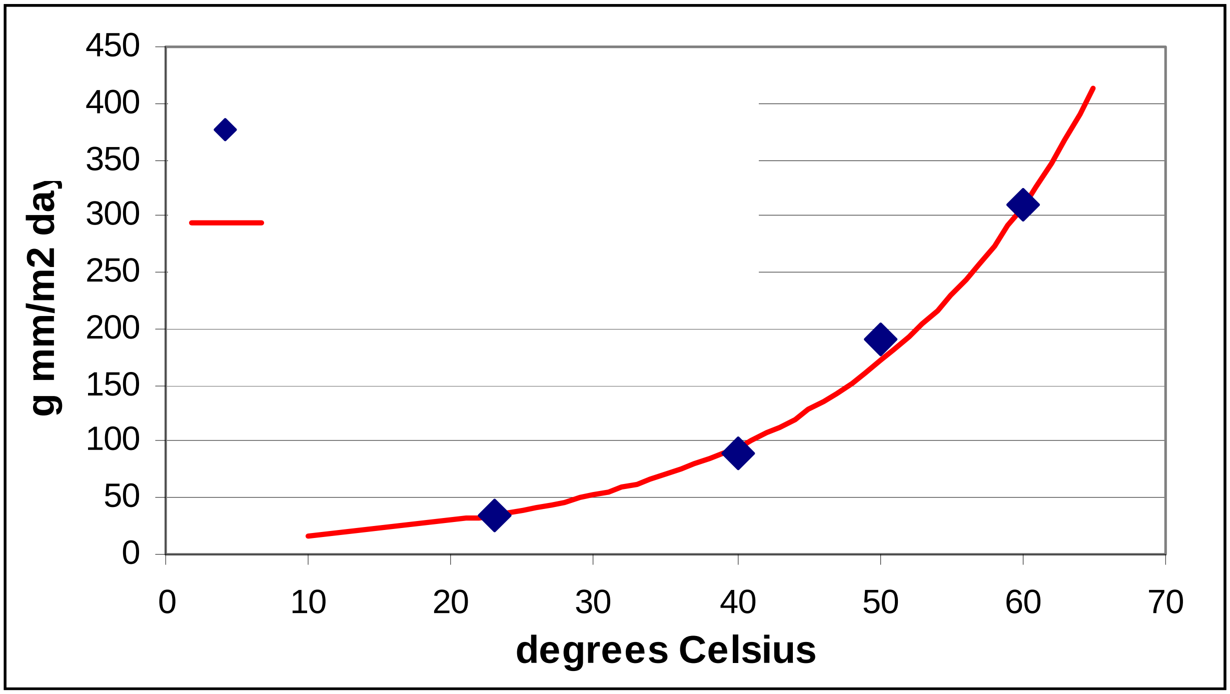
It is well known that the rate of permeation is a function of temperature. For most materials, permeability increases by about a factor of 2 for every 10°C increase in temperature.[61] To determine this relationship for nonroad fuel tanks, we performed permeation testing on nine HDPE Small SI fuel tanks 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/m^2/day]	36°C [g/m^2/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[62,63] 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.[64] 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

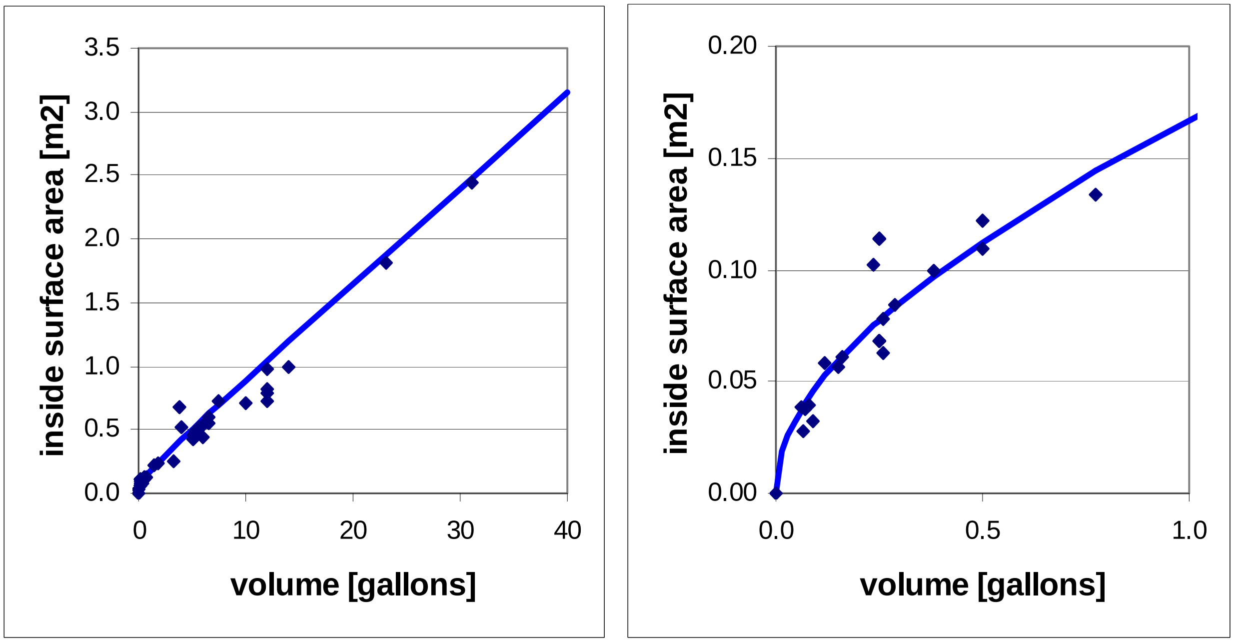
Fuel System	Fuel Tank	29°C [mg/hr]	40°C [mg/hr]	Increase per 10°C
2001 Toyota Tacoma	Metal	9	20	101%
2000 Honda Odyssey	Plastic (enhanced evap)	21	55	136%
1999 Toyota Corolla	Metal	10	24	124%
1997 Chrysler Town & Country	Plastic (enhanced evap)	23	52	110%
1995 Ford Ranger	HDPE	309	677	102%
1993 Chevrolet 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.[65,66,67,68] 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

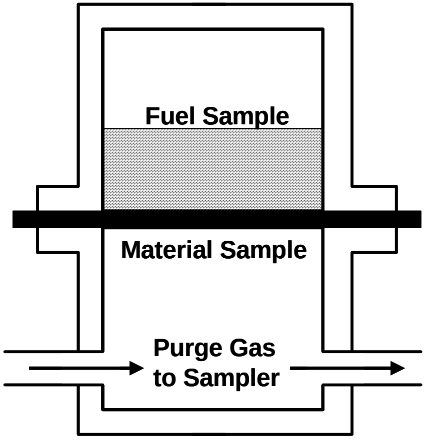


Table 5.3-8: Permeation Measured in Cup Method with Fuel Versus Vapor Fuel Exposure

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.[69] 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.[70] 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.[71] 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.[72] 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 1500	0.77 0.78
23 gallon cross-link PE	30 150 1350	0.64 0.67 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.[73]

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 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 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 durability testing requirements.

The California Air Resources Board (ARB) collected test data on permeation rates from sulfonated portable fuel containers using California certification fuel.[74] 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.[75]

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.[76,77] 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.[78] 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[79] which was less than half of what the CARB testing showed on their constant temperature test at 40°C.[80] A list of resins and additives that are compatible with the sulfonation process is included in the docket.[81,82]

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/m^2/day	10.4	10.4	10.4	10.4
Set #1 Sulfonated	g/m^2/day % reduction	0.73 93%	0.82 92%	1.78 83%	1.11 89%
Set #1 Sulfonated & Sloshed	g/m^2/day % reduction	1.04 90%	1.17 89%	2.49 76%	1.57 85%
Set #2 Average Baseline	g/m^2/day	12.1	12.1	12.1	12.1
Set #2 Sulfonated	g/m^2/day % reduction	1.57 87%	1.67 86%	1.29 89%	1.51 88%
Set #2 Sulfonated & Sloshed	g/m^2/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/m^2/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/m^2/day	13.9	13.7	14.4	14.0
Sulfonated	g/m^2/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.[83] 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.[84] 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 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 durability testing requirements.

The California Air Resources Board (ARB) collected test data on permeation rates from fluorinated fuel containers using California certification fuel.[85,86] 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.[87] 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.[88]

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.[89,90] 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 5.3-19a 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 5.3-19a: 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 5.3-19b presents this comparison.

Table 5.3-19b: 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 standard.

Table 5.3-20: 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%

The handheld industry also tested a number of fluorinated fuel tanks for their products.[91] This testing included three fuel types and two test temperatures. These test results suggest that fluorination may be used to significantly reduce permeation from handheld fuel tanks. Higher permeation rates were observed in CE10 than gasoline; however, it is not clear whether these impacts were due to increased permeation through the gaskets or through the tank. As shown earlier in Table 5.3-4b, the use of low permeation gasket materials can significantly improve permeation rates, especially on fuel CE10. This test data is presented in Table 5.3-21.

Table 5.3-21: Permeation Rates for Handheld Fuel Tanks Tested by Industry

Tank Capacity	Gasket Material	Test Temp.	Test Fuel	Permeation Loss [g/m^2/day]
695	NBR	28˚C	CE10	2.01 2.88
420	NBR	28˚C	CE10	1.46 1.32
400*	NBR FKM	40˚C	gasoline	0.56 0.64
252	NBR	40˚C	CE10 gasoline CE10 E10	2.94 0.84 1.95 1.40

* A similar, untreated, tank was measured to have a permeation rate of 17.5 g/m^2/day.

Another study also looked at the effect of alcohol in the fuel on permeation rates from fluorinated fuel tanks.[92] 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.[93] 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.[94]

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.[95] 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 Federal test procedure.[96] Under this testing, E10 fuel was used. Weight loss tests were performed before and after the durability tests in 40 CFR 1501.515.[97] 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 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	4.1	no
			0.39	5.9	no
			0.32	4.9	no
			0.36	5.4	no
			0.38	5.8	no
2	12 gallons	29 weeks	0.39	5.7	yes
			0.34	5.0	no
			0.42	6.2	no
			0.32	4.6	no
3	12 gallons	29 weeks	0.28	3.4	yes
			0.22	2.6	no
			0.22	2.8	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 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 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.[98] 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 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.[99] 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 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.[100] 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.[101]

Table 5.3-29: Permeation Results Acetal Copolymer Fuel Tanks at 29°C on E10

Material Name	Material Type	g/gal/day	g/m²/day
Vandar V1	thermoplastic polyester	1.7	5.6
Impact C10 Resistant C11 Celcon C13	modified acetal copolymer	0.13 0.09 0.10	0.75 0.53 0.59

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.[102] 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.[103] 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.[104]

Another study looks at the permeation rates, using ARB test procedures, through multi-layer fuel tanks.[105] 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%

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[4] Chemically modified montmorillonite for nanocomposite formulation

The California Air Resources Board tested two sets of three 5-gallon portable fuel containers.[106] 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 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

The handheld industry also tested a number of fuel tanks for their products that had been coextruded with an EVOH barier.[107] Even with NBR gaskets on the fuel caps, these tanks had permeation rates well below the new standards. This test data is presented in Table 5.3-32.

Table 5.3-32: Permeation Rates for Handheld Fuel Tanks Tested by Industry

Tank Capacity	Gasket Material	Test Temp.	Test Fuel	Permeation Loss [g/m^2/day]
1840	NBR	28˚C	CE10	0.23 0.26
470	NBR	28˚C	CE10	0.75 0.54

Another approach has recently been developed in which a multi-layer fuel tank can be blow-molded with only two layers.[108] 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.

Permeation emissions were measured on five 2.5 liter fuel tanks at 28˚C using fuel CE10.[109] During the preconditioning of these fuel tanks, the pressure-vacuum, slosh, and UV-exposure durability tests were performed. All of the testing was performed using stock fuel caps and gaskets. One of the fuel tanks showed considerably higher emissions than the others. This higher emitting tank was found to have an issue with the interface between the tank and the fuel cap. In general, the permeation rates were well below the tank permeation standard. These test results are presented in Table 5.3-33.

We also tested three test bottles and three fuel tanks made using this construction for permeation emissions. The test bottles were about 1.3 liters in volume and used a fluoropolymer gasket under the caps. The fuel tanks were similar to those described above. Each of the test bottles and tanks was filled with E10 and soaked for more than 20 weeks. Prior to the two week weight loss test, fresh fuel was added to each bottle/tank. As shown in Table 5.3-33, the measured permeation results were well below the new tank permeation standard.

Table 5.3-33: Permeation Results Ixef Barrier Test Bottles at 29°C on E10

Tank	Conditions	Preconditioning	g/gal/day	g/m^2/day
tank 1	28˚C, Fuel CE10	fuel soak, slosh, pressure-vacuum, and UV exposure	0.11	0.67
tank 2			0.14	0.87
tank 3			0.19	1.17
tank 4			0.13	0.80
tank 5[a]			0.34	2.07
tank 6	29˚C, Fuel E10	fuel soak	0.04	0.36
tank 7			0.19	1.80
tank 8			0.04	0.36
bottle 1[b]	29˚C, Fuel E10	fuel soak	0.05/0.02	0.26/0.12
bottle 2[b]			0.14/0.02	0.72/0.12
bottle 3[b]			0.07/0.02	0.39/0.12

[a] interface issue reported with cap

[b] repeated test with epoxy seal on fuel cap

Tanks 6-8 and bottles 1-3 were tested by EPA using screw on fuel caps with gaskets. For the test bottles, gaskets were cut at EPA from FKM rubber. It was thought that the permeation results were affected by the seal at the fuel cap. Therefore, the tests were rerun 6 months later using epoxy as a secondary seal at the fuel cap. As a result, much lower permeation rates were measured for all three test bottles. For the fuel tanks, the stock fuel caps and gaskets were used. One of the tanks had significantly higher permeation emissions than the other two tanks. This difference may have been a seal issue at the fuel cap.

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.[110] 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.[111] 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 5.3-34. The manufacturer reported that this tank design passed testing on the Coast Guard burn, pressure, shock, and impulse test requirements.[112,113,114,115] In addition, a tank of this construction was tested and passed the tank durability tests for snowmobiles specified in SAE J288.[116] 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 5.3-34: 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.[117] 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 5.3-35 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 5.3-35: ARB Fuel Tank Executive Orders for Small Offroad Equipment

EO#	Test Fuel	$g/m^2/day$
C-U-05-005	CE10	0.81
	Phase II	0.18
C-U-06-014	CE10	0.10
	CE10	0.00
	CE10	0.09

There is another approach to dual-layer rotomolded fuel tanks under development that uses a "single shot" approach to molding.[118] 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.[119] 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.[120] 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.[121] 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 5.3-36 presents the test results for each of the three tests.

Table 5.3-36: Permeation Results Multilayer Thermoformed Fuel Tanks at 29°C on E10

Soak (weeks)	Tank	g/gal/day	g/m²/day
27	#16	0.01	0.15
	#21	0.01	0.05
35	#16	0.01	0.07
	#21	0.01	0.09
44	#16	0.01	0.11
	#21	0.00	0.04
Average	#16	0.01	0.11
	#21	0.01	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 5.3-37, show that this technology can be used to reduce permeation emissions by more than 90 percent.

Table 5.3-37: 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.[122] 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 5.3-38 presents the test results after a 9 week fuel soak at 40°C.

Table 5.3-38: Permeation Data: Epoxy Coated HDPE Fuel Tanks at 40°C on CA Cert Fuel

Fuel Tank	g/gal/day	g/m^2/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.[123]

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.[124] 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[125] (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.[126]

We collected test data on marine hose permeation through contracts with outside laboratories.[127,128,129,130,131] Data was also available on a fuel feed hose testing funded by the marine industry.[132] 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.[133] 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.[134] 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[135] 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.[136] 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.[137] In this modified procedure, E10 fuel was used and the testing followed a 30 day fuel soak intended to stabilize the permeation rate. Further testing was later performed by industry on similar fuel lines exposed to E10 and to CE10.[138] This testing showed much higher permeation on CE10 than on E10 for these hose samples. Table 5.4-4 presents the test results.

Table 5.4-4: Handheld Product Fuel Line Permeation Test Data [23˚C]

Hose ID	Construction	Test Fuel	Material	g/m^2/day
90014	extruded	E10	NBR	198
90015				192
90016				168
S3				165
S4				171
H1				360
H2				455
B1*				205
B2*				224
S1	molded	E10	NBR	198
S2			NBR/PVC	386
C*			NBR/PVC	270
B1*	extruded	CE10	NBR	742
B2*				662
E*	molded	CE10	NBR	1148
F*			NBR/PVC	736
A*			NBR/PVC	975

* average of 5 measurements

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.[139] 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.[140] 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.[141,142] 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.[143] 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.[144] 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.[145] 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.

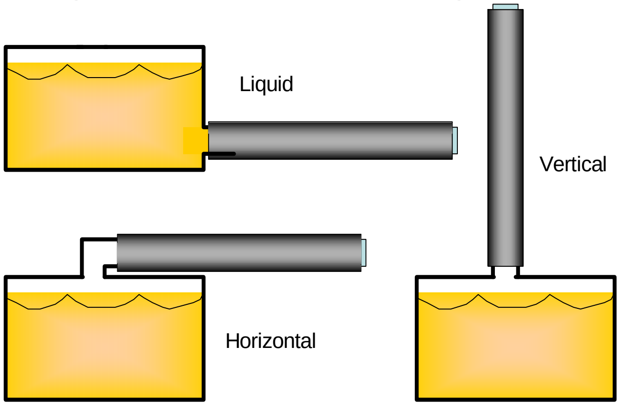
Table 5.4-9: Industry Permeation Data on Marine Fill Neck Hose [g/m^2/day]

Hose manufacturer	Vapor Exposure	Liquid Exposure
#1	4.8, 4.8	129
	4.5, 4.4	114
	4.7, 4.8	113
	4.7, 4.7	121
#2	1.3, 1.1	5.6
	0.6, 6.9	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.[146] 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 10 weeks. Fuel soaking was performed at 40˚C.

Figure 5.4-1: Hose Test Configurations



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.[147] 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.[148] 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.[149] 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.[150] 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.[151,152]

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 requiring 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[153] 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.[154] 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).

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 hose permeation standard on CE10 fuel. Although hose using THV 800 is available, it is produced for automobiles that must meet the tighter evaporative emission requirements in the Tier 2 standards. Hose produced in mass quantities today uses THV 500. This hose is less expensive and could be used to meet the 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.[155] In addition, this data shows that permeation rates more than double when tested on CE10 versus Fuel C.

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[5] THV = tetrafluoroethylene hexafluoropropylene, ECO = epichlorohydrin/ethylene oxide

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.[156,157,158,159,160,161] 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.[162] 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.[163]

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 were available prior to our 2002 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.[164,165,166,167,168,169]

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.[170] 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.[171] 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 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 2002 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.[172] 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).[173] This particular fuel line construction also uses Teflon® as a barrier layer. Table 5.4-19 presents permeation test data on this hose.[174]

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 fuel line permeation standard. Alternatively, primer bulbs could be manufactured to meet the 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).

One manufacturer has developed a low-permeation primer bulb replacement that meets the hose permeation standard.[175,176] This design uses a rigid, low permeation housing in the shape of a traditional primer bulb. However, it uses a simple piston displacement pump inside to take the place of soft elastomer squeeze type bulb. It is designed to have similar dimensions to existing primer bulbs and to be easily retrofitted into current applications.

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.[177] 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.[178] 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.[179,180] 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.[181,182] For instance, low temperature o-rings are common in automotive applications.[183,184,185] 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.[186] 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.[187] 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.[188] 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 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.[189,190] 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.[191] 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.[192]

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.[193] 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 is 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 gives 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.[194] 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.[195] 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.[196] 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 Fuel line Permeation Testing

Fuel line permeation must be measured at a temperature of 23 ± 2°C using the weight loss method specified in SAE J30[197] and SAE J1527.[198] 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 care has been taken to ensure that no air bubbles are trapped in the fuel line, 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 including 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[199] (50 percent toluene, 50 percent iso-octane) blended with 10 percent ethanol.[6] This fuel is known as CE10 and is commonly used in industry standards and test procedures such as in SAE recommended practices (including SAE J1527). 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 using a soak period of 8 weeks at 23 ± 5°C. If a longer time period is necessary to achieve a stabilized permeation rate for a given hose design, we 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. In addition, we are clarifying that the weight loss measurement period should be two weeks.

Alternatively, for purposes of submission of data at certification, permeation could be measured using alternative equipment and procedures that provide equivalent results. One alternative approaches that we anticipate manufacturers may use are the recirculation technique described in SAE J1737.[200] To use other alternative methods, such as enclosure-type testing such as in 40 CFR part 86, manufacturers have to apply to us and demonstrate equivalence. In enclosure testing, manufacturers would need to show how they would account for the ethanol fraction of the permeate.

Recommended practice for automotive fuel tubing is defined in SAE J2260.[201] 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.[202]

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

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[6] An exception to this is that fuel IE10 may be used for cold-weather fuel lines.

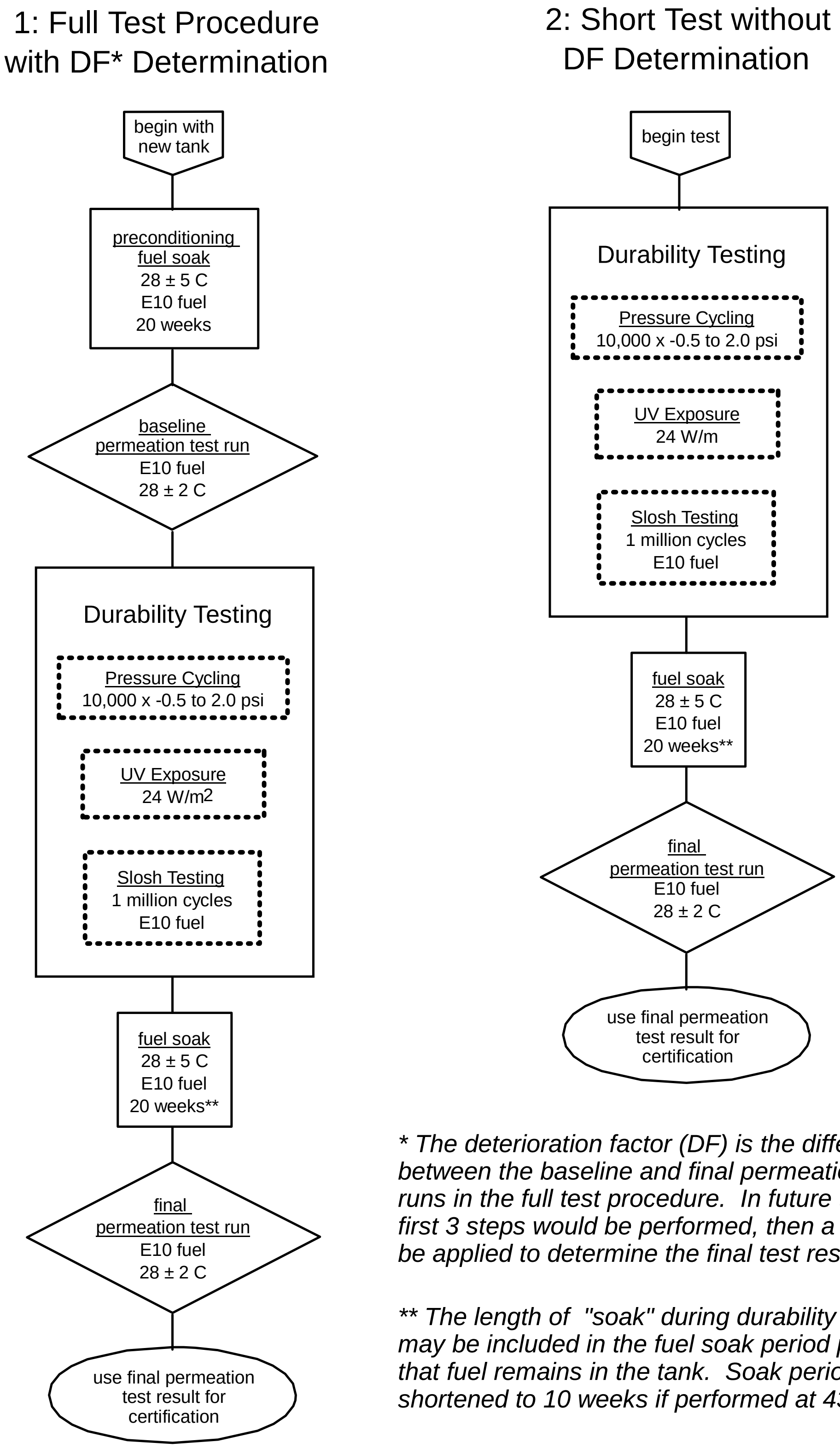
measure these low permeation rates. In addition, this procedure requires exposing the material to be tested for hundreds of hours, depending on the material and fuel, to reach a steady-state permeation rate. In this procedure, fuel is heated to 60°C and circulated through a tube running through a glass 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 applying 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 differences in the test procedure compared to recreational vehicles are minor and are intended to simplify the testing. For instance, the durability testing is 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 (2) compared to the recreational vehicle test (1) 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



** 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) is 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 slosh test, is acceptable.

To determine a permeation emission deterioration factor, we established 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.[203] 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. Only fuel tanks using surface barrier treatments or barriers consisting of post-processing coatings are subject to the slosh and pressure-vacuum tests. In addition, a fuel tank that is only used in vehicles where an outer shell prevents the tank from being exposed to sunlight may not be subject 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 is 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 much of the fuel sold in the U.S. contains ethanol and this percentage is expected to increase dramatically in 2012 and later. The fuel tank permeation test fuel is 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 would allow testing on ASTM Fuel C blended with 10 percent ethanol (Fuel CE10). 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.[204] 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 [205,206,207,208] 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[a]	69[a]	-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	--[b]	7.5 8.5	minimal

[a] ASTM Fuel C was used as gasoline (50% toluene, 50% isooctane). Units are per mm of thickness
[b] 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 requiring E10 as a test fuel to ensure that the permeation standard will be met on in-use fuels.

One study found that permeation from automotive fuel systems increased significantly when gasoline containing ethanol was used compared to gasoline without ethanol.[209] 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.

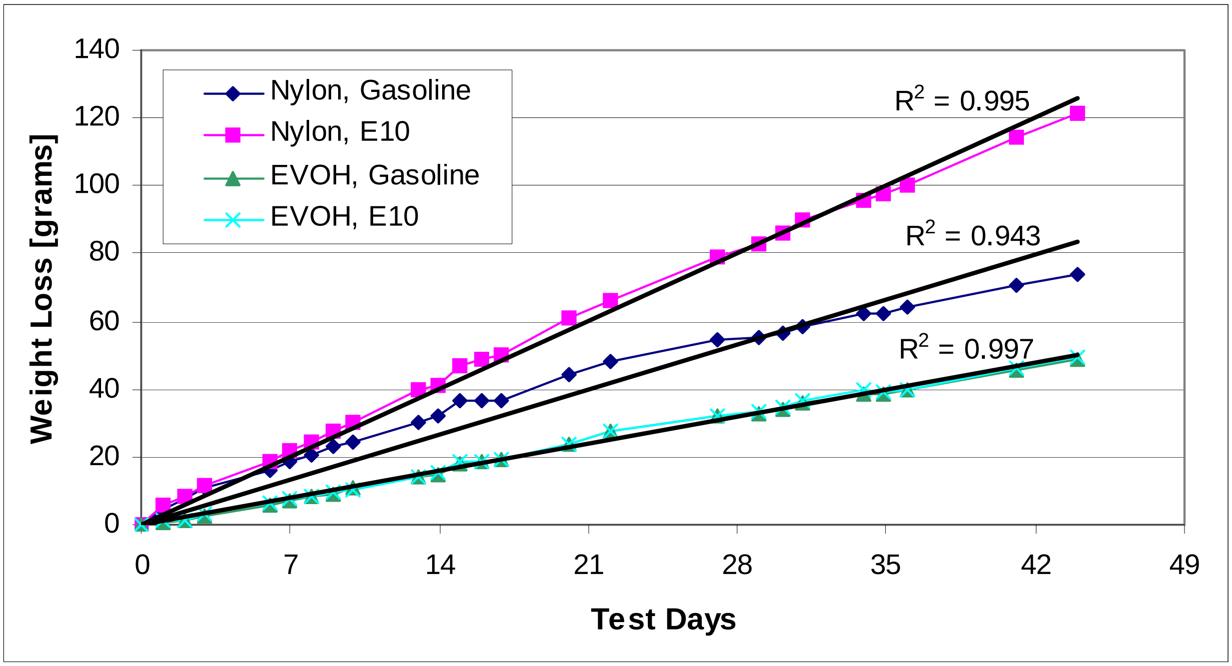
Table 5.6-2: Effect of Ethanol on Permeation from Automotive Fuel Systems

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 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 are 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 will 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 standard when tested on fuel CE10. The fuel tank with a continuous EVOH barrier was well below the 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.[210]

One testing laboratory presented data to EPA on their experience with variability in weight loss measurements when performing permeation testing on portable fuel tanks.[211] 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.[212]

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 is tested without fuel in it and used as a reference fuel tank. Dry sand can be added to this tank to make up the difference in mass associated with the test tank being full of fuel. The reference tank is then sealed so that the buoyancy effect on the reference tank is the same as the test tank. The measured weight loss of the test tank can then be corrected by any measured changes in weight in the reference tank. The California Air Resources Board uses this approach for measuring portable fuel tank emissions, and they refer to the reference tank as a “trip blank.”[213]

5.6.2.4 Engineering Design-Based Certification

A metal fuel tank automatically meets the design criteria for a design-based certification as a low-permeation fuel tank, subject to the restrictions on fuel caps and seals described below. There is also a body of existing test data showing that co-extruded fuel tanks from automotive applications have permeation rates that are well below the new standard. We are allowing design-based certification for co-extruded high-density polyethylene fuel tanks with a continuous ethylene vinyl alcohol (EVOH) barrier layer. The EVOH barrier layer is required to be at least 2 percent of the wall thickness of the fuel tank. In addition, the ethylene content of the EVOH can be no higher than 40 mole percent.

To address the permeability of the gaskets, and seals used on metal and co-extruded tanks, the design criteria include a specification that seals (e.g. gaskets and o-rings) not made of low-permeation materials must have a total exposed surface area less than 0.25 percent of the total inside surface area of the fuel tank. For example, consider a four gallon fuel tank with an inside surface area of 0.40 square meters. The total exposed surface area of these seals on the fuel tank, in this example, must be smaller than 1000 mm^2 (= 0.25%/100 × 0.40m^2 × 1,000,000 mm^2/m^2). This is consistent with the proposed rule and the current requirements for recreational vehicles, but allows for larger seals for larger tanks. In addition, if a non-metal fuel cap is directly mounted to the fuel tank, the surface area of the fuel cap (determined by the cross-sectional area of the fill opening) may not exceed 3.0 percent of the total inside surface area of the fuel tank.

A metal or co-extruded fuel tank with a fuel cap and seals that meet these design criteria would be expected to reliably pass the standard. However, we believe it is not appropriate to assign an emission level to fuel tanks using a design-based certification option that will allow them to generate emission credits. Given the uncertainty of emission rates from the seals and gaskets, we will not consider these tanks to be any more effective than other fuel tanks meeting emission standards.

In the case where the fuel cap is directly mounted on the fuel tank, we consider the cap and associated seals to be part of the fuel tank. As discussed above, we allow the fuel cap to be tested either mounted on the fuel tank, or individually. As an alternative to testing the fuel cap, the manufacturer may opt to use a default permeation rate of 30 g/m^2/day. To be eligible for this default rate, the seal on the fuel cap must be made of a low-permeation material, such as a fluoroelastomer. The surface area associated with this default value is the cross sectional area of the opening that is sealed by the fuel cap. If this default value were used, the fuel fill would be sealed with a non-permeable plug during the tank permeation test, and the default permeation rate would be factored into the final result.

For the purposes of this provision, we consider low-permeation materials to be those that haves 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.[214]

5.6.3 Diurnal Emission Testing

The test procedure for diurnal emissions is to place the fuel tank in a SHED[7], vary the temperature over a prescribed profile, and measure the hydrocarbons escaping from the fuel tank. The final result is reported in grams per gallon where the grams are the mass of hydrocarbons escaping from the fuel tank over 24 hours and the gallons are the nominal fuel tank capacity. The test procedure is based on the automotive evaporative emission test described in 40 CFR part 86, subpart B, with modifications specific to marine applications.

5.6.3.1 Temperature Profile

For installed marine fuel tanks, we believe that the fuel temperature profile observed in the tank has 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 sees 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 consider a boat that is at or below 8.5 feet in width and below 26 feet 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 established a

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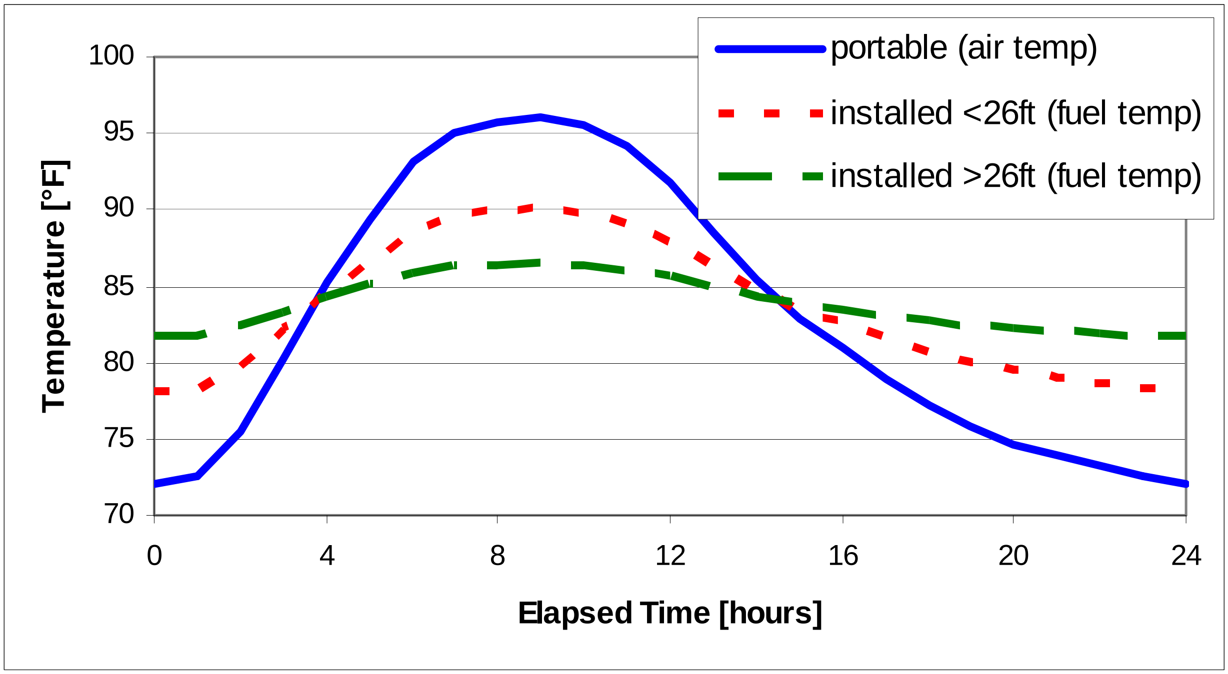
[7] Sealed Housing for Emission Determination

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 and at or below 8.5 feet in width. For larger boats, we established a test temperature profile of 81.6-86.4˚F (27.6-30.2˚C). These test temperature profiles are 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: 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 established 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 using a different approach. Prior to the first day of testing, the canister is loaded to full working capacity, then run over the diurnal test temperature cycle to allow one day of passive purging. The test result is then 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 is necessary. Prior to the first day of testing, the fuel is stabilized at the initial test temperature. Following this stabilization, the SHED is 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 established 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, the test must take place using certification gasoline with a vapor pressure of 9.0 RVP. We do not 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, the fill level at the start of the test must be 40 percent of the nominal capacity of the fuel tank. Nominal capacity of the fuel tank is 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,” is not considered in the nominal capacity of the fuel tank.

5.6.3.3 Tank Configuration

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, open vent marine fuel tanks that are designed with a connection for a vent line must 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 standards are 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 is appropriate to correct for permeation. In such a case, the permeation rate could be measured from the fuel tank and subtracted from the final diurnal test result. The fuel tank permeation rate has 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 is 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 needs 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 will 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 is not removed after the diurnal test, and the second permeation test begins within 8 hours of the end of the diurnal test.

5.6.3.4 Carbon Canister Engineering Design

Design-based certification may be used 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 standards. The following discussion outlines the requirements that are 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.[215]

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 is 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 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. The BWC of the carbon must be at least 9 g/dL based on the test procedures specified in ASTM D5228-92.[216] 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, the ASTM procedure 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 requiring 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 trailerable boats (<26 feet in length and ≤8.5 feet in width). For larger boats, the fuel temperature may be less affected by diurnal temperature swings for two reasons. First, these fuel tanks are in larger vessels which are more likely to be stored in the water and therefore, subject to smaller temperature fluctuations. Second, these fuel tanks are generally larger and have larger thermal inertia in the fuel which may lead to lower temperature fluctuation. Therefore, for fuel tanks installed on non-trailerable boats (≥26 feet in length or

>8.5 feet in width), the design minimum volume is 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 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.[217]

Design-based certification requirements for humidity resistance are 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.[218]

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 including 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. Pellet strength must be at least 85 percent. The test procedure is ASTM D3802-79[219] 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 uses twenty ½" steel balls and ten ¾" steel balls rather than fifteen of each as specified in ASTM D3802-79. These 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.[220]

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). In addition, to prevent flow restriction, the carbon granules must have a minimum mean diameter of 3.1 mm based on the procedures in ASTM D2862.[221]

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.[222] 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 is important that a carbon canister system be appropriately integrated into the fuel system. For instance, the canister must be positioned in the vent line, and potentially a liquid separation valve added, to ensure that liquid fuel does not reach the canister during refueling. We 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, is not 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 do 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 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 will be about 1.4 gallons for an average piece of Small SI equipment and 28 gallons for an average boat. This translates to a fuel savings of about 45 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. is expected to have evaporative emission control.

5.7.3 Safety

As part of the development of this rule, EPA performed a technical study on the safety of emission control technology for Small SI equipment and Marine SI vessels.[223] 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.[224] 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 do 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 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 need to pass these standards and every indication is that they will 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 will 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 evaporative emissions standards will 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

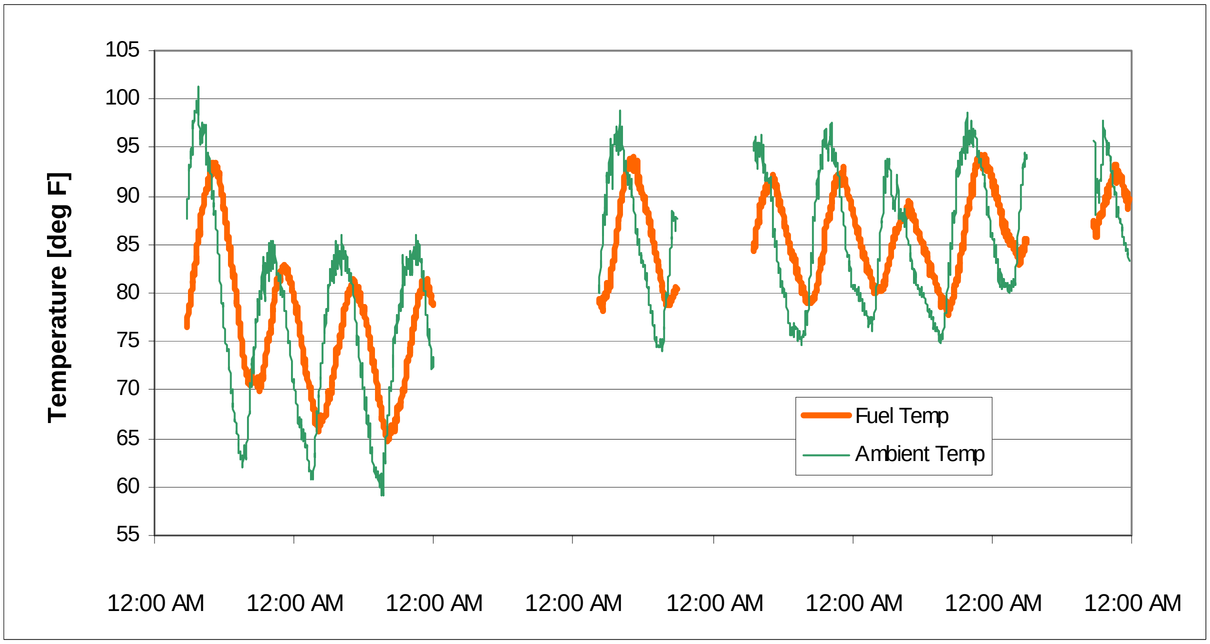


Figure 5A-2: Temperature Trace for Jet Boat on Trailer

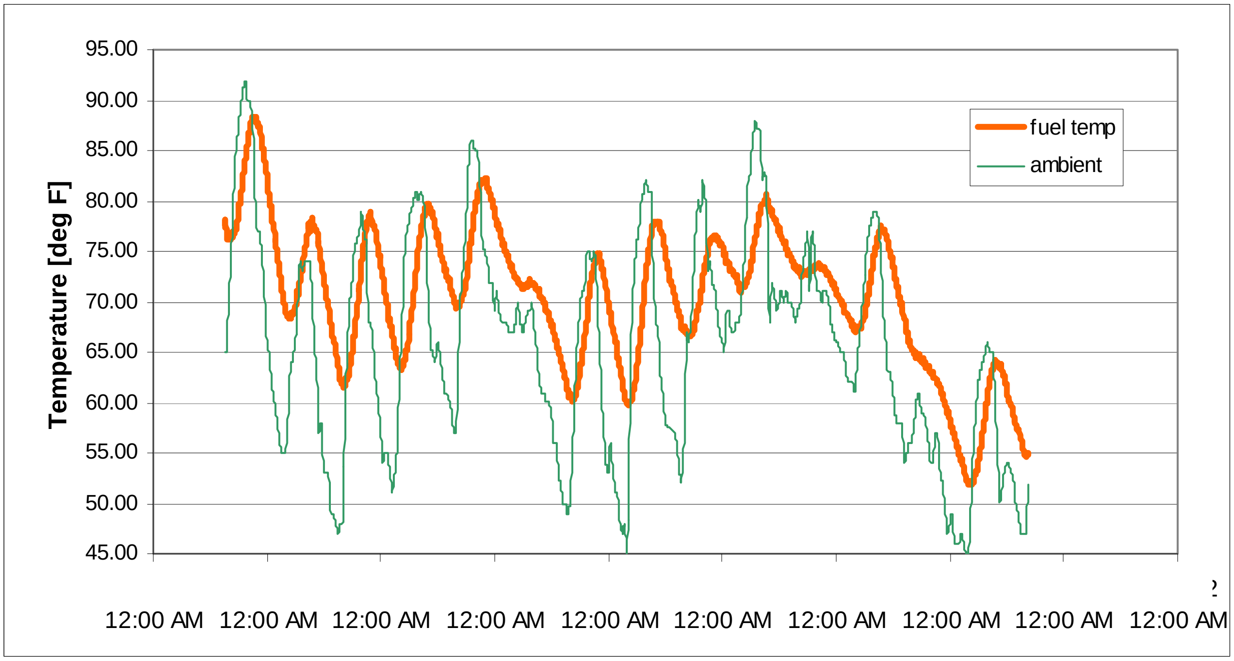


Figure 5A-3: Temperature Trace for Runabout on Trailer

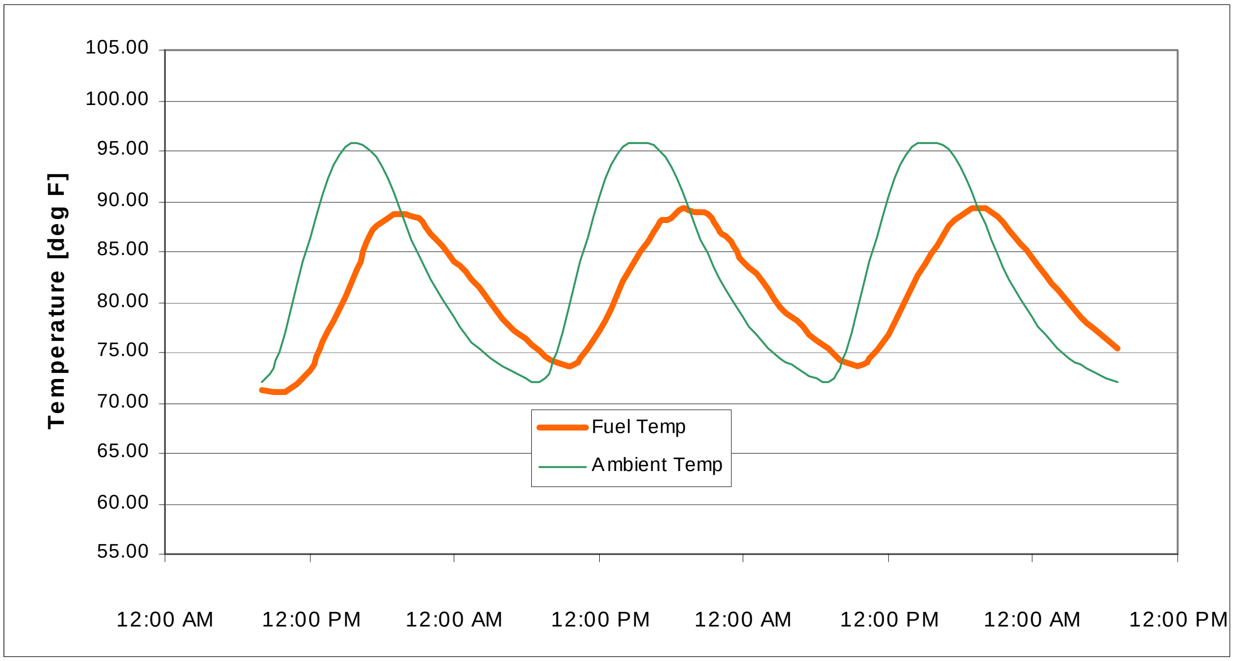


Figure 5A-4: Temperature Trace for Jet Boat on Trailer

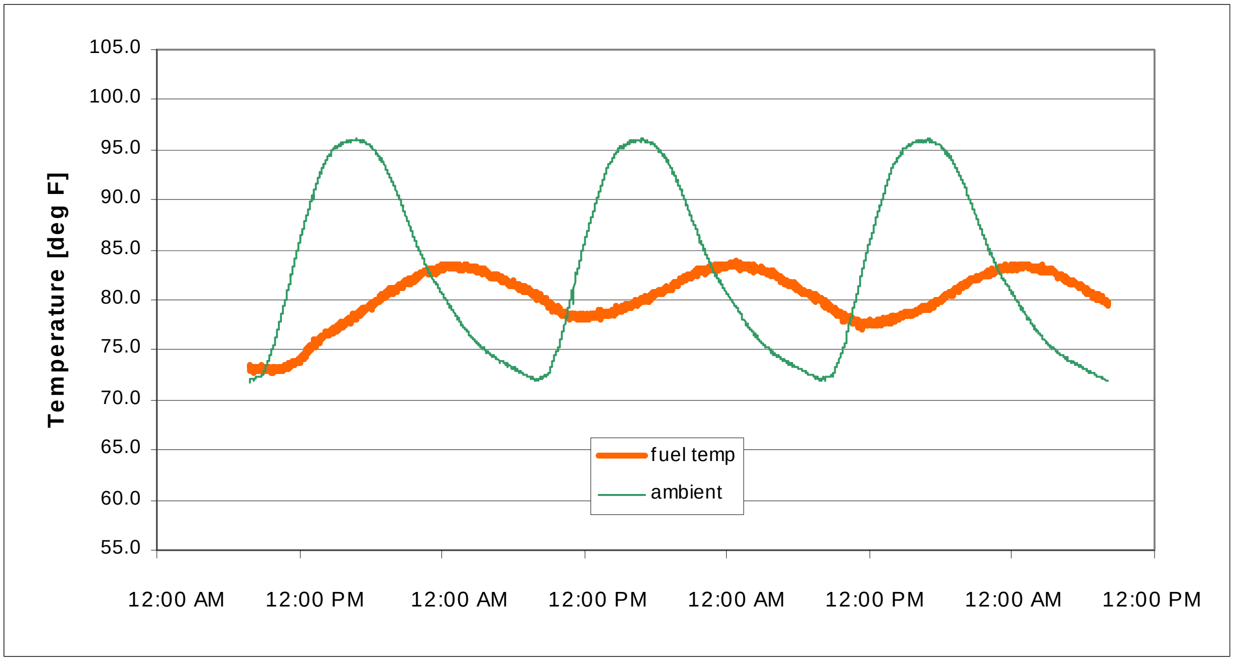


Figure 5A-5: Temperature Trace for Runabout in Water

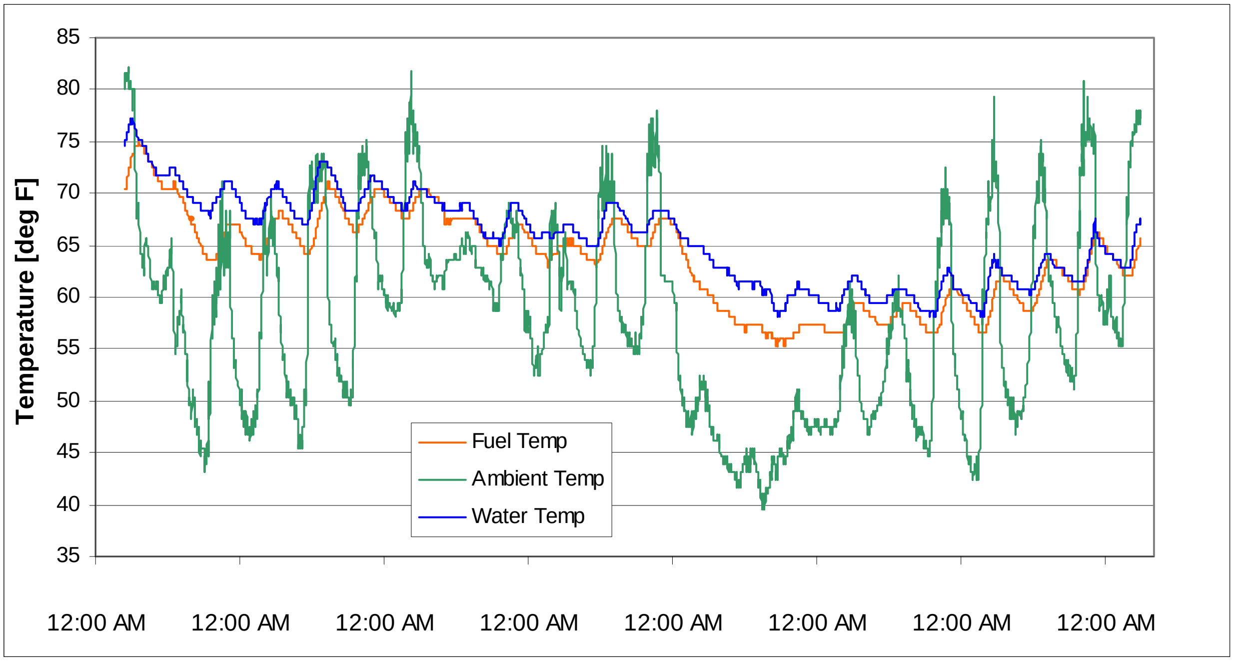
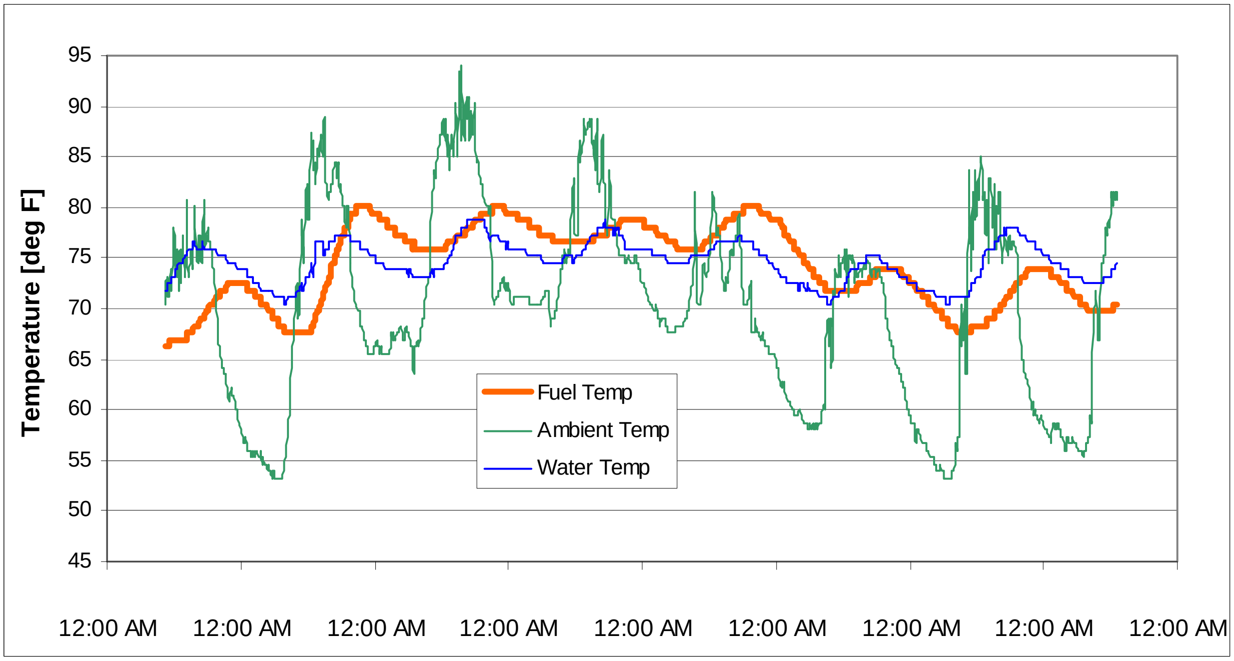


Figure 5A-6: Temperature Trace of Deckboat in Water



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)

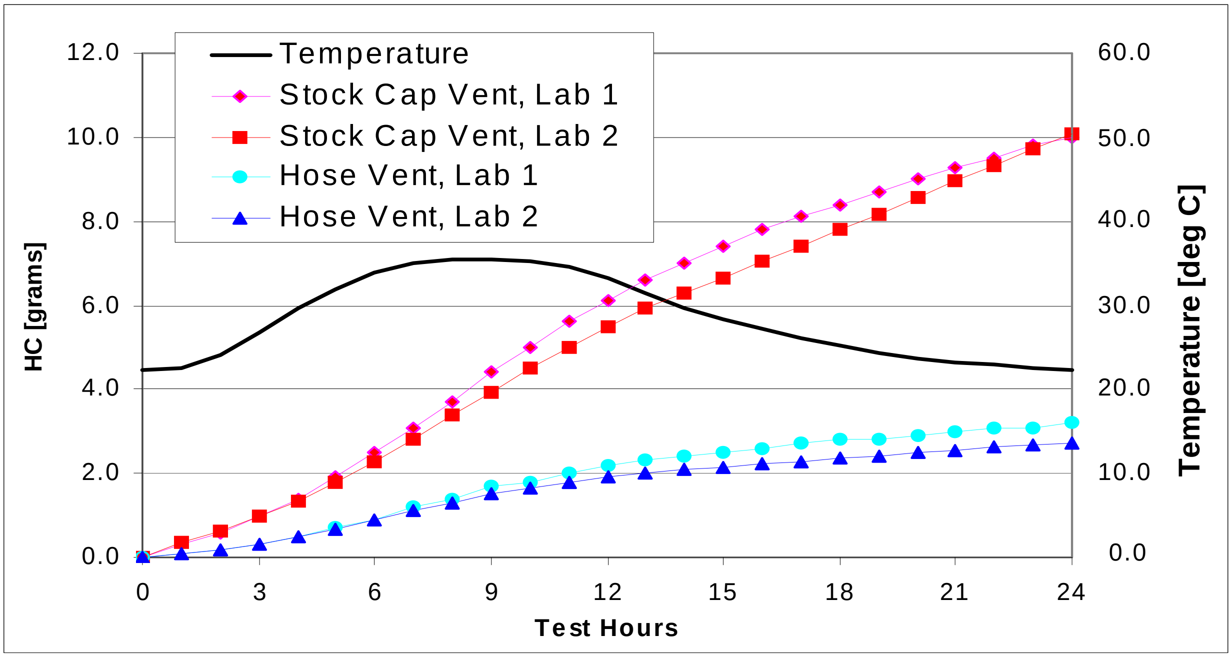


Figure 5B.1-2: Diurnal/Diffusion Test Results for BP Plastic Fuel Tank

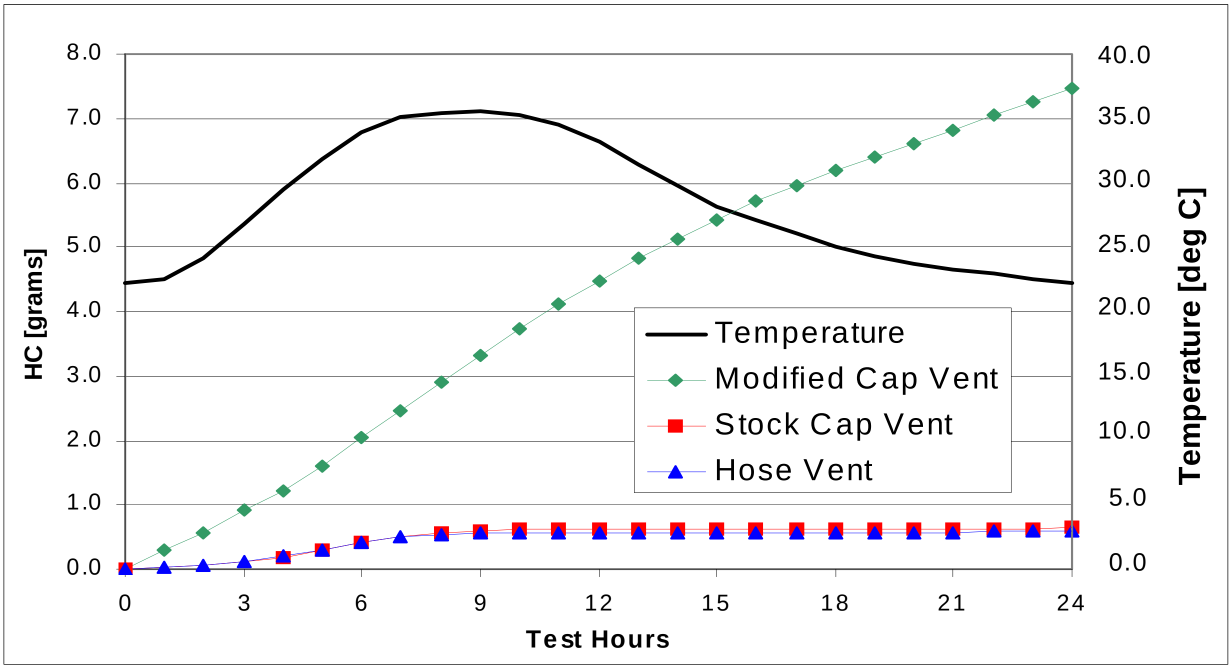


Figure 5B.1-3: Diurnal/Diffusion Test Results for HP Plastic Fuel Tank

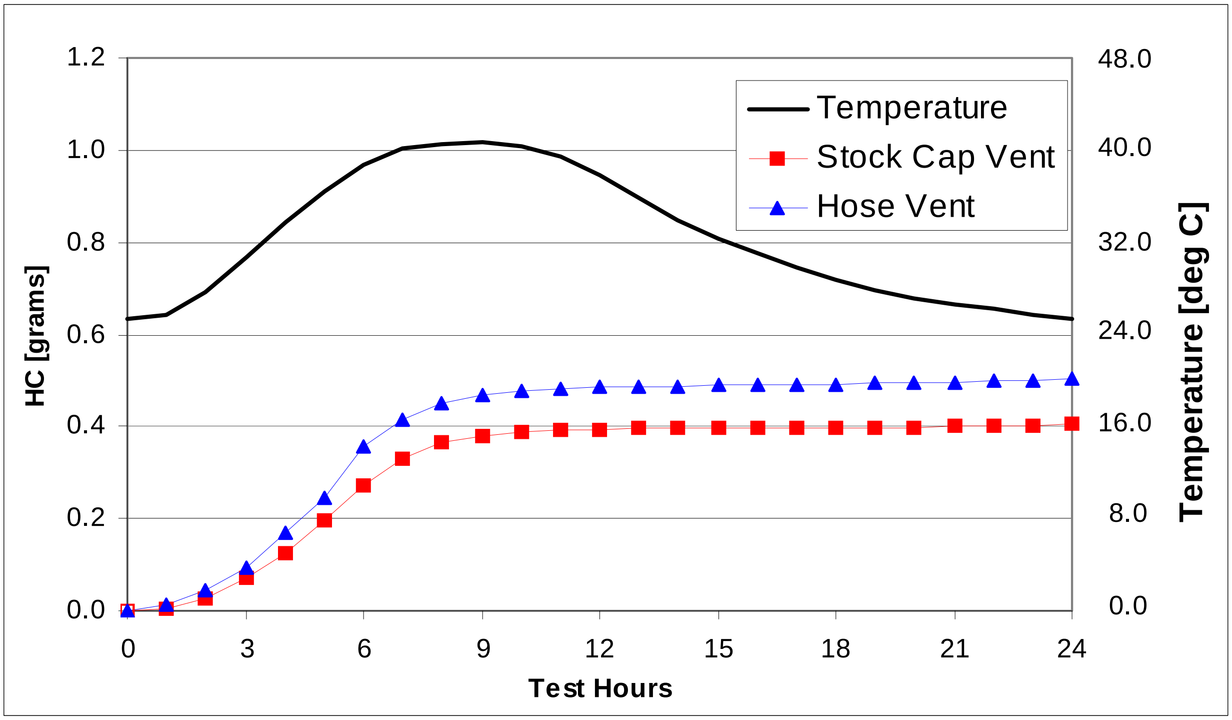
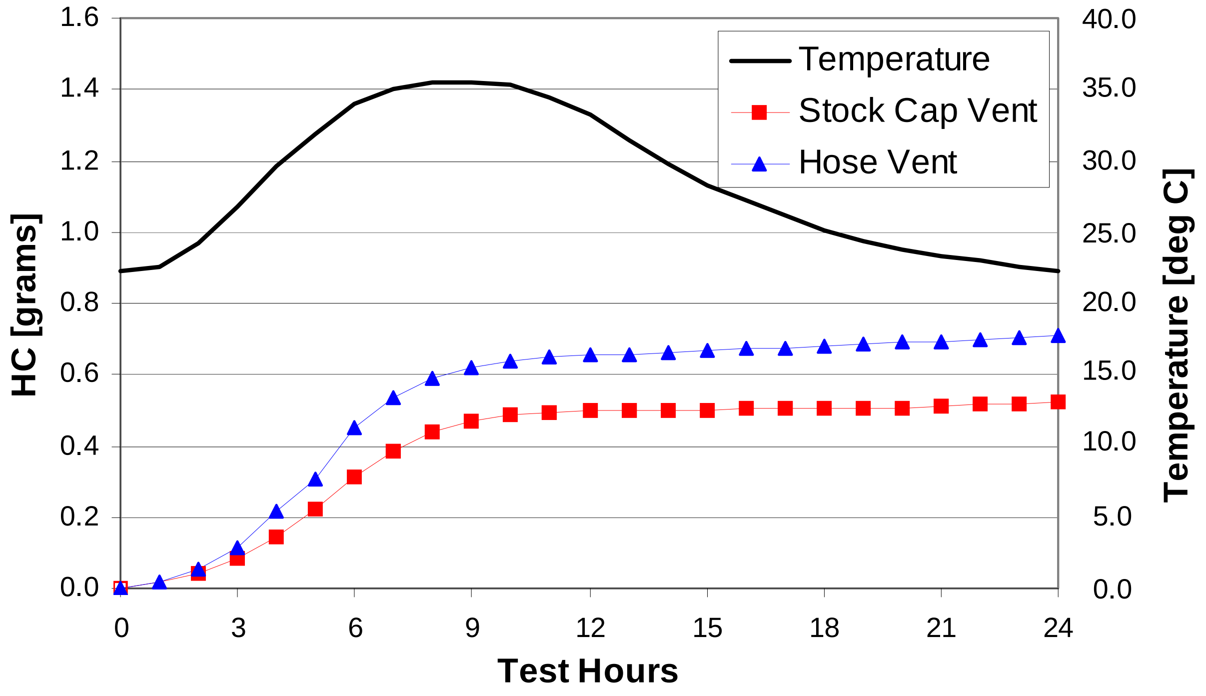


Figure 5B.1-4: Diurnal/Diffusion Test Results for TP Plastic Fuel Tank



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

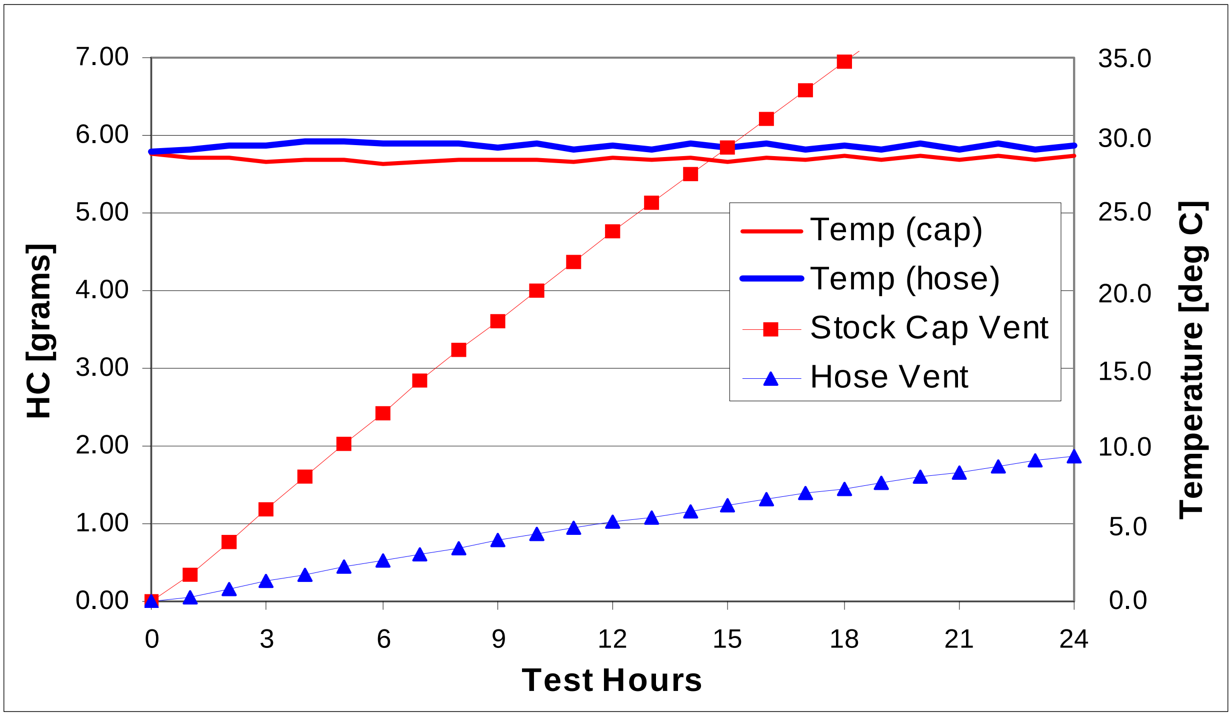


Figure 5B.2-2: Isothermal Diffusion Test Results for BP Plastic Fuel Tank

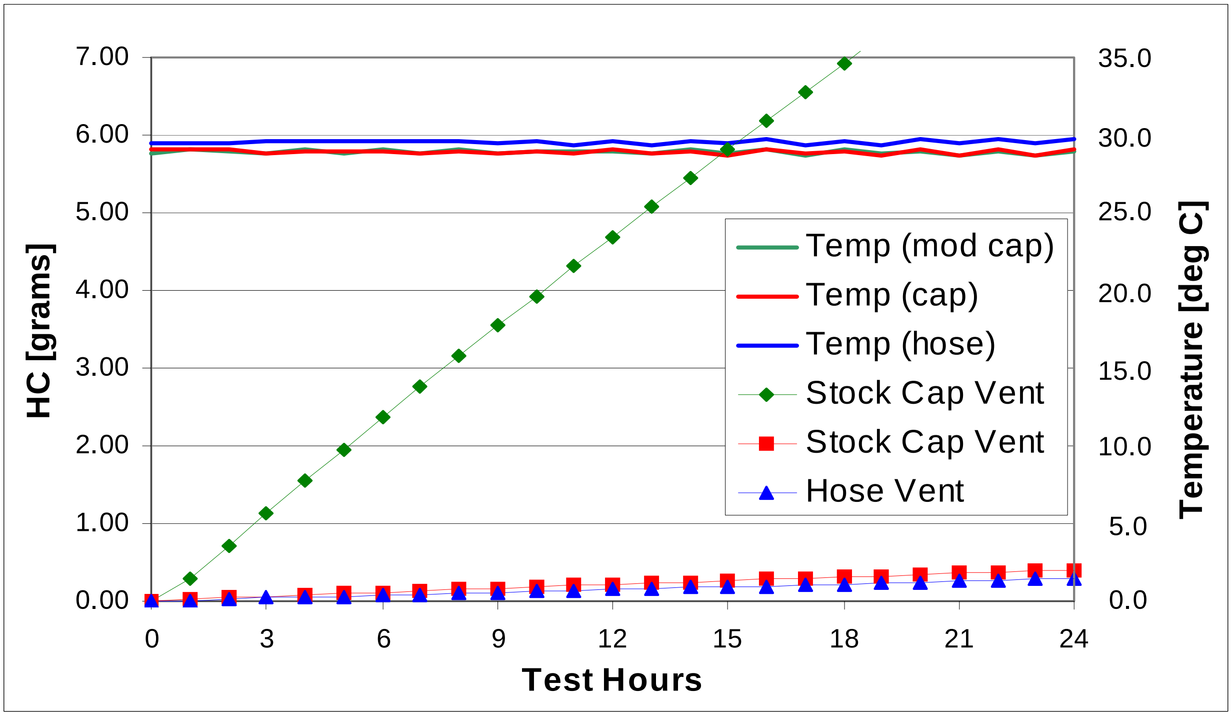


Figure 5B.2-3: Isothermal Diffusion Test Results for HP Plastic Fuel Tank

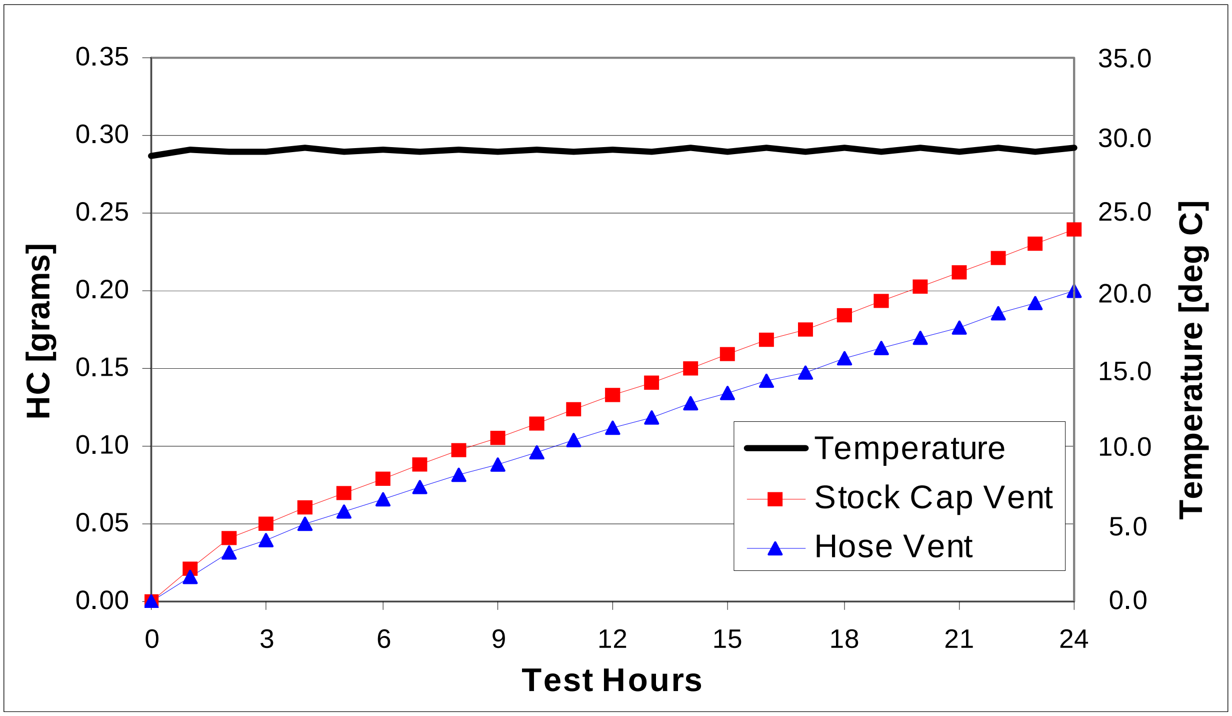
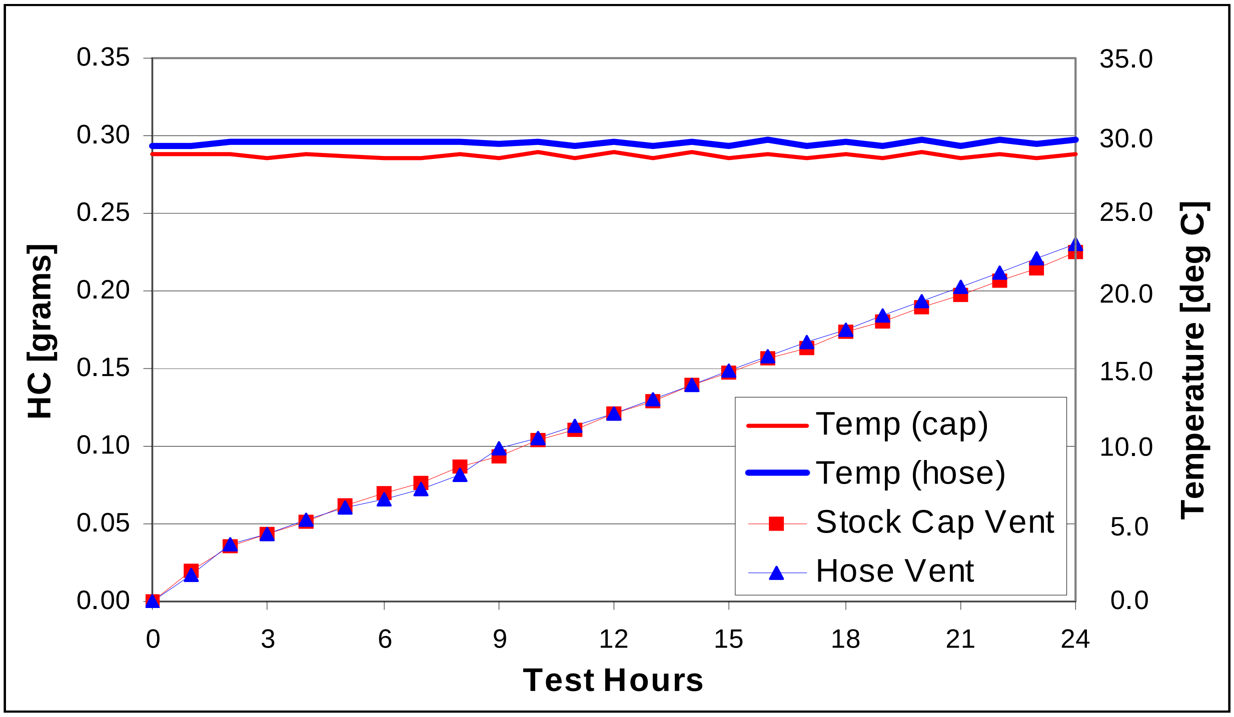
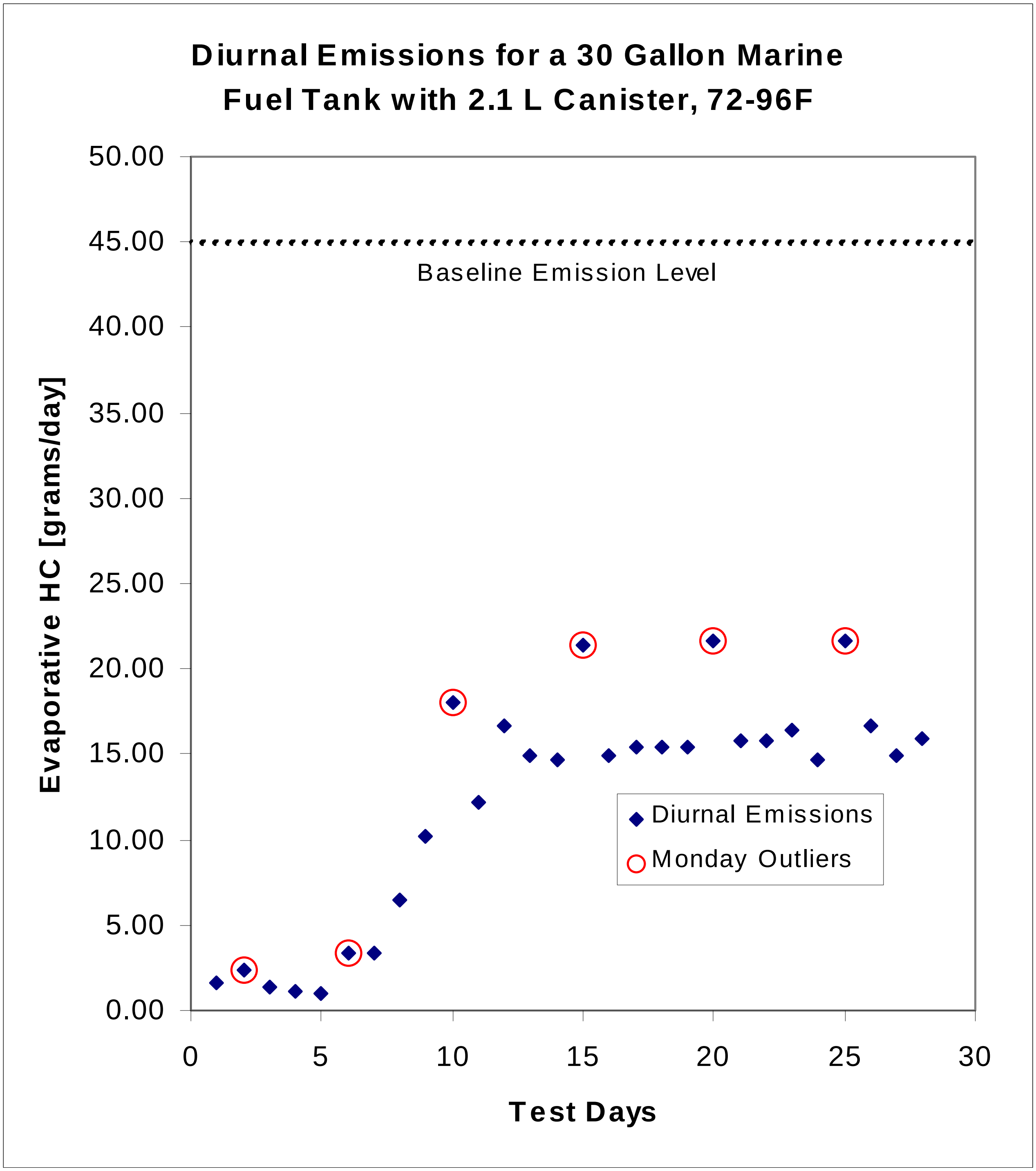


Figure 5B.2-4: Isothermal Diffusion Test Results for TP Plastic Fuel Tank



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 [225,226,227,228,229,230]

Material Name	Fuel C g-mm/m²/day	Fuel CE10 g-mm/m²/day	CM15 g-mm/m²/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 [231,232]

Material Name	Fuel C $g\text{-}mm/m^2/day$	Fuel CE10 $g\text{-}mm/m^2/day$	CM15 $g\text{-}mm/m^2/day$
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 [233]

Material Name	Fuel C $g\text{-}mm/m^2/day$	Fuel CE10 $g\text{-}mm/m^2/day$	CM15 $g\text{-}mm/m^2/day$
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 [234,235,236,237]

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 Diurnal Testing

Test Time* [minutes]	Portable Fuel Tanks SHED Air Temperature		Installed Fuel Tanks Trailerable Boat Fuel Temperature		Installed Fuel Tanks Nontrailerable boat 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

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CHAPTER 6: Costs of Control

This chapter describes our approach to estimating the cost of complying with the new 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 reflects 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 per-unit 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 standards.

Many of the engine technologies available to Marine SI 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 new exhaust emission standards for Small land-based spark-ignition (Small SI) engines. EPA has relied upon model year 2008 certification data for this analysis to characterize the current Class I and Class II market and the technology mix needed to comply with the Phase 3 standards. EPA chose not include data from Chinese manufacturers in this analysis because we have no information on actual sales of their engines in the United States. Manufacturers do submit sales estimates to EPA at the time of certification. However, the sales estimates provided by Chinese manufacturers would suggest that sales of Small SI nonhandheld engines have doubled over the last few years. Based on discussions with nonhandheld engine manufacturers that have been certifying with EPA for over ten years now, we do not believe this is the case and it is our understanding that sales of nonhandheld engines from Chinese manufacturers are relatively small at this time. Therefore, we believe it is appropriate to not include certification data from Chinese manufacturers in our analysis.

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 ≥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 2008 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 2008 technology market mix is presented in Table 6.2-1.

For the final Phase 3 standards, the EPA 2008 certification database was referenced. It was found that the majority of Class I engines were in need of some emission reduction and therefore it is estimated that these engines would use catalysts and the related engine design improvements required to use catalysts safely. For Class II engines, the 2008 certification database revealed some engine families meet the Phase 3 emission levels and therefore technologies are not required on all engine families. For those engine families needing emission reduction technology, different technologies were assigned depending on whether the engine was a one cylinder or a multiple cylinder engine. A number of one cylinder engine families were estimated to use catalysts. For two or more cylinders, the largest engine family per engine manufacturer needing emission reduction technology 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: 2008 Technology Market Mix

	Class I	Class II
SV	66%	2%
OHV	34%	98%
w/ Catalyst	0.003%	0.4%
w/ Other (EFI and/or watercooled)	0	1%

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	66%	2%
OHV	34%	98%
w/ Catalyst	95%	50%
w/ Other (EFI and/or watercooled)	0	6.6%

*EPA 2008 certification data

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 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 2005 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 for we are most familiar with the performance of these engines. 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 estimates 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 the 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 the 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 the 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 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 the 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 13-14 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 15-57 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 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 estimated 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 new 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 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 2008 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. The number of engine families listed under catalyst development will need emission reduction technology such as catalysts.

Table 6.2-26: Number of LPG 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 1cyl/2cyl	
125	--	--	--	250	9	9	1	2
250	--	--	--	500	20	20	2	10
500	2	2	1	1000	13	13	1	8

For Phase 3, companies with small volume production (<10,000) can use an assigned df.

Table 6.2-27 lists the certification costs.

Table 6.2-27: Certification Costs - LPG

	Class I	Class II
Baseline Emission Testing	$8,048	$169,008
Dynamometer Aging	$66,706	$1,769,774
End of Life Emission Test	$8,048	$169,008
Total	$82,802	$2,107,790

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 2008 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 some of the V-twin LPG engines are already certified with catalysts. Costs for catalyst system redesign for some of the existing 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.

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 2005$

	Class I	Class II
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$ - LPG

	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	0	0	0
250	905,005	0%	1	0	0	0
500	623,431	0.63%	1	3574	0	0
Class II						
250	3,334,488	0.58%	1	14,500	$1.38	$20,027
			2	10,469	-$2.95	-$30,923
500	724,231	1.94%	1	12,918	$9.25	$119,523
			2	90,630	$5.17	$ 468,553
1000	821,463	3.19%	2	18,700	$15.59	$ 291,517
					2012 Total Increase	$868,698

* use the same technology as gasoline counterpart

Table 6.2-32 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. Nearly all engines in Class I (96.9% 125 useful life (UL), 99.4% 250 UL and 72.65% 500 UL) are 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 six 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 2008 EPA Certification Database were utilized to determine the percentage of technologies per useful life. A portion of the engines, the largest multi-cylinder engine family per engine manufacturer needing emission reduction, are assigned the use of electronic fuel injection. The remaining engine families are assigned catalysts and related engine improvements. Some engines would not to require any costs. Long term costs (learning) are six 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	43.66%	5.88%	0.61%	49.85%
500	59.84%	5.62%	0.30%	34.24%
1000	28.50%	10.80%	18.24%	42.46%

Table 6.2-33: Variable Costs Per Engine for Meeting 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	10.41	9.43	--	--
125 - OHV	8.55	7.80	--	--
250	12.17	11.33	16.8	14.24
500	11.71	10.87	11.93	9.87
1000	--	--	30.07	25.21

*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 2008 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	66%	---
125 - OHV	23%	---
250	6%	74%
500	5%	11%
1000	---	15%

Table 6.2-35: Class I and Class II Projected Sales per Useful Life Category (snowblowers excluded)

YEAR	CLASS I				CLASS II		
	125	125	250	500	250	500	1,000
	SV	OHV	OHV	OHV	OHV	OHV	OHV
2008	6,139,695	2,112,583	565,168	489,249	3,375,298	485,273	687,306
2009	6,250,204	2,150,608	575,340	498,055	3,436,078	494,012	699,683
2010	6,360,351	2,188,508	585,479	506,832	3,497,169	502,795	712,123
2011	6,474,907	2,227,925	596,025	515,961	3,560,736	511,934	725,067
2012	6,584,353	2,265,584	606,099	524,682	3,621,924	520,731	737,527
2013	6,698,636	2,304,907	616,619	533,789	3,685,741	529,906	750,522
2014	6,810,588	2,343,428	626,924	542,710	3,747,698	538,814	763,138
2015	6,921,857	2,381,714	637,167	551,577	3,809,238	547,662	775,669
2016	7,031,516	2,419,446	647,261	560,315	3,870,775	556,509	788,200
2017	7,144,731	2,458,402	657,683	569,337	3,933,230	565,488	800,917
2018	7,256,744	2,496,944	667,994	578,263	3,995,499	574,441	813,597
2019	7,370,110	2,535,952	678,429	587,296	4,058,405	583,485	826,406
2020	7,482,752	2,574,710	688,798	596,272	4,120,822	592,459	839,116
2021	7,594,978	2,613,326	699,129	605,215	4,183,226	601,431	851,824
2022	7,706,370	2,651,654	709,382	614,091	4,245,149	610,333	864,433
2023	7,818,799	2,690,339	719,732	623,051	4,307,507	619,299	877,131
2024	7,931,065	2,728,969	730,066	631,997	4,369,904	628,270	889,837
2025	8,043,780	2,767,752	740,442	640,978	4,432,728	637,302	902,629
2026	8,157,416	2,806,853	750,902	650,034	4,495,615	646,344	915,435
2027	8,270,846	2,845,883	761,343	659,072	4,558,320	655,359	928,203
2028	8,383,989	2,884,814	771,758	668,088	4,620,946	664,363	940,956
2029	8,497,471	2,923,861	782,204	677,131	4,683,749	673,392	953,744
2030	8,610,967	2,962,913	792,652	686,175	4,746,567	682,423	966,536
2031	8,724,583	3,002,007	803,110	695,229	4,809,474	691,468	979,345
2032	8,838,143	3,041,082	813,564	704,278	4,872,290	700,499	992,137
2033	8,951,587	3,080,116	824,006	713,318	4,935,044	709,521	1,004,915
2034	9,064,949	3,119,122	834,442	722,352	4,997,777	718,540	1,017,689
2035	9,178,412	3,158,163	844,886	731,393	5,060,568	727,568	1,030,475
2036	9,291,898	3,197,212	855,333	740,436	5,123,362	736,596	1,043,262
2037	9,405,435	3,236,279	865,784	749,484	5,186,178	745,627	1,056,053

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: Engine only			Class II: Engine & Equipment		
	125	250	500	250	500	1,000
2008	-	-	-	-	-	-
2009	-	-	-	-	-	-
2010	-	-	-	-	-	-
2011	-	-	-	59,835,023	6,105,598	21,799,867
2012	86,472,768	7,376,417	6,141,854	60,863,232	6,210,517	22,174,477
2013	87,973,661	7,504,448	6,248,457	61,935,618	6,319,944	22,565,182
2014	89,443,931	7,629,867	6,352,885	62,976,746	6,426,181	22,944,499
2015	90,905,230	7,754,521	6,456,676	64,010,872	6,531,704	23,321,265
2016	92,345,393	7,877,372	6,558,965	55,130,893	5,493,685	19,873,736
2017	86,511,329	7,449,638	6,191,089	56,020,430	5,582,326	20,194,399
2018	87,867,634	7,566,432	6,288,151	56,907,330	5,670,704	20,514,111
2019	89,240,307	7,684,635	6,386,385	57,803,283	5,759,984	20,837,087
2020	90,604,228	7,802,085	6,483,993	58,692,279	5,848,571	21,157,554
2021	91,963,103	7,919,100	6,581,239	59,581,099	5,937,140	21,477,959
2022	93,311,878	8,035,245	6,677,763	60,463,047	6,025,024	21,795,886
2023	94,673,217	8,152,473	6,775,185	61,351,207	6,113,527	22,116,052
2024	96,032,587	8,269,530	6,872,467	62,239,924	6,202,086	22,436,419
2025	97,397,383	8,387,055	6,970,137	63,134,711	6,291,250	22,758,975
2026	98,773,331	8,505,540	7,068,606	64,030,407	6,380,504	23,081,857
2027	100,146,794	8,623,812	7,166,896	64,923,505	6,469,500	23,403,804
2028	101,516,776	8,741,783	7,264,937	65,815,481	6,558,384	23,725,346
2029	102,890,863	8,860,108	7,363,272	66,709,969	6,647,518	24,047,793
2030	104,265,113	8,978,447	7,461,619	67,604,683	6,736,674	24,370,323
2031	105,640,825	9,096,912	7,560,070	68,500,650	6,825,955	24,693,303
2032	107,015,858	9,215,318	7,658,473	69,395,337	6,915,109	25,015,822
2033	108,389,476	9,333,603	7,756,775	70,289,133	7,004,174	25,338,020
2034	109,762,116	9,451,803	7,855,006	71,182,631	7,093,210	25,660,111
2035	111,135,969	9,570,108	7,953,324	72,076,956	7,182,327	25,982,500
2036	112,510,105	9,688,438	8,051,663	72,971,320	7,271,449	26,304,902
2037	113,884,858	9,806,820	8,150,046	73,865,999	7,360,602	26,627,419

6.2.5.2 Fixed Costs

Fixed costs for the small spark ignition engines include test cell modifications for 1065 compliance, emission certification of engine families as well as R&D and tooling expenditures for engine design changes and equipment modifications. This section presents the aggregate fixed costs for small spark ignition engines.

The test procedure for small spark ignited engines for this rulemaking is governed by Part 1065 with regulation specific details in Part 1054. Evaluation of Part 1065 reveals that there are some differences in calibration procedures with existing Part 90 and programming must be changed to calculate via 1065. As industry begins to apply 1065 requirements in its test cells there may be some other modifications that will be revealed. To cover these costs, EPA is allocating $600,000 per engine manufacturer for 1065 compliance. The number of engine manufacturers is taken from the the certification database which lists 16 different engine manufacturers of nonhandheld engines and 15 engine manufacturers of handheld engines. The certification database 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. For this cost analysis, one additional manufacturer for nonhandheld and handheld is added to the certification database totals to cover test labs. Therefore, for nonhandheld engine manufacturers, a total of 17 test facilities at 600,000 per test facility yields a total estimated cost of $10,200,000. For the purpose of this cost analysis, this cost is spread evenly across all useful lives per class for a total of 1,700,000 for each. Upgrades for test cells for handheld engines are calculated at $9,600,000. Engine manufacturers are to begin using compliant test cells for new engine family certifications beginning in 2013. This cost analysis estimates engine manufacturers will invest in their test cells from 2008-2011.

Table 6.2-37: Fixed Costs for Compliance with 1065, 2005$ (thousands)

	CLASS I			CLASS II			HANDHELD
	125	250	500	250	500	1000	
TOTAL	1,700	1,700	1,700	1,700	1,700	1,700	9,600
Investment Per Year							
2008	425	425	425	425	425	425	2,400
2009	425	425	425	425	425	425	2,400
2010	425	425	425	425	425	425	2,400
2011	425	425	425	425	425	425	2,400

Each engine family must certify each year to the emissions standards applicable in that year. This cost analysis assumes no carryover data, but that all engine families will undergo durability aging and emission testing. The number of engine families per Class and per useful life category were taken from EPA's 2008 Certification Database. For Class I, the 2008 database lists 66 engine families from traditionally regulated companies. For Class II, the 2008 database lists 121 engine families. The engine families are designated per useful life class by the claim in the certification application. 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. Costs for certifiers of LPG engines are covered in Section 6.2.4.

Table 6.2-38: Number of Engine Families Per Class and Useful Life Designation for Certification

CLASS I		CLASS II	
125	31	250	39
250	15	500	18
500	20	1000	64

It should be noted that the certification database does contain certifications from a large number of companies that have a short history of compliance and claim large sales numbers. These companies were not used in this analysis for we are not yet convinced they are actually selling in this country nor in the numbers they claim. Engine families still certified to Phase 1 (either through credits, small engine family flexibilities or averaging) were also 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.

The total engine exhaust emission certification costs are calculated by taking the number of engine families from Table 6.2-38 and multiplying them by the emission test and dynamometer aging costs from Table 6.2-23. This analysis estimates that engine certification costs are expended over two years prior to standard implementation as shown in Table 6.2-39. The combined 1065 compliance and engine certification costs are presented in Table 6.2-40.

Table 6.2-39: Engine Certification Costs to Exhaust Standards

	CLASS I			CLASS II			Handheld
	125	250	500	250	500	1000	$0
2008							
2009				635,064	811,414	3,007,505	
2010	272,490	191325	455,411	635,064	811,414	3,007,505	
2011	272,490	191325	455,411				

Table 6.2-40: Total Stream of Costs for Engine Certification by Year, (thousands)

	CLASS I			CLASS II			
	125	250	500	250	500	1000	Handheld
2008	425	425	425	425	425	425	2,400
2009	425	425	425	1,060	1,236	3,432	2,400
2010	697	616	880	1,060	1,236	3,432	2,400
2011	697	616	880	425	425	425	2,400

Fixed costs for engine research and development and tooling changes 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, engine improvements with catalyst development or EFI development and application. Class I engine families are assigned engine improvements and/or engine improvements and catalyst development costs. The number of engine families per Class are from the 2008 EPA Certification Database. Table 6.2-41 presents the number of engine families estimated per technology package for Class I and Table 6.2-42 presents the number of engine families estimated per technology for Class II.

Table 6.2-41: Estimated Number of Engine Families per Technology Package, Class I

Technology/Useful Life	125	250	500
- Engine Improvements (all)	31	15	20
- Catalysts	26	13	14

Table 6.2-42: Estimated Number of Engine Families per Technology Package, Class II

Technology/Useful Life	250	500	1000
- Engine Improvements (all)	39	18	64
- One Cylinder Engine Catalyst	16	4	14
- Two or More Cylinders per Engine for Catalyst	7	3	27
- Electronic Fuel Injection on Two or More Cylinder Engines	4	3	5

Table 6.2-43: Total Fixed Costs (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	5,286	5,598	5,335	6,567	12,412	5,225	20,780
Tooling	10,164	5,571	5,205	6,540	12,412	12,412	12,412
TOTAL	15,450	11,169	10,540	13,107	15,450	15,450	15,450

Table 6.2-44: Total Fixed Costs Investment (thousands)
for Engines to Meet Phase 3 Exhaust Emission Standards

	CLASS I				CLASS II		
	125-sv	125-ohv	250	500	250	500	1000
2008	1,322	1,400	1,334	1,642	4,301	2,398	7,419
2009	1,322	1,400	1,334	1,642	11,150	5,263	18,498
2010	6,404	4,185	3,936	4,912	11,150	5,263	18,498
2011	6,404	4,185	3,936	4,912			

Total fixed costs for Small SI exhaust emissions are shown in Table 6.2-45.

Table 6.2-45: Certification and Technology Fixed Costs for Engines to Meet Phase 3 Exhaust Standards

	Class I			Class II			Handheld
	125	250	500	250	500	1,000	
2008	3,146	1,759	2,067	4,562	2,167	7,352	2,400
2009	3,146	1,759	2,067	12,046	5,843	21,438	2,400
2010	11,286	4,553	5,792	12,046	5,843	21,438	2,400
2011	11,286	4,553	5,792	425	425	425	2,400

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 two unique models requiring clearly different redesign yields a number of 826 redesigns. Table 6.2-22 contains equipment costs per equipment model and Table 6.2-46 contains the total equipment costs.

Table 6.2-46: Total Class II Equipment Cost

	250	500	1000
2009	10325000	10325000	10325000
2010	10325000	10325000	10325000

6.2.5.3 Operating Cost Savings

The application of electronic fuel injection to an estimated 6.6% 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 6.2-47 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 chapter.

Table 6.2-46: Fuel Savings from the Increased Use of Electronic Fuel Injection on Class II Engines

Year	Gallons	Fuel Savings $
2008	0	0
2009	0	0
2010	0	0
2011	3,916,719	$7,104,929
2012	7,074,990	$12,834,033
2013	10,071,145	$18,269,057
2014	11,966,500	$21,707,230
2015	13,835,431	$25,097,472
2016	15,252,178	$27,667,451
2017	16,221,164	$29,425,191
2018	16,966,562	$30,777,343
2019	17,576,831	$31,884,371
2020	18,104,416	$32,841,410
2021	18,532,855	$33,618,599
2022	18,916,185	$34,313,960
2023	19,267,974	$34,952,106
2024	19,607,579	$35,568,148
2025	19,935,933	$36,163,782
2026	20,259,628	$36,750,965
2027	20,579,305	$37,330,860
2028	20,896,206	$37,905,717
2029	21,210,286	$38,475,459
2030	21,521,549	$39,040,090
2031	21,830,758	$39,600,995
2032	22,138,949	$40,160,054
2033	22,446,266	$40,717,527
2034	22,752,947	$41,273,846
2035	23,059,059	$41,829,132
2036	23,363,883	$42,382,085
2037	23,667,468	$42,932,787

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 Certification Upgrades Handheld
	CLASS I	CLASS II	
2008	7,012,721	15,393,779	2,400,000
2009	7,012,721	71,614,262	2,400,000
2010	21,671,947	71,614,262	2,400,000
2011	21,671,947	93,177,678	2,400,000
2012	99,991,039	93,481,939	0
2013	101,726,567	95,129,055	0
2014	103,426,684	96,728,158	0
2015	105,116,426	98,316,508	0
2016	106,781,731	85,010,277	0
2017	100,152,057	86,381,917	0
2018	101,722,217	87,749,492	0
2019	103,311,327	89,131,026	0
2020	104,890,306	90,501,833	0
2021	106,463,442	91,872,369	0
2022	108,024,886	93,232,307	0
2023	109,600,875	94,601,825	0
2024	111,174,585	95,972,201	0
2025	112,754,576	97,351,938	0
2026	114,347,477	98,733,075	0
2027	115,937,502	100,110,208	0
2028	117,523,496	101,485,609	0
2029	119,114,243	102,864,885	0
2030	120,705,179	104,244,509	0
2031	122,297,808	105,626,063	0
2032	123,889,649	107,005,647	0
2033	125,479,854	108,383,854	0
2034	127,068,925	109,761,603	0
2035	128,659,401	111,140,627	0
2036	130,250,205	112,519,710	0
2037	131,841,723	113,899,279	0

Table 6.2-48 presents a sales weighted average per-equipment cost estimate for engines

meeting the Phase 3 exhaust standards. Note that the fixed costs are invested prior to the implementation date for Class I and Class II engines and therefore the variable costs are what remain in these years. Near term costs for Class I are from 2012-2016 and for Class II are from 2011-2015. Long term costs include a learning curve deduction in manufacturing/production for these engines in the 6th year and the Class I costs start in 2017 and Class II starts in 2016.

Table 6.2-48: Sales Weighted Average Per-Equipment Cost Estimates (Without Fuel Savings) for Exhaust Standards, 2005$

Short Term Costs (years 1-5) per Class per Useful Life	Class I			Class II			Handheld (no Exhaust)
	125	250	500	250	500	1000	
Near Term	10.48	7.51	11.12	17.70	13.66	31.93	0.00
Long Term*	9.01	11.33	10.87	15.02	10.76	26.49	0.00

* Long term is with learning, if applicable

The aggregate costs with fuel savings is presented in Table 6.2-49. Fuel savings are available from Class II engines using electronic fuel injection and start in 2011 which is the first year of standard implementation.

Table 6.2-49: Total Aggregate for 30 year Cost Analysis for Exhaust Emission Standard Compliance with Fuel Savings, 2005$

	Class I	Class II	Handheld
2008	7,012,721	15,393,779	2,400,000
2009	7,012,721	71,614,262	2,400,000
2010	21,671,947	71,614,262	2,400,000
2011	21,671,947	89,260,959	2,400,000
2012	99,991,039	86,406,949	0
2013	101,726,567	85,057,910	0
2014	103,426,684	84,761,659	0
2015	105,116,426	84,481,077	0
2016	106,781,731	69,758,099	0
2017	100,152,057	70,160,753	0
2018	101,722,217	70,782,931	0
2019	103,311,327	71,554,195	0
2020	104,890,306	72,397,418	0
2021	106,463,442	73,339,514	0
2022	108,024,886	74,316,122	0
2023	109,600,875	75,333,851	0
2024	111,174,585	76,364,623	0
2025	112,754,576	77,416,005	0
2026	114,347,477	78,473,447	0
2027	115,937,502	79,530,903	0
2028	117,523,496	80,589,404	0
2029	119,114,243	81,654,598	0
2030	120,705,179	82,722,959	0
2031	122,297,808	83,795,305	0
2032	123,889,649	84,866,697	0
2033	125,479,854	85,937,588	0
2034	127,068,925	87,008,656	0
2035	128,659,401	88,081,568	0
2036	130,250,205	89,155,827	0
2037	131,841,723	90,231,811	0

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 $182 million. The corresponding estimated annualized fuel savings due to the use of electronic fuel injection on Class II engines is $24 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for Small SI exhaust emission control, without fuel savings, is $189 million. The corresponding estimated annualized fuel savings due to the use of electronic fuel injection on Class II engines is $27 million.

6.3 Exhaust Emission Control Costs for Outboard and Personal Watercraft Marine Engines

This section presents our cost estimates for meeting the new exhaust emission standards for outboard and personal watercraft marine engines.

As of about 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 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 the new national standards, manufacturers have already started with design and testing efforts to meet our 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 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.[29] 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 new 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 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 standards. In addition, manufacturers are likely to meet the new standards by selling more of their lower-emission engines, which are certified today. However, manufacturers may need to adjust engine calibrations to meet the new standard and collect further data to demonstrate compliance with the 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. If this cost is 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 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.[30]

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.[31]

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%)	$75	$142

6.3.7 Total OB/PWC Engine Costs

As discussed above, we anticipate that manufacturers would meet the 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.[32]

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 standards will 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	$11	$280	$291	$224
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	$19	$340	$359	$272
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 variable cost estimates described above by projected engine sales. These variable costs are then added to the fixed costs as incurred. 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.[33] Table 6.3-14 presents the projected costs of meeting the exhaust emission standards over a 30-year time period, with and without the fuel savings. Fuel savings from the 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 updating 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 $95 million. The corresponding estimated annualized fuel savings due to more efficient engines is $48 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for OB/PWC exhaust emission control is $95 million. The corresponding estimated annualized fuel savings due to more efficient engines is $57 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
2008	$8,347,493	$3,773,815	$8,347,493	$3,773,815
2009	$8,347,493	$3,773,815	$8,347,493	$3,773,815
2010	$83,474,059	$26,775,058	$79,497,283	$24,485,325
2011	$84,087,276	$26,971,752	$76,139,850	$22,376,416
2012	$84,700,492	$27,168,447	$72,816,127	$20,292,925
2013	$85,313,708	$27,365,142	$69,526,261	$18,241,565
2014	$85,926,924	$27,561,836	$66,259,388	$16,224,620
2015	$69,232,112	$22,206,825	$45,684,931	$8,714,463
2016	$69,716,553	$22,362,213	$42,316,350	$6,764,827
2017	$70,200,994	$22,517,602	$38,991,304	$4,885,794
2018	$70,685,435	$22,672,991	$35,708,089	$3,100,364
2019	$71,169,876	$22,828,380	$32,473,153	$1,454,031
2020	$71,654,317	$22,983,769	$29,314,449	$587,570
2021	$72,138,757	$23,139,157	$26,232,921	$(9,566)
2022	$72,623,198	$23,294,546	$23,265,756	$(471,718)
2023	$73,107,639	$23,449,935	$20,500,653	$(844,125)
2024	$73,592,080	$23,605,324	$18,356,730	$(1,149,312)
2025	$74,076,521	$23,760,712	$16,648,131	$(1,387,033)
2026	$74,564,028	$23,917,085	$15,128,141	$(1,568,545)
2027	$75,051,534	$24,073,457	$13,767,757	$(1,705,040)
2028	$75,539,041	$24,229,829	$12,656,743	$(1,796,384)
2029	$76,026,548	$24,386,201	$11,676,039	$(1,842,344)
2030	$76,514,055	$24,542,574	$10,870,140	$(1,854,155)
2031	$77,001,562	$24,698,946	$10,196,651	$(1,865,959)
2032	$77,489,069	$24,855,318	$9,613,547	$(1,877,784)
2033	$77,976,576	$25,011,690	$9,148,071	$(1,889,601)
2034	$78,464,083	$25,168,062	$8,757,202	$(1,901,412)
2035	$78,951,590	$25,324,435	$8,450,580	$(1,913,224)
2036	$79,439,097	$25,480,807	$8,228,217	$(1,925,042)
2037	$79,926,603	$25,637,179	$8,059,025	$(1,936,853)

6.4 Exhaust Emission Control Costs for Sterndrive/Inboard Marine Engines

This section presents our cost estimates for meeting the new 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.[34]

Because California ARB has adopted standards similar to the new national standards, manufacturers have already started with design and testing efforts to meet our 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 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 new 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 exhaust emission standards. However, in developing this rule, 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 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. If this cost is 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 new 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.[35] 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	101
Lifetime Cost Savings	$185
Discounted Cost Savings (7%)	$105

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 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 electronic fuel injection for engine models that are projected to be carbureted in 2009. Except for high-performance engines, we also apply costs for catalysts. 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. Fixed costs for high-performance engines 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	$21	$334	$355	$266
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	$280	$257	$537	$216

6.4.7 SD/I Aggregate Costs

Aggregate costs are calculated by multiplying the per-engine variable cost estimates described above by projected engine sales. These variable costs are then added to the fixed costs as incurred. 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.[36] Table 6.4-8 presents the projected costs of the 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 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 $28 million. The corresponding estimated annualized fuel savings due to more efficient engine controls is $8 million. At a 3 percent discount rate, over 30 years, the estimated annualized cost to manufacturers for SD/I exhaust emission control is $28 million. The corresponding estimated annualized fuel savings due to more efficient engine controls is $10 million.

Table 6.4-8: Projected 30-Year Aggregate Cost Stream for SD/I Engines

Year	Without Fuel Savings	With Fuel Savings
2008	$4,971,723	$4,971,723
2009	$4,971,723	$4,971,723
2010	$31,909,535	$31,207,005
2011	$32,143,949	$30,512,049
2012	$32,378,362	$29,822,674
2013	$32,612,775	$29,128,682
2014	$32,847,189	$28,440,869
2015	$26,361,975	$21,040,258
2016	$26,546,438	$20,317,643
2017	$26,730,902	$19,601,606
2018	$26,915,366	$18,896,409
2019	$27,099,830	$18,205,484
2020	$27,284,293	$17,523,304
2021	$27,468,757	$16,828,978
2022	$27,653,221	$16,141,908
2023	$27,837,685	$15,467,722
2024	$28,022,149	$14,804,334
2025	$28,206,612	$14,154,769
2026	$28,392,244	$13,524,906
2027	$28,577,875	$12,917,862
2028	$28,763,506	$12,338,401
2029	$28,949,137	$11,804,572
2030	$29,134,769	$11,474,294
2031	$29,320,400	$11,259,905
2032	$29,506,031	$11,088,594
2033	$29,691,662	$10,948,483
2034	$29,877,294	$10,831,791
2035	$30,062,925	$10,732,954
2036	$30,248,556	$10,650,884
2037	$30,434,187	$10,582,255

6.5 Evaporative Emission Control Costs for Small SI Equipment

This section presents our cost estimates for meeting the new evaporative emission standards for land-based equipment using small spark-ignition engines.

In our analysis of the costs of the 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 non-handheld

(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 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.[37,38,39] For baseline fuel lines, we consider nitrile rubber hose such as that used to meet SAE J30 R7 recommendations. For handheld equipment, we consider the baseline fuel lines 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 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 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[40] and sulfonation.[41] 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).[42]

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.[43] 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.[44] 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[45], 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 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.[46] 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 new 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.[47,48,49] 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.[50] 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.[51] 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.[52] 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.[53,54] 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 requiring 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 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 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 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 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	4.8	28.6
Lifetime Gallons Saved	0.2	0.8	4.7
Lifetime Cost Savings	$0.41	$1.45	$8.55
Average Equipment Life [years]	4.2	5.3	5.9
Discounted Cost Savings (7%)	$0.40	$1.31	$5.96

6.5.6 Total Small SI Equipment Costs

We expect that Small SI manufacturers will use a variety of technologies to meet the 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 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.

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	$2.58	$3.05	$0.19	$2.01	$2.20
tank permeation	$0.45	$0.33	$0.78	$0.19	$0.27	$0.46
hose permeation	$0.02	$0.33	$0.35	$0	$0.20	$0.20
running loss	$0	$1.92	$1.92	$0	$1.53	$1.53
Class II aggregate	$1.26	$5.47	$6.73	$0.69	$4.48	$5.16
tank permeation	$1.21	$2.15	$3.37	$0.69	$1.73	$2.42
hose permeation	$0.04	$1.09	$1.13	$0	$0.96	$0.96
running loss	$0	$2.23	$2.23	$0	$1.78	$1.78

6.5.7 Small SI Equipment Aggregate Costs

Aggregate costs are calculated by multiplying the per-equipment variable cost estimates described above by projected equipment sales. Fixed costs are added as incurred. Fuel savings are calculated directly from the projected HC reductions due to the evaporative emission standards. Table 6.5-8 presents the projected costs of the 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 $65 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from Small SI equipment is $53 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for Small SI evaporative emission control is $68 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from Small SI equipment is $59 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	$224,312	$4,648,719	$7,105,928	$224,312	$3,697,028	$4,886,033
2009	$5,942,463	$4,732,285	$13,749,794	$5,707,932	$2,634,260	$8,715,782
2010	$5,816,345	$9,215,094	$12,455,089	$5,135,637	$6,081,748	$4,833,539
2011	$5,923,313	$9,277,641	$35,396,135	$4,845,509	$5,276,627	$20,401,655
2012	$7,752,522	$30,008,965	$36,003,944	$6,079,623	$21,187,318	$14,937,731
2013	$7,883,770	$29,122,813	$35,892,762	$5,677,010	$16,186,469	$9,525,916
2014	$6,810,314	$29,609,400	$36,495,479	$4,191,701	$13,744,050	$6,260,075
2015	$6,922,632	$30,093,095	$37,094,450	$4,019,074	$12,389,454	$3,382,349
2016	$7,034,855	$30,569,878	$32,298,515	$3,902,020	$11,344,204	$(4,288,346)
2017	$7,147,090	$25,830,285	$32,819,027	$3,897,310	$5,337,945	$(5,765,846)
2018	$7,259,067	$26,235,145	$33,338,022	$3,924,431	$4,963,819	$(6,881,442)
2019	$7,371,143	$26,644,831	$33,862,125	$3,968,150	$4,768,572	$(7,709,855)
2020	$7,483,470	$27,051,954	$34,382,368	$4,021,523	$4,660,933	$(8,357,363)
2021	$7,595,660	$27,457,582	$34,902,482	$4,080,576	$4,604,761	$(8,820,939)
2022	$7,707,763	$27,860,231	$35,418,720	$4,139,728	$4,586,374	$(9,198,114)
2023	$7,819,853	$28,266,579	$35,938,441	$4,198,990	$4,607,753	$(9,511,148)
2024	$7,931,999	$28,672,351	$36,458,489	$4,258,379	$4,648,613	$(9,799,648)
2025	$8,044,212	$29,079,725	$36,981,966	$4,317,834	$4,691,017	$(10,064,140)
2026	$8,156,448	$29,490,381	$37,505,944	$4,377,298	$4,733,531	$(10,315,949)
2027	$8,268,656	$29,900,304	$38,028,453	$4,436,735	$4,775,266	$(10,558,303)
2028	$8,380,840	$30,309,200	$38,550,330	$4,496,146	$4,815,980	$(10,793,367)
2029	$8,493,060	$30,719,307	$39,073,626	$4,555,595	$4,857,899	$(11,021,049)
2030	$8,605,303	$31,129,464	$39,597,054	$4,615,066	$4,899,855	$(11,243,155)
2031	$8,717,528	$31,540,051	$40,121,181	$4,674,519	$4,942,267	$(11,460,730)
2032	$8,829,741	$31,950,436	$40,644,586	$4,733,961	$4,984,464	$(11,676,805)
2033	$8,941,949	$32,360,405	$41,167,490	$4,793,398	$5,026,247	$(11,890,232)
2034	$9,054,168	$32,770,086	$41,690,229	$4,852,844	$5,067,730	$(12,101,049)
2035	$9,166,396	$33,180,125	$42,213,436	$4,912,301	$5,109,583	$(12,309,918)
2036	$9,278,617	$33,590,247	$42,736,659	$4,971,750	$5,151,512	$(12,516,613)
2037	$9,390,834	$34,000,550	$43,260,062	$5,031,196	$5,193,635	$(12,721,142)

6.6 Costs of Evaporative Emission Controls for Marine Vessels

This section presents our cost estimates for meeting the new evaporative emission standards for marine vessels.

To determine the cost impacts of the 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.[55]

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.[56,57,58,59,60] 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 not 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[61] and sulfonation.[62] 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.[63]

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.[64] 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)[65], 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.[66] 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.[67] 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.[68,69] 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.[70] 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	$9.30	$26	NA
	long term	$7.44	$21	
sulfonation:	short term	$1.67	$3.27	NA
	long term	$1.26	$1.29	
non-continuous platelets		$1.27	$3.37	NA
multi-layer:	short term	$7.74	$15	$81
EVOH	long term	$4.22	$8.58	$68
multi-layer:	short term	NA	NA	$81
PA11	long term			$68
multi-layer:	CBT	NA	NA	$54
UPE fiberglass	short term	NA	NA	$48
nanocomposite	long term			$39
epoxy coating:	short term	$5.47	$12	$43
	long term	$4.85	$11	$39

6.6.3 Venting Losses

For portable fuel tanks, the 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.[71]

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[72] 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.[73] 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 long term	$1.29 $1.03	$26 $21
passive purge canister:	short term long term	NA NA	$32 $25
bladder fuel tank:	short term long term	NA NA	$259 $207
volume compensating air bag:	short term long term	NA NA	$91 $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 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 evaporative emission standards.

Table 6.6-5: Projected Evaporative Fuel Savings for Marine Vessels

	Portable	PWC	Installed
Evaporative HC Reduced [lbs/life]	80	53	228
Lifetime Gallons Saved	13	9	38
Lifetime Cost Savings	$24	$16	$68
Average Equipment Life [years]	12.7	9.9	17
Discounted Cost Savings (7%)	$17	$12	$42

6.6.6 Total Marine Vessel Costs

We expect that marine vessel manufactures will make use of a variety of technologies to meet the 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 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-vessel variable cost estimates described above by projected vessel sales and adding in fixed costs as incurred. 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.[74] Fuel savings are calculated directly from the projected HC reductions due to the evaporative emission standards. Table 6.6-7 presents the projected costs of the 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 updating 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 $21 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from boats is $22 million. At a 3 percent discount rate, the estimated annualized cost to manufacturers for marine evaporative emission control is $23 million. The estimated corresponding annualized fuel savings due to control of evaporative emissions from boats is $27 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
2008	$36,474	$67,297	$425,096	$36,474	$67,297	$425,096
2009	$803,917	$1,461,840	$2,437,783	$550,181	$1,401,963	$1,913,103
2010	$857,095	$1,395,094	$2,118,774	$299,968	$1,271,709	$1,028,968
2011	$594,826	$855,964	$13,113,533	$(352,563)	$516,639	$10,845,446
2012	$599,164	$862,207	$25,655,601	$(787,374)	$308,552	$21,179,415
2013	$603,502	$868,449	$25,841,342	$(1,194,787)	$103,461	$19,143,903
2014	$607,839	$874,691	$26,027,084	$(1,593,995)	$(97,802)	$17,118,227
2015	$593,848	$880,933	$26,212,826	$(2,011,013)	$(295,433)	$15,098,006
2016	$598,004	$887,097	$24,120,397	$(2,403,445)	$(487,095)	$10,806,108
2017	$602,159	$893,262	$22,380,137	$(2,791,322)	$(673,068)	$6,882,907
2018	$606,314	$899,426	$22,534,578	$(3,170,164)	$(850,586)	$4,872,062
2019	$610,470	$905,590	$22,689,018	$(3,541,264)	$(1,000,808)	$2,878,316
2020	$614,625	$911,754	$22,843,458	$(3,893,751)	$(1,134,586)	$901,070
2021	$618,781	$917,918	$22,997,898	$(4,217,582)	$(1,212,981)	$(1,069,567)
2022	$622,936	$924,083	$23,152,338	$(4,502,321)	$(1,270,967)	$(3,020,477)
2023	$627,091	$930,247	$23,306,778	$(4,715,380)	$(1,318,185)	$(4,922,205)
2024	$631,247	$936,411	$23,461,218	$(4,892,031)	$(1,357,627)	$(6,725,979)
2025	$635,402	$942,575	$23,615,659	$(5,047,877)	$(1,391,089)	$(8,386,163)
2026	$639,584	$948,778	$23,771,076	$(5,189,699)	$(1,418,920)	$(9,827,107)
2027	$643,765	$954,982	$23,926,494	$(5,318,214)	$(1,441,800)	$(11,086,083)
2028	$647,947	$961,185	$24,081,911	$(5,440,156)	$(1,460,469)	$(12,248,543)
2029	$652,129	$967,388	$24,237,329	$(5,551,536)	$(1,475,218)	$(13,295,437)
2030	$656,310	$973,591	$24,392,747	$(5,655,549)	$(1,486,959)	$(14,225,862)
2031	$660,492	$979,794	$24,548,164	$(5,745,992)	$(1,496,432)	$(15,039,376)
2032	$664,674	$985,998	$24,703,582	$(5,828,655)	$(1,505,907)	$(15,694,795)
2033	$668,855	$992,201	$24,859,000	$(5,903,314)	$(1,515,381)	$(16,270,514)
2034	$673,037	$998,404	$25,014,417	$(5,963,979)	$(1,524,855)	$(16,778,147)
2035	$677,219	$1,004,607	$25,169,835	$(6,018,898)	$(1,534,329)	$(17,215,402)
2036	$681,400	$1,010,810	$25,325,252	$(6,068,556)	$(1,543,803)	$(17,601,830)
2037	$685,582	$1,017,014	$25,480,670	$(6,116,187)	$(1,553,278)	$(17,945,566)

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
2008	$319,871	$67,297	$141,699	$319,871	$67,297	$141,699
2009	$2,656,653	$1,461,840	$585,047	$1,906,143	$1,401,963	$557,141
2010	$2,502,577	$1,395,094	$473,292	$912,594	$1,271,709	$416,341
2011	$8,678,125	$855,964	$5,030,234	$5,726,980	$516,639	$4,765,903
2012	$15,269,926	$862,207	$10,984,838	$10,170,561	$308,552	$10,221,480
2013	$15,380,478	$868,449	$11,064,366	$8,145,273	$103,461	$9,803,842
2014	$15,491,029	$874,691	$11,143,894	$6,134,930	$(97,802)	$9,389,302
2015	$15,583,252	$880,933	$11,223,423	$4,108,869	$(295,433)	$8,978,125
2016	$14,360,302	$887,097	$10,358,098	$776,555	$(487,095)	$7,626,108
2017	$13,168,410	$893,262	$9,813,887	$(2,506,681)	$(673,068)	$6,598,266
2018	$13,259,282	$899,426	$9,881,610	$(4,483,567)	$(850,586)	$6,185,465
2019	$13,350,154	$905,590	$9,949,333	$(6,438,915)	$(1,000,808)	$5,775,967
2020	$13,441,026	$911,754	$10,017,057	$(8,363,328)	$(1,134,586)	$5,370,647
2021	$13,531,898	$917,918	$10,084,780	$(10,247,532)	$(1,212,981)	$4,960,383
2022	$13,622,771	$924,083	$10,152,503	$(12,075,309)	$(1,270,967)	$4,552,511
2023	$13,713,643	$930,247	$10,220,227	$(13,785,575)	$(1,318,185)	$4,147,990
2024	$13,804,515	$936,411	$10,287,950	$(15,367,391)	$(1,357,627)	$3,749,381
2025	$13,895,387	$942,575	$10,355,674	$(16,791,879)	$(1,391,089)	$3,357,839
2026	$13,986,834	$948,778	$10,423,826	$(17,990,346)	$(1,418,920)	$2,973,540
2027	$14,078,282	$954,982	$10,491,978	$(19,002,879)	$(1,441,800)	$2,598,583
2028	$14,169,729	$961,185	$10,560,130	$(19,924,799)	$(1,460,469)	$2,236,099
2029	$14,261,176	$967,388	$10,628,281	$(20,741,603)	$(1,475,218)	$1,894,631
2030	$14,352,623	$973,591	$10,696,433	$(21,455,586)	$(1,486,959)	$1,574,175
2031	$14,444,071	$979,794	$10,764,585	$(22,105,569)	$(1,496,432)	$1,320,201
2032	$14,535,518	$985,998	$10,832,737	$(22,684,596)	$(1,505,907)	$1,161,147
2033	$14,626,965	$992,201	$10,900,889	$(23,205,543)	$(1,515,381)	$1,031,715
2034	$14,718,413	$998,404	$10,969,041	$(23,661,696)	$(1,524,855)	$919,570
2035	$14,809,860	$1,004,607	$11,037,193	$(24,055,883)	$(1,534,329)	$821,583
2036	$14,901,307	$1,010,810	$11,105,345	$(24,404,310)	$(1,543,803)	$733,924
2037	$14,992,754	$1,017,014	$11,173,497	$(24,716,953)	$(1,553,278)	$655,200

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 (EIA) which posts gasoline price samples throughout the year on-line.[75] For 2004 and 2005, national fuel prices are based on an analysis of fuel prices by PADD as reported by EIA in 2006.[76] For years later than 2005, we use the estimates reported in the 2008 Annual Energy Outlook report also developed by EIA.[77] Based on this information, the national average fuel price, with taxes, grew from $2.20 in 2005 to $2.99 in 2008. 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 $2.60/gallon for 2008.

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 2007. 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 2008 projected price were used, the estimated fuel savings would have been about 33 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	$2.63	$2.44
2007	$2.77	$2.37
2008 (projected)	$2.99	$2.60

As discussed above, our analysis of fuel savings uses a constant fuel price for all future years. To the extent that fuel prices were to fluctuate in future years, this could have an impact on realized fuel savings. To investigate the sensitivity of our analysis to future fuel prices, we considered fuel price projections from the EIA's 2008 Annual Energy Outlook.[79] EIA projections include primary estimates of fuel prices, known as the "reference case," as well as "high price" estimates. These projections, which include taxes on motor gasoline, are shown in Figure 6.7-1. EIA projections from AEO 2007 and AEO 2006 are also presented for comparison. Note that the EIA reference cases show relatively flat fuel price projections beyond 2010, when the fuel savings associated with this rule would be realized.

Figure 6.7-1: EIA Motor Gasoline Projections [Include Taxes]

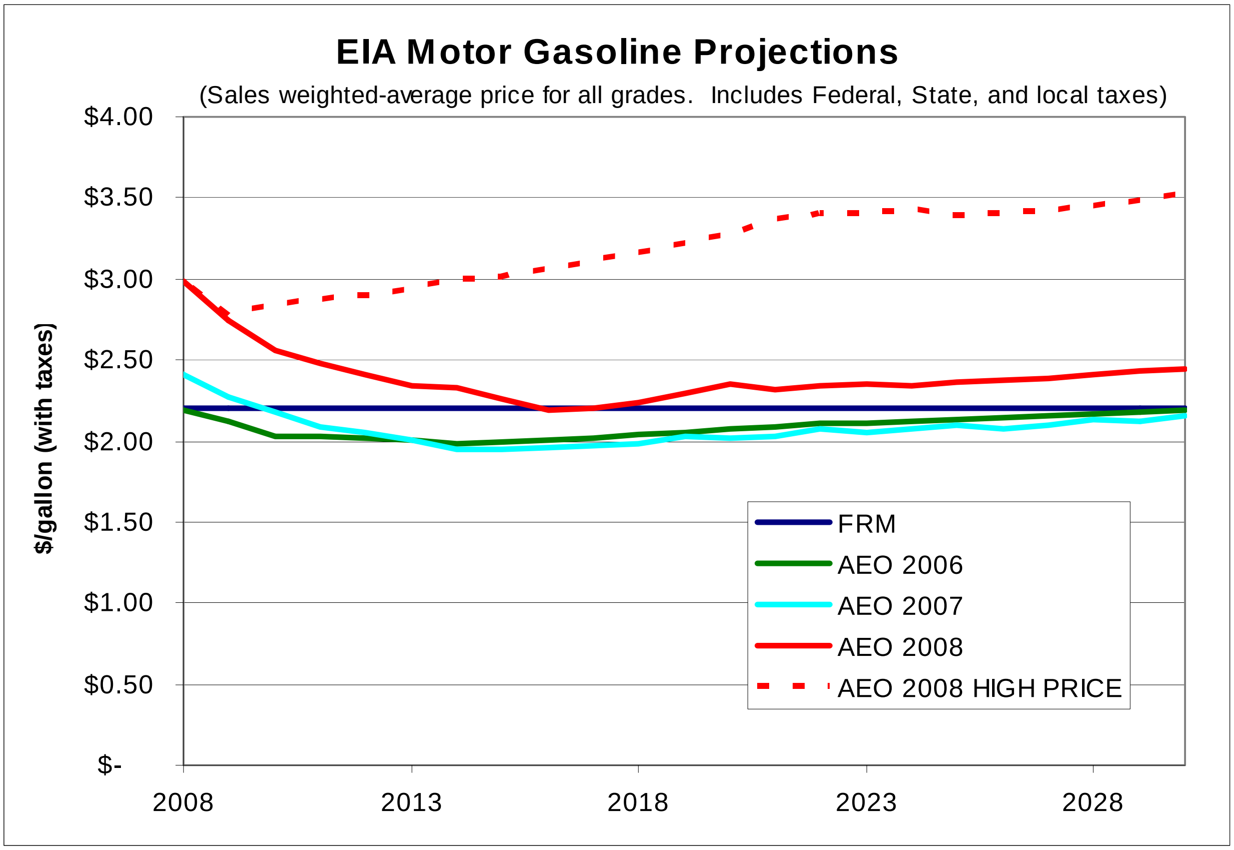

Table 6.7-2 presents our fuel savings estimates for this rule and presents a comparison with modified estimates using the EIA fuel price projections. Consistent with the above discussion, we adjusted the fuel price estimates to remove taxes on motor gasoline. Compared to the primary EPA estimate, using the reference case projections would result in about a 9 percent increase in estimated fuel savings. Using the high price estimate would result in about a 60 percent increase in estimated fuel savings.

Table 6.7-2: Sensitivity of Fuel Savings Estimates to Gasoline Price Projections

Year	Price without Taxes Per Gallon			Fuel Savings [million dollars]		
	Primary	AEO 2008 Reference	AEO 2008 High Price	Primary	AEO 2008 Reference	AEO 2008 High Price
2008	$1.81	$2.60	$2.60	$3	$5	$5
2009	$1.81	$2.36	$2.39	$8	$11	$11
2010	$1.81	$2.16	$2.45	$20	$24	$27
2011	$1.81	$2.09	$2.48	$45	$52	$61
2012	$1.81	$2.02	$2.51	$72	$80	$100
2013	$1.81	$1.95	$2.55	$97	$105	$137
2014	$1.81	$1.94	$2.61	$118	$126	$169
2015	$1.81	$1.86	$2.62	$137	$140	$198
2016	$1.81	$1.80	$2.67	$154	$153	$226
2017	$1.81	$1.82	$2.73	$168	$168	$253
2018	$1.81	$1.84	$2.77	$181	$184	$277
2019	$1.81	$1.91	$2.82	$194	$204	$301
2020	$1.81	$1.97	$2.89	$204	$221	$325
2021	$1.81	$1.93	$2.97	$214	$228	$351
2022	$1.81	$1.95	$3.01	$224	$241	$371
2023	$1.81	$1.96	$3.01	$233	$251	$386
2024	$1.81	$1.95	$3.03	$241	$259	$402
2025	$1.81	$1.97	$3.00	$248	$269	$411
2026	$1.81	$1.98	$3.01	$255	$278	$423
2027	$1.81	$1.99	$3.04	$261	$287	$437
2028	$1.81	$2.02	$3.06	$267	$297	$450
2029	$1.81	$2.04	$3.09	$272	$306	$464
2030	$1.81	$2.06	$3.13	$277	$314	$479
2031	$1.81	$2.06[a]	$3.13[a]	$282	$319	$487
2032	$1.81	$2.06[a]	$3.13[a]	$286	$324	$494
2033	$1.81	$2.06[a]	$3.13[a]	$290	$329	$501
2034	$1.81	$2.06[a]	$3.13[a]	$294	$333	$507
2035	$1.81	$2.06[a]	$3.13[a]	$297	$337	$514
2036	$1.81	$2.06[a]	$3.13[a]	$301	$341	$520
2037	$1.81	$2.06[a]	$3.13[a]	$304	$345	$525
Annualized Savings [million dollars]			3%	$180	$197	$293
			7%	$156	$169	$249

[a] Based on estimate for 2030. AEO 2008 does not project fuel prices beyond 2030.

6.7.2 Variation in Precious Metal Prices

Precious metal prices for Platinum and Rhodium have increased over the past 5 years.[80] 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 6.7-3.

Table 6.7-3: 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 6.7-4 presents the impact on per-engine costs of using the spot price and 10 year average price in our analysis. These costs, which are broken down by class and useful life, are presented for the near term without fuel savings.

Table 6.7-4: 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 Increase % Increase	$15.69 $1.57 10%	$22.60 $2.78 12%	$30.25 $4.18 14%	$47.48 $1.27 3%	$52.67 $1.84 4%	$96.11 $3.94 4%
10 YEAR AVERAGE						
Cost/Equip Increase %Increase	$13.91 -$0.21 -1.5%	$19.45 -$0.37 -1.9%	$25.51 -$0.56 -2.2%	45.84 $-0.37 -1%	$51.39 $0.56 1%	$93.80 $1.63 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 6.7-5 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 6.7-5: 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
Primary Analysis	$483	$396	$317	$300	$377
September 2006 Precious Metal Prices					
Cost	$511	$417	$342	$328	$416
Increase	$28	$21	$24	$28	$39
% Increase	5%	5%	7%	8%	9%
10 Year Average Precious Metal Prices					
Cost	$479	$393	$314	$296	$371
Increase	-$4	-$3	-$4	-$4	-$6
% Increase	-1%	-1%	-1%	-1%	-2%

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 6.7-6.

Table 6.7-6: 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 analysis 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 6.7-7 compares the estimated costs of catalysts and fuel injection.

Table 6.7-7: 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	$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 6.7-8. 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 6.7-8
Sales Weighted Average Cost Per Class II Equipment

	250	500	1000
Short Term (first year - includes fixed costs)			
Primary analysis	$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)			
Primary analysis	$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 6.7-9: 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 6.7-10: 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	$5.18	$68
Increase	($0.85)	($14)
% Increase	-15%	-17%
20% Increase in Material Costs		
Cost	$6.40	$95
Increase	$0.86	($14)
% Increase	15%	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:

$$DNAE = \sum (NE)_i / (1.07)^{i-2008}$$

Where:

DNAE = Reduction in nationwide 30-year net present value emissions in tons
$(NE)_i$ = 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

$$DNAC = \sum (NC)_i / (1.07)^{i-2008}$$

Where:

DNAC = Nationwide 30-year net present value costs in dollars
$(NC)_i$ = 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	$2,257	1,785,000	$1,264
Evaporative	$809	1,098,000	$736
Exhaust + Evap	$3067	2,883,000	$1,063

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	$1,959	1,785,000	$1,097
Evaporative	$151	1,098,000	$137
Exhaust + Evap	$2,110	2,883,000	$856

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	$1,521	1,826,000	$833
Evaporative	$270	461,000	$585
Exhaust + Evap	$1,790	2,287,000	$783

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	$823	1,826,000	$451
Evaporative	($6)	461,000	--
Exhaust + Evap	$817	2,287,000	$357

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	$3,718	3,227,000	$1,152
Evaporative	$1,327	1,932,000	$687
Exhaust + Evap	$5,044	5,159,000	$978

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	$3,181	3,227,000	$986
Evaporative	$170	1,932,000	$88
Exhaust + Evap	$3,351	5,159,000	$650

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	$2,407	3,425,000	$703
Evaporative	$444	885,000	$502
Exhaust + Evap	$2,852	4,310,000	$662

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	$1,100	3,425,000	$321
Evaporative	($86)	885,000	--
Exhaust + Evap	$1,014	4,310,000	$235

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

This chapter presents our analysis of the health and environmental benefits that are estimated to occur as a result of the final Small SI and Marine SI engine standards throughout the period from initial implementation through 2030. Nationwide, the engines subject to the final emission standards in this rule are a significant source of nonroad mobile source air pollution. The final standards will reduce exposure to direct PM2.5, NOx, VOCs and air toxics emissions and help avoid a range of adverse health effects associated with ambient ozone and $PM_{2.5}$ levels.

EPA is required by Executive Order (E.O.) 12866 to estimate the benefits and costs of regulations with estimated annual impacts of over 100 million dollars. Such regulations tend to include major new pollution control regulations. To estimate these benefits and costs, the analysis presented here attempts to answer three questions: (1) what are the physical health and welfare effects projected to result from particulate matter (PM) and ozone precursors (direct PM, VOCs and NOx)? (2) what is the monetary value of the projected changes in health and welfare attributable to the final rule? and (3) how do the projected monetized benefits compare to the projected costs? This analysis constitutes one part of EPA's thorough examination of the relative merits of this regulation.

The benefits analysis relies on three major components to answer these questions:

- Calculation of the projected impact of the final rule on the national nonroad emissions inventory of precursors to ozone and $PM_{2.5}$, specifically NOx, VOCs and direct PM, for two future years (2020 and 2030).

- Air quality modeling for 2020 and 2030 to determine projected changes in ambient concentrations of ozone and $PM_{2.5}$, reflecting baseline and post-control emissions inventories.

- A benefits analysis to determine the projected changes in human health and welfare, both in terms of physical effects and monetary value, that result from the projected changes in ambient concentrations of ozone and $PM_{2.5}$ for the modeled standards.

A wide range of human health and welfare effects are linked with exposure to PM, VOCs and NOx. 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.

The benefits modeling is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality and peer-reviewed studies of the dollar values of those public health and welfare effects. All of the benefit estimates for the control options in this analysis are based on an analytical structure and sequence consistent with benefits analyses performed for the recent analysis of the final Ozone NAAQS and the final PM NAAQS analysis.[1,2] For a more detailed discussion of the principles of benefits analysis used here, we refer the reader to those documents, as well as to the EPA Guidelines for Economic Analysis.

Table 8.1-1 summarizes the annual monetized health and welfare benefits associated with the final standards for two years, 2020 and 2030. The estimates in Table 8.1-1, and all monetized benefits presented in this chapter, are in year 2005 dollars. There are a few items to note about these benefits:

- Using a conservative benefits estimate, the 2020 benefits outweigh the costs by a factor of 5. Using the upper end of the benefits range, the benefits could outweigh the costs by a factor of 19. Likewise, in 2030 benefits outweigh the costs by at least a factor of 8 and could be as much as a factor of 34. Thus, even taking the most conservative benefits assumptions, benefits of the final standards clearly outweigh the costs.

- Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission control program. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario.

- The RIA for the proposal for this rulemaking only quantified benefits from PM; in the current RIA we quantify and monetize the ozone-related health impacts associated with the final rule. The science underlying the analysis is based on the current ozone criteria document.[3] The analytic approach to characterizing uncertainty is consistent with the analysis used in the RIA for the final Ozone NAAQS.

- In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC),[4] a panel of experts and reviewers concluded that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure. The report also recommended that the estimation of ozone-related premature mortality be accompanied by broad uncertainty analyses while giving little or no weight to the assumption that there is no causal association between ozone exposure and premature mortality. Because EPA has yet to develop a coordinated response to the NRC report's findings and recommendations, however, we have retained the approach to estimating ozone-related premature mortality used in RIA for the final Ozone NAAQS. EPA will specifically address the report's findings and recommendations in future rulemakings.

Table 8.1-1. Estimated Monetized PM- and Ozone-Related Health Benefits of the Small SI and Marine SI Engine Standards

2030 Total Ozone and PM Benefits – PM Mortality Derived from American Cancer Society Analysis[a]			
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2005$, 3% Discount Rate)[c,d]	Mean Total Benefits (Billions, 2005$, 7% Discount Rate)[c,d]
NMMAPS	Bell et al., 2004	$2.4	$2.2
Meta-analysis	Bell et al., 2005	$3.7	$3.5
	Ito et al., 2005	$4.4	$4.2
	Levy et al., 2005	$4.4	$4.3
Assumption that association is not causal[e]		$1.8	$1.6
2030 Total Ozone and PM Benefits – PM Mortality Derived from Expert Elicitation[b]			
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2005$, 3% Discount Rate)[c,d]	Mean Total Benefits (Billions, 2005$, 7% Discount Rate)[c,d]
NMMAPS	Bell et al., 2004	$1.7 - $9.7	$1.6 - $8.8
Meta-analysis	Bell et al., 2005	$3.0 - $11	$2.9 - $10
	Ito et al., 2005	$3.7 - $12	$3.6 - $11
	Levy et al., 2005	$3.7 - $12	$3.7 - $11
Assumption that association is not causal[e]		$1.1 to $9.1	$1.0 - $8.2

[a] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from the American Cancer Society analysis (Pope et al., 2002).

[b] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the $PM_{2.5}$ premature mortality functions characterized in the expert elicitation. The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 8.4-1.

[d] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

[e] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

Table 8.1-1 reflects those human health and welfare effects we are able to quantify and monetize. However, the full complement of known or suspected human health and welfare effects associated with PM, ozone and air toxics remain unquantified because of current limitations in methods or available data. We have not quantified potential health and welfare effects of ozone and PM because impact functions are not available or do not provide easily interpretable outcomes (e.g., changes in heart rate variability, acid and particulate deposition damage to cultural monuments and other materials, and reductions in acidification of lakes and streams and eutrophication in coastal areas). As a result, we may underestimate the total benefits attributable to the implementation of the final standards.

This chapter is organized as follows. In Section 8.2, we provide an overview of the air quality impacts modeled for the final standards that are used as inputs to the benefits analysis. In Section 8.3, we discuss how uncertainty is characterized in this analysis. Section 8.4 discusses the literature on ozone- and PM-related health effects and describes the specific set of health impact functions we used in the benefits analysis. Section 8.5 describes the economic values selected to estimate the dollar value of ozone- and PM-related health impacts. In Section 8.6, we report the results of the analysis for human health and welfare effects. Finally, Section 8.7 presents a comparison of the costs and benefits associated with the final standards. There are also two appendices associated with this chapter. The first, Appendix 8A, presents the results of the health-based cost effectiveness analysis. The second, Appendix 8A, presents the results of sensitivity analyses of key parameters in the benefits analysis.

8.2 Air Quality Impacts for Benefits Analysis

In Chapter 2, we summarize the methods for and results of estimating air quality for the 2020 and 2030 base case and final control scenario. These air quality results are in turn associated with human populations and ecosystems to estimate changes in health and welfare effects. For the purposes of the benefits analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emission reductions estimated to occur due to the final standards. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). The air quality modeling Technical Support Document (TSD), which can be found in the docket for this rule, contains detailed information about the modeling conducted for this rule. In this section, we describe how the modeled air quality results were used for the benefits analysis.

We remind the reader that the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission control program. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Emissions and air quality modeling decisions are made early in the analytical process. Chapter 3 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario.

8.2.1 Converting CMAQ Outputs to Full-Season Profiles for Benefits Analysis

This analysis extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[A,B] The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (i.e., the Environmental Benefits Mapping and Analysis Program [BenMAP]).

To estimate ozone-related health and welfare effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily 8-hour maximum.[C,D]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2002 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 1999). The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the final emissions controls. Full documentation of the revised SMAT methodology is contained in the Air Quality Modeling TSD.

[A] The ozone season for this analysis is defined as the 5-month period from May to September.

[B] Based on AIRS, there were 961 ozone monitors with sufficient data (i.e., 50 percent or more days reporting at least nine hourly observations per day [8 am to 8 pm] during the ozone season).

[C] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.

[D] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www.epa.gov/air/benmap.

8.2.2 Ozone and $PM_{2.5}$ Air Quality Results

This section provides a summary of the predicted ambient $PM_{2.5}$ and ozone concentrations from the CMAQ model for the 2020 and 2030 base cases and changes associated with the final rule. Table 8.2-1 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

Table 8.2-1. Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Due to the Final Small SI and Marine SI Engine Standards

	2020		2030	
Statistic[a]	Baseline	Change[b]	Baseline	Change[b]
Ozone Metrics: National Population-Weighted Average (ppb)[c]				
Daily 1-Hour Maximum Concentration	47.60	0.078	46.91	0.108
Daily 8-Hour Maximum Concentration	44.07	0.066	43.47	0.093
Daily 8-Hour Average Concentration	42.63	0.062	42.06	0.088
Daily 24-Hour Average Concentration	35.39	0.047	35.02	0.068
$PM_{2.5}$ Metrics: National Population-Weighted Average (ug/m^3)				
Annual Average Concentration	9.41	0.015	9.38	0.021

[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates based on the results of spatial and temporal Voronoi Neighbor Averaging. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (i.e., May through September). For the 8-hour average, for example, the relevant time period is 9 am to 5 pm.

[b] The change is defined as the base-case value minus the control-case value.

[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

8.3 Characterizing Uncertainty: Moving Toward a Probabilistic Framework for Benefits Assessment

The National Research Council (NRC)[5] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that process include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

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, it is particularly important to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies.[E] In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs. In addition, we characterize the uncertainty introduced by the inability of existing empirical studies to discern whether the relationship between ozone and pre-mature mortality is causal by providing an effect estimate preconditioned on an assumption that the effect estimate for pre-mature mortality from ozone is zero.

For premature mortality associated with exposure to PM, we follow the same approach that has been used in several recent RIAs.[F,G,H] First, we use Monte Carlo methods for estimating random sampling error associated with the concentration response functions from epidemiological studies and economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. Distributions for individual effect estimates are based on the reported standard errors in the epidemiological studies. Distributions for unit values are described in Table 8.5-1.

Second, we use the results of our expert elicitation of the concentration response function describing the relationship between premature mortality and ambient $PM_{2.5}$ concentration.[I, J] Incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model; whether or not a

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[E] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration.

[F] U.S. Environmental Protection Agency, 2004a. Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. EPA420-R-04-007. Prepared by Office of Air and Radiation. Available at http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf

[G] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the Clean Air Interstate Rule. EPA 452/-03-001. Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/interstateairquality/tsd0175.pdf

[H] U.S. Environmental Protection Agency, 2006. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

[I] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

[J] Industrial Economics, Inc. 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Prepared for EPA Office of Air Quality Planning and Standards, September. Available at: http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf threshold may exist). This second approach attempts to incorporate these other sources of uncertainty.

Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA.

These multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

8.4 Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: 1) an effect estimate from a particular study; 2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); 3) the size of the potentially affected population; and 4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. Section 6.2 described the ozone and PM air quality inputs to the health impact functions. The following subsections describe the sources for each of the other elements: size of potentially affected populations; effect estimates; and baseline incidence rates.

8.4.1 Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[6] Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2020 using growth factors based on economic projections.[7]

8.4.2 Effect Estimate Sources

The most significant monetized benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents[8,9] and the World Health Organization's 2003 and 2004[10,11] reports outline numerous health effects known or suspected to be linked to exposure to ambient ozone and PM. EPA recently evaluated the PM literature for use in the benefits analysis for the 2006 PM NAAQS RIA. Because we used the same literature for the PM benefits analysis in this RIA, and also in the RIA for the proposed rule, we do not provide a detailed discussion of individual effect estimates for PM in this section. Instead, we refer the reader to the 2006 PM NAAQS RIA and the proposed Small SI and Marine SI RIA for details.[K]

The RIA for the proposal for this rulemaking only quantified benefits from PM; in the current RIA we quantify and monetize the ozone-related health and environmental impacts associated with the final rule using an approach consistent with the final ozone NAAQS RIA. More than one thousand new ozone health and welfare studies have been published since EPA issued the 8-hour ozone standard in 1997. Many of these studies investigated the impact of ozone exposure on health effects such as: changes in lung structure and biochemistry; lung inflammation; asthma exacerbation and causation; respiratory illness-related school absence; hospital and emergency room visits for asthma and other respiratory causes; and premature death. We provide a discussion of those ozone-related impacts in this section. For a more detailed discussion of the health effects of ozone exposure, we point the reader to EPA's ozone Criteria Document.[12]

It is important to note that we were not able to separately quantify all of the PM and ozone health effects that have been reported in the ozone and PM criteria documents in this analysis for four reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; (3) the lack of an established concentration-response relationship; or 4) the inability to appropriately value the effect (for example, changes in forced expiratory volume) in economic terms. Table 8.4-1 lists the human health and welfare effects of pollutants affected by the final standards. Table 8.4-2 lists the health endpoints included in this analysis.

[K] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf pp. 5-29.

Table 8.4-1 Human Health and Welfare Effects of Pollutants Affected by the Final Standards

Pollutant/Effect	*Quantified and Monetized in Base Estimates*[a]	*Unquantified Effects - Changes in:*
PM/Health[b]	Premature mortality based on both cohort study estimates and on expert elicitation[c,d] 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	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
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 Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Acute respiratory symptoms	Cardiovascular emergency room visits Chronic respiratory damage[g] Premature aging of the lungs[g] Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare	Decreased outdoor worker productivity	Yields for commercial crops Yields for commercial forests and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]

Pollutant/Effect	*Quantified and Monetized in Base Estimates*[a]	*Unquantified Effects - Changes in:*
Nitrogen Deposition/ Welfare		Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
NOx/Health		Lung irritation Lowered resistance to respiratory infection Hospital admissions for respiratory and cardiac diseases
HC/Toxics Health[h]		Cancer, including lung (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)
HC/Toxics 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 final 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).

[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.

[f] The public health impact of biological responses such as increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection are likely partially represented by our quantified endpoints.

[g] The public health impact of effects such as chronic respiratory damage and premature aging of the lungs may be partially represented by quantified endpoints such as hospital admissions or premature mortality, but a number of other related health impacts, such as doctor visits and decreased athletic performance, remain unquantified.

[h] The categorization of unquantified toxic health and welfare effects is not exhaustive.

Table 8.4-2. Ozone- and PM-Related Health Endpoints

Endpoint	*Pollutant*	*Study*	*Study Population*
Premature Mortality			
Premature mortality – daily time series, non-accidental	ozone	Bell et al (2004) (NMMAPS study)[13] Meta-analyses: Bell et al (2005)[14] Ito et al (2005)[15] Levy et al (2005)[16]	All ages
Premature mortality —cohort study, all-cause	PM$_{2.5}$	Pope et al. (2002)[17] Laden et al. (2006)[18]	>29 years >25 years
Premature mortality, total exposures	PM$_{2.5}$	Expert Elicitation (IEc, 2006)[19]	>24 years
Premature mortality — all-cause	PM$_{2.5}$	Woodruff et al. (1997)[20]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	PM$_{2.5}$	Abbey et al. (1995)[21]	>26 years
Nonfatal heart attacks	PM$_{2.5}$	Peters et al. (2001)[22]	Adults (>18 years)
Hospital Admissions			
Respiratory	ozone	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[23] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[24,25] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[26] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[27]	<2 years
	PM$_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[28] Ito (2003)—ICD 490-496 (COPD)[29]	>64 years
	PM$_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[30]	20–64 years
	PM$_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	PM$_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[31]	<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	ozone	Pooled estimate: Jaffe et al (2003)[32] Peel et al (2005)[33] Wilson et al (2005)[34]	 5–34 years All ages All ages

Endpoint	*Pollutant*	*Study*	*Study Population*
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[35]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[36]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[37]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[38]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[39] (cough, wheeze and shortness of breath) Vedal et al. (1998)[40] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[41]	18–65 years
School absence days	ozone	Pooled estimate: Gilliland et al. (2001)[42] Chen et al. (2000)[43]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	ozone	Ostro and Rothschild (1989)[44]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

[a] 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 Science Advisory Board Health Effects Subcommittee (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. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations.* Washington, DC: The National Academies Press.

[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.[45,46]

A number of endpoints that are not health-related also may significantly contribute to monetized benefits. Potential welfare benefits associated with ozone exposure include: increased outdoor worker productivity; increased yields for commercial and non-commercial crops; increased commercial forest productivity; reduced damage to urban ornamental plants; increased recreational demand for undamaged forest aesthetics; and reduced damage to ecosystem functions.[47,48] While we include estimates of the value of increased outdoor worker productivity, estimation of other welfare impacts is beyond the scope of this analysis.

8.4.2.1 Ozone Exposure Metric

Both the NMMAPS analysis and the individual time series studies upon which the meta-analyses were based use the 24-hour average or 1-hour maximum ozone levels as exposure metrics.[L] The 24-hour average is not the most relevant ozone exposure metric to characterize population-level exposure. Given that the majority of the people tend to be outdoors during the daylight hours and concentrations are highest during the daylight hours, the 24-hour average metric is not appropriate. The maximum 1-hour average metric uses an exposure window different than that that used for the current ozone NAAQS. Together, this means that the most biologically relevant metric is the maximum 8-hour average, which has also been the metric for ozone NAAQS since 1997. Thus, for the final rule analysis, we have converted ozone mortality health impact functions that use a 24-hour average or 1-hour maximum ozone metric to maximum 8-hour average ozone concentration using standard conversion functions.

This practice is consistent both with the available exposure modeling and with the form of the current ozone standard. This conversion also does not affect the relative magnitude of the health impact function. An equivalent change in the 24-hour average, maximum1-hour average, and maximum 8-hour average will provide the same overall change in incidence of a health effect. The conversion ratios are based on observed relationships between the 24-hour average and maximum 8-hour average ozone values. For example, in the Bell et al., 2004 analysis of ozone-related premature mortality, the authors found that the relationship between the 24-hour average, the maximum 8-hour average, and the maximum 1-hour average was 2:1.5:1, so that the derived health impact effect estimate based on the maximum 1-hour average should be half that of the effect estimate based on the 24-hour values (and the maximum 8-hour average three-quarters of the 24-hour effect estimate).

8.4.2.2 Premature Mortality Effect Estimates

While particulate matter is the criteria pollutant most clearly associated with premature mortality, recent research suggests that short-term repeated ozone exposure likely contributes to premature death. The 2006 Ozone Criteria Document states: “Consistent with observed ozone-related increases in respiratory- and cardiovascular-related morbidity, several newer multi-city studies, single-city studies, and several meta-analyses of these studies have provided relatively strong epidemiologic evidence for associations between short-term ozone exposure and all-cause mortality, even after adjustment for the influence of season and PM” (EPA, 2006: E-17).[49] The epidemiologic data are also supported by newly available experimental data from both animal and human studies which provide evidence suggestive of

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[L] An exposure metric is a measure of air quality calculated as the average or maximum of modeled ambient concentrations over a relevant time period, such as during the daylight hours of the “ozone season” (which is May through September for this analysis). The 24-hour average is therefore calculated as the average of all hourly ozone concentrations throughout the day (from 12am to 11:59pm). The 8-hour maximum is the maximum hourly value observed between 9am and 5pm each day. The 1-hour maximum is the maximum hourly value observed throughout an entire day.

plausible pathways by which risk of respiratory or cardiovascular morbidity and mortality could be increased by ambient ozone. With respect to short-term exposure, the ozone Criteria Document concludes: "This overall body of evidence is highly suggestive that ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to more fully establish underlying mechanisms by which such effects occur" (pg. E-18).

With respect to the time-series studies, the conclusion regarding the relationship between short-term exposure and premature mortality is based, in part, upon recent city-specific time-series studies such as the Schwartz (2004) analysis in Houston and the Huang et al. (2004) analysis in Los Angeles.[M] This conclusion is also based on recent meta-analyses by Bell et al. (2005), Ito et al. (2005), and Levy et al. (2005), and a new analysis of the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) data set by Bell et al. (2004), which specifically sought to disentangle the roles of ozone, PM, weather-related variables, and seasonality. The 2006 Criteria Document states that "the results from these meta-analyses, as well as several single- and multiple-city studies, indicate that co-pollutants generally do not appear to substantially confound the association between ozone and mortality" (p. 7-103). However, CASAC raised questions about the implications of these time-series results in a policy context. Specifically, CASAC emphasized that "…while the time-series study design is a powerful tool to detect very small effects that could not be detected using other designs, it is also a blunt tool" (Henderson, 2006: 3). They point to findings (e.g., Stieb et al., 2002, 2003) that indicated associations between premature mortality and all of the criteria pollutants, indicating that "findings of time-series studies do not seem to allow us to confidently attribute observed effects to individual pollutants" (id.). They note that "not only is the interpretation of these associations complicated by the fact that the day-to-day variation in concentrations of these pollutants is, to a varying degree, determined by meteorology, the pollutants are often part of a large and highly correlated mix of pollutants, only a very few of which are measured" (id.). Even with these uncertainties, the CASAC Ozone Panel, in its review of EPA's Staff Paper, found "…premature total non-accidental and cardiorespiratory mortality for inclusion in the quantitative risk assessment to be appropriate."

Consistent with the methodology used in the ozone risk assessment found in the Characterization of Health Risks found in the Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, we included ozone mortality in the primary health effects analysis, with the recognition that the exact magnitude of the effects estimate is subject to continuing uncertainty. We used effect estimates from the Bell et al. (2004) NMMAPS analysis, as well as effect estimates from the three meta-analyses.

[M] For an exhaustive review of the city-specific time-series studies considered in the ozone staff paper, see: U.S. Environmental Protection Agency, 2007. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. Prepared by the Office of Air and Radiation. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2007_01_ozone_staff_paper.pdf. pp. 5-36.

In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC),[50] a panel of experts and reviewers concluded that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure. The report also recommended that the estimation of ozone-related premature mortality be accompanied by broad uncertainty analyses while giving little or no weight to the assumption that there is no causal association between ozone exposure and premature mortality. Because EPA has yet to develop a coordinated response to the NRC report's findings and recommendations, however, we have retained the approach to estimating ozone-related premature mortality used in RIA for the final Ozone NAAQS. EPA will specifically address the report's findings and recommendations in future rulemakings.

We estimate the change in mortality incidence and estimated credible interval[N] resulting from application of the effect estimate from each study and present them separately to reflect differences in the study designs and assumptions about causality. However, it is important to note that this procedure only captures the uncertainty in the underlying epidemiological work, and does not capture other sources of uncertainty, such as uncertainty in the estimation of changes in air pollution exposure (Levy et al., 2000).

8.4.2.3 Respiratory Hospital Admissions Effect Estimates

Detailed hospital admission and discharge records provide data for an extensive body of literature examining the relationship between hospital admissions and air pollution. This is especially true for the portion of the population aged 65 and older, because of the availability of detailed Medicare records. In addition, there is one study (Burnett et al., 2001) providing an effect estimate for respiratory hospital admissions in children under two.

Because the number of hospital admission studies we considered is so large, we used results from a number of studies to pool some hospital admission endpoints. Pooling is the process by which multiple study results may be combined in order to produce better estimates of the effect estimate, or β. For a complete discussion of the pooling process, see Abt (2005).[O] To estimate total respiratory hospital admissions associated with changes in ambient ozone concentrations for adults over 65, we first estimated the change in hospital admissions for each of the different effects categories that each study provided for each city. These cities included Minneapolis, Detroit, Tacoma and New Haven. To estimate total respiratory hospital admissions for Detroit, we added the pneumonia and COPD estimates, based on the effect estimates in the Schwartz study (1994). Similarly, we summed the estimated hospital admissions based on the effect estimates the Moolgavkar study reported for Minneapolis (Moolgavkar et al., 1997). To estimate total respiratory hospital admissions for Minneapolis using the Schwartz study (1994), we simply estimated pneumonia hospital admissions based on the effect estimate. Making this assumption that pneumonia admissions represent the total

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[N] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[O] Abt Associates, Incorporated. Environmental Benefits Mapping and Analysis Program, Technical Appendices. May 2005. pp. I-3 impact of ozone on hospital admissions in this city will give some weight to the possibility that there is no relationship between ozone and COPD, reflecting the equivocal evidence represented by the different studies. We then used a fixed-effects pooling procedure to combine the two total respiratory hospital admission estimates for Minneapolis. Finally, we used random effects pooling to combine the results for Minneapolis and Detroit with results from studies in Tacoma and New Haven from Schwartz (1995). As noted above, this pooling approach incorporates both the precision of the individual effect estimates and between-study variability characterizing differences across study locations.

8.4.2.4 Asthma-Related Emergency Room Visits Effect Estimates

We used three studies as the source of the concentration-response functions we used to estimate the effects of ozone exposure on asthma-related emergency room (ER) visits: Peel et al. (2005); Wilson et al. (2005); and Jaffe et al. (2003). We estimated the change in ER visits using the effect estimate(s) from each study and then pooled the results using the random effects pooling technique (see Abt, 2005). The study by Jaffe et al. (2003) examined the relationship between ER visits and air pollution for populations aged five to 34 in the Ohio cities of Cleveland, Columbus and Cincinnati from 1991 through 1996. In single-pollutant Poisson regression models, ozone was linked to asthma visits. We use the pooled estimate across all three cities as reported in the study. The Peel et al. study (2005) estimated asthma-related ER visits for all ages in Atlanta, using air quality data from 1993 to 2000. Using Poisson generalized estimating equations, the authors found a marginal association between the maximum daily 8-hour average ozone level and ER visits for asthma over a 3-day moving average (lags of 0, 1, and 2 days) in a single pollutant model. Wilson et al. (2005) examined the relationship between ER visits for respiratory illnesses and asthma and air pollution for all people residing in Portland, Maine from 1998-2000 and Manchester, New Hampshire from 1996-2000. For all models used in the analysis, the authors restricted the ozone data incorporated into the model to the months ozone levels are usually measured, the spring-summer months (April through September). Using the generalized additive model, Wilson et al. (2005) found a significant association between the maximum daily 8-hour average ozone level and ER visits for asthma in Portland, but found no significant association for Manchester. Similar to the approach used to generate effect estimates for hospital admissions, we used random effects pooling to combine the results across the individual study estimates for ER visits for asthma. The Peel et al. (2005) and Wilson et al. (2005) Manchester estimates were not significant at the 95 percent level, and thus, the confidence interval for the pooled incidence estimate based on these studies includes negative values. This is an artifact of the statistical power of the studies, and the negative values in the tails of the estimated effect distributions do not represent improvements in health as ozone concentrations are increased. Instead these should be viewed as a measure of uncertainty due to limitations in the statistical power of the study. Note that we included both hospital admissions and ER visits as separate endpoints associated with ozone exposure, because our estimates of hospital admission costs do not include the costs of ER visits, and because most asthma ER visits do not result in a hospital admission.

8.4.2.5 Minor Restricted Activity Days Effects Estimate

Minor restricted activity days (MRADs) occur when individuals reduce most usual daily activities and replace them with less-strenuous activities or rest, but do not miss work or school. We estimated the effect of ozone exposure on MRADs using a concentration-response function derived from Ostro and Rothschild (1989). These researchers estimated the impact of ozone and $PM_{2.5}$ on MRAD incidence in a national sample of the adult working population (ages 18 to 65) living in metropolitan areas. We developed separate coefficients for each year of the Ostro and Rothschild analysis (1976-1981), which we then combined for use in EPA's analysis. The effect estimate used in the impact function is a weighted average of the coefficients in Ostro and Rothschild (1989, Table 4), using the inverse of the variance as the weight.

8.4.2.6 School Absences Effect Estimate

Children may be absent from school due to respiratory or other acute diseases caused, or aggravated by, exposure to air pollution. Several studies have found a significant association between ozone levels and school absence rates. We use two studies (Gilliland et al., 2001; Chen et al., 2000) to estimate changes in school absences resulting from changes in ozone levels. The Gilliland et al. study estimated the incidence of new periods of absence, while the Chen et al. study examined daily absence rates. We converted the Gilliland et al. estimate to days of absence by multiplying the absence periods by the average duration of an absence. We estimated 1.6 days as the average duration of a school absence, the result of dividing the average daily school absence rate from Chen et al. (2000) and Ransom and Pope (1992) by the episodic absence duration from Gilliland et al. (2001). Thus, each Gilliland et al. period of absence is converted into 1.6 absence days.

Following recent advice from the National Research Council (2002), we calculated reductions in school absences for the full population of school age children, ages five to 17. This is consistent with recent peer-reviewed literature on estimating the impact of ozone exposure on school absences (Hall et al. 2003). We estimated the change in school absences using both Chen et al. (2000) and Gilliland et al. (2001) and then, similar to hospital admissions and ER visits, pooled the results using the random effects pooling procedure.

8.4.2.7 Worker Productivity

To monetize benefits associated with increased worker productivity resulting from improved ozone air quality, we used information reported in Crocker and Horst (1981). Crocker and Horst examined the impacts of ozone exposure on the productivity of outdoor citrus workers. The study measured productivity impacts. Worker productivity is measuring the value of the loss in productivity for a worker who is at work on a particular day, but due to ozone, cannot work as hard. It only applies to outdoor workers, like fruit and vegetable pickers, or construction workers. Here, productivity impacts are measured as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration. The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income. Given the national median daily income for outdoor workers engaged in strenuous activity reported by the U.S. Census Bureau (2002), $68 per day (2000$), a ten percent reduction in ozone yields about $0.97 in increased daily wages. We adjust the national median daily income estimate to reflect regional variations in income using a factor based on the ratio of county median household income to national median household income. No information was available for quantifying the uncertainty associated with the central valuation estimate. Therefore, no uncertainty analysis was conducted for this endpoint.

8.4.2.8 Unquantified Effects

8.4.2.8.1 Direct Ozone Effects on Vegetation

The Ozone Criteria Document notes that “current ambient concentrations in many areas of the country are sufficient to impair growth of numerous common and economically valuable plant and tree species.” (U.S. EPA, 2006, page 9-1). Changes in ground-level ozone resulting from the implementation of alternative ozone standards are expected to affect crop and forest yields throughout the affected area. Recent scientific studies have also found the ozone negatively impacts the quality or nutritive value of crops (U.S. EPA, 2006, page 9-16).

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 the supply of and demand for agricultural products. 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 benefits estimates for the final rule.

An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 2006, page 9-19). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals (floriculture and nursery crops) represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to affect large economic sectors. 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 economic benefits analysis has been conducted. The farm production value of ornamental crops was estimated at over $14 billion in 2003 (USDA, 2004). This is therefore a potentially important welfare effects category. However, information and valuation 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.

8.4.2.8.2 Nitrogen Deposition

Deposition to Estuarine and Coastal Waters

Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999). A recent study found that for the period 1990-2002, atmospheric deposition accounted for 17 percent of nitrate loadings in the Gulf of Mexico, where severe hypoxic zones have been existed over the last two decades (Booth and Campbell, 2007)[P].

Reductions in atmospheric deposition of NOx are expected to reduce the adverse impacts associated with nitrogen deposition to estuarine and coastal waters. However, direct functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP-based measure of benefits depends on the availability of these functions and on estimates of the value of environmental responses. Because neither appropriate functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

Deposition to Agricultural and Forested Land

Implementation strategies for alternative standards which reduce NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers’ use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

[P] Booth, M.S., and C. Campbell. 2007. Spring Nitrate Flux in the Mississippi River Basin: A Landscape Model with Conservation Applications. Environ. Sci. Technol.; 2007; ASAP Web Release Date: 20-Jun-2007; (Article) DOI: 10.1021/es070179e

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (US EPA, 1993). Moreover, any positive effect that nitrogen deposition has on forest productivity would enhance the level of carbon dioxide sequestration as well.[Q,R,S]

On the other hand, there is evidence that forest ecosystems in some areas of the United States (such as the western U.S.) are nitrogen saturated (US EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

8.4.2.8.3 Ultraviolet Radiation

Atmospheric ozone absorbs a harmful band of ultraviolet radiation from the sun called UV-B, providing a protective shield to the Earth's surface. The majority of this protection occurs in the stratosphere where 90% of atmospheric ozone is located. The remaining 10% of the Earth's ozone is present at ground level (referred to as tropospheric ozone) (NAS, 1991; NASA). Only a portion of the tropospheric fraction of UV-B shielding is from anthropogenic sources (e.g., power plants, byproducts of combustion). The portion of ground level ozone associated with anthropogenic sources varies by locality and over time. Even so, it is reasonable to assume that reductions in ground level ozone would lead to increases in the same health effects linked to in UV-B exposures. These effects include fatal and nonfatal melanoma and non-melanoma skin cancers and cataracts. The values of $15,000 per case for non-fatal melanoma skin cancer, $5,000 per case for non-fatal non-melanoma skin cancer, and $15,000 per case of cataracts have been used in analyses of stratospheric ozone depletion (U.S. EPA, 1999). Fatal cancers are valued using the standard VSL estimate, which for 2020 is $6.6 million (1999$). UV-B has also been linked to ecological effects including damage to crops and forest. For a more complete listing of quantified and unquantified UV-B radiation effects, see Table G-4 and G-7 in the Benefits and Costs of the Clean Air Act, 1990-2010 (U.S. EPA, 1999. UV-B related health effects are also discussed in the context of stratospheric ozone in a 2006 report by ICF Consulting, prepared for the U.S. EPA.

[Q] Peter M. Vitousek et. al., "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences" *Issues in Ecology* No. 1 (Spring) 1997.

[R] Knute J. Nadelhoffer et. al., "Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests" *Nature* 398, 145-148 (11 March 1999)

[S] Martin Köchy and Scott D. Wilson, "Nitrogen deposition and forest expansion in the northern Great Plains Journal of Ecology *Journal of Ecology* 89 (5), 807–817

There are many factors that influence UV-B radiation penetration to the earth's surface, including latitude, altitude, cloud cover, surface albedo, PM concentration and composition, and gas phase pollution. Of these, only latitude and altitude can be defined with small uncertainty in any effort to assess the changes in UV-B flux that may be attributable to any changes in tropospheric ozone as a result of any revision to the ozone NAAQS. Such an assessment of UV-B related health effects would also need to take into account human habits, such as outdoor activities (including age- and occupation-related exposure patterns), dress and skin care to adequately estimate UV-B exposure levels. However, little is known about the impact of these factors on individual exposure to UV-B.

Moreover, detailed information does not exist regarding other factors that are relevant to assessing changes in disease incidence, including: type (e.g., peak or cumulative) and time period (e.g., childhood, lifetime, current) of exposures related to various adverse health outcomes (e.g., damage to the skin, including skin cancer; damage to the eye, such as cataracts; and immune system suppression); wavelength dependency of biological responses; and interindividual variability in UV-B resistance to such health outcomes. Beyond these well recognized adverse health effects associated with various wavelengths of UV radiation, the Criteria Document (section 10.2.3.6) also discusses protective effects of UV-B radiation. Recent reports indicate the necessity of UV-B in producing vitamin D, and that vitamin D deficiency can cause metabolic bone disease among children and adults, and may also increase the risk of many common chronic diseases (e.g., type I diabetes and rheumatoid arthritis) as well as the risk of various types of cancers. Thus, the Criteria Document concludes that any assessment that attempts to quantify the consequences of increased UV-B exposure on humans due to reduced ground-level ozone must include consideration of both negative and positive effects. However, as with other impacts of UVB on human health, this beneficial effect of UVB radiation has not previously been studied in sufficient detail.

The Agency is currently evaluating the feasibility of estimating the effects of increased UVB exposures resulting from reductions in tropospheric ozone. Please refer to the final Ozone NAAQS RIA for a sensitivity analysis that explores the quantification of UV-B-related health effects.[51]

8.4.2.8.4 Climate Implications of Tropospheric Ozone

Although climate and air quality are generally treated as separate issues, they are closely coupled through atmospheric processes. Ozone, itself, is a major greenhouse gas and climate directly influences ambient concentrations of ozone.

The concentration of tropospheric ozone has increased substantially since the pre-industrial era and has contributed to warming. Tropospheric ozone is (after CO2 and CH4) the third most important contributor to greenhouse gas warming. The National Academy of Sciences recently stated[T] that regulations targeting ozone precursors would have combined

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[T] National Academy of Sciences, "Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties," October 2005.

benefits for public health and climate. As noted in the OAQPS Staff Paper, the overall body of scientific evidence suggests that high concentrations of ozone on a regional scale could have a discernible influence on climate. However, the Staff Paper concludes that insufficient information is available at this time to quantitatively inform the secondary NAAQS process with regard to this aspect of the ozone-climate interaction.

Climate change can affect tropospheric ozone by modifying emissions of precursors, chemistry, transport and removal.[U] Climate change affects the sources of ozone precursors through physical response (lightning), biological response (soils, vegetation, and biomass burning) and human response (energy generation, land use, and agriculture). Increases in regional ozone pollution are expected due to higher temperatures and weaker circulation. Simulations with global climate models for the 21st century indicate a decrease in the lifetime of tropospheric ozone due to increasing water vapor which could decrease global background ozone concentrations.

The Intergovernmental Panel on Climate Change (IPCC) recently released a report[V] which projects, with "virtual certainty," declining air quality in cities due to warmer and fewer cold days and nights and/or warmer/more frequent hot days and nights over most land areas. The report states that projected climate change-related exposures are likely to affect the health status of millions of people, in part, due to higher concentrations of ground level ozone related to climate change.

The IPCC also reports[W] that the current generation of tropospheric ozone models is generally successful in describing the principal features of the present-day global ozone distribution. However, there is much less confidence in the ability to reproduce the changes in ozone associated with perturbations of emissions or climate. There are major discrepancies with observed long-term trends in ozone concentrations over the 20th century, including after 1970 when the reliability of observed ozone trends is high. Resolving these discrepancies is needed to establish confidence in the models.

[U] Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment*

Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[V] IPCC, Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability,

Summary for Policymakers

[W] Denman, et al, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis.*

The EPA is currently leading a research effort with the goal of identifying changes in regional US air quality that may occur in a future (2050) climate, focusing on fine particles and ozone. The research builds first on an assessment of changes in US air quality due to climate change, which includes direct meteorological impacts on atmospheric chemistry and transport and the effect of temperature changes on air pollution emissions. Further research will result in an assessment that adds the emission impacts from technology, land use, demographic changes, and air quality regulations to construct plausible scenarios of US air quality 50 years into the future. As noted in the Staff Paper, results from these efforts are expected to be available for consideration in the next review of the ozone NAAQS.

8.4.3 Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 100 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per 100,000 people, that number must be multiplied by the number of 100,000s in the population.

Table 8.4-3 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth (Abt Associates, 2005).

Table 8.4-3. National Average Baseline Incidence Rates[a]

Endpoint	Source	Notes	Rate per 100 people per year[d] by Age Group						
			<18	*18-24*	*25-34*	*35-44*	*45-54*	*55-64*	*65+*
Mortality	CDC Compressed Mortality File, accessed through CDC Wonder (1996-1998)	non-accidental	0.025	0.022	0.057	0.150	0.383	1.006	4.937
Respiratory Hospital Admissions.	1999 NHDS public use data files[b]	incidence	0.043	0.084	0.206	0.678	1.926	4.389	11.629
Asthma ER visits	2000 NHAMCS public use data files[c]; 1999 NHDS public use data files[b]	incidence	1.011	1.087	0.751	0.438	0.352	0.425	0.232
Minor Restricted Activity Days (MRADs)	Ostro and Rothschild (1989, p. 243)	incidence	–	780	780	780	780	780	–
School Loss Days	National Center for Education Statistics (1996) and 1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year	all-cause	990.0	–	–	–	–	–	–

Endpoint	Source	Notes		Rate per 100 people per year
Asthma Exacerbations	Ostro et al. (2001)	Incidence (and prevalence) among asthmatic African-American children	Daily wheeze	0.076 (0.173)
			Daily cough	0.067 (0.145)
			Daily dyspnea	0.037 (0.074)
	Vedal et al. (1998)	Incidence among asthmatic children	Daily wheeze	0.038
			Daily cough	0.086
			Daily dyspnea	0.045

[a] The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS - National Hospital Discharge Survey; NHAMCS - National Hospital Ambulatory Medical Care Survey.

[b] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/

[c] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/

[d] All of the rates reported here are population-weighted incidence rates per 100 people per year. Additional details on the incidence and prevalence rates, as well as the sources for these rates are available upon request.

8.5 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993). Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987). We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 8.5-1. All values are in constant year 2000 dollars, adjusted for growth in real income out to 2020 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. Table 8.5-1 presents the values for individual endpoints adjusted to year 2020 income levels. The discussion below provides additional details on ozone related endpoints not previously included in the proposal for this rule. For details on valuation estimates for PM-related endpoints, see the 2006 PM NAAQS RIA and the proposed Small SI and Marine SI RIA.

8.5.1 Mortality Valuation

To estimate the monetary benefit of reducing the risk of premature death, we used the "value of statistical lives" saved (VSL) approach, which is a summary measure for the value of small changes in mortality risk for a large number of people. The VSL approach applies information from several published value-of-life studies to determine a reasonable monetary value of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be roughly $6.2 million at 1990 income levels (2005$), and $7.5 million at 2020 income levels. This represents an intermediate value from a variety of estimates in the economics literature (see the 2006 PM NAAQS RIA for more details on the calculation of VSL).

8.5.2 Hospital Admissions Valuation

In the absence of estimates of societal WTP to avoid hospital visits/admissions for specific illnesses, estimates of total cost of illness (total medical costs plus the value of lost productivity) typically are used as conservative, or lower bound, estimates. These estimates are biased downward, because they do not include the willingness-to-pay value of avoiding pain and suffering.

The International Classification of Diseases (ICD-9, 1979) code-specific COI estimates used in this analysis consist of estimated hospital charges and the estimated opportunity cost of time spent in the hospital (based on the average length of a hospital stay for the illness). We based all estimates of hospital charges and length of stays on statistics provided by the Agency for Healthcare Research and Quality (AHRQ 2000). We estimated the opportunity cost of a day spent in the hospital as the value of the lost daily wage, regardless of whether the hospitalized individual is in the workforce. To estimate the lost daily wage, we divided the 1990 median weekly wage by five and inflated the result to year 2005$ using the CPI-U "all items." The resulting estimate is $135.59. The total cost-of-illness estimate for an ICD code-specific hospital stay lasting *n* days, then, was the mean hospital charge plus $136 • *n*.

8.5.3 Asthma-Related Emergency Room Visits Valuation

To value asthma emergency room visits, we used a simple average of two estimates from the health economics literature. The first estimate comes from Smith et al. (1997), who reported approximately 1.2 million asthma-related emergency room visits in 1987, at a total cost of $186.5 million (1987$). The average cost per visit that year was $155; in 2005$, that cost was $386.32 (using the CPI-U for medical care to adjust to 2005$). The second estimate comes from Stanford et al. (1999), who reported the cost of an average asthma-related emergency room visit at $323.23 (in 2005$), based on 1996-1997 data. A simple average of the two estimates yields a (rounded) unit value of $355.

8.5.4 Minor Restricted Activity Days Valuation

No studies are reported to have estimated WTP to avoid a minor restricted activity day. However, one of EPA's contractors, IEc (1993) has derived an estimate of willingness to pay to avoid a minor *respiratory* restricted activity day, using estimates from Tolley et al. (1986) of WTP for avoiding a combination of coughing, throat congestion and sinusitis. The IEc estimate of WTP to avoid a minor respiratory restricted activity day is $38.37 (1990$), or about $59 (2005$).

Although Ostro and Rothschild (1989) statistically linked ozone and minor restricted activity days, it is likely that most MRADs associated with ozone exposure are, in fact, minor *respiratory* restricted activity days. For the purpose of valuing this health endpoint, we used the estimate of mean WTP to avoid a minor respiratory restricted activity day.

8.5.5 School Absences

To value a school absence, we: (1) estimated the probability that if a school child stays home from school, a parent will have to stay home from work to care for the child; and (2) valued the lost productivity at the parent's wage. To do this, we estimated the number of families with school-age children in which both parents work, and we valued a school-loss day as the probability that such a day also would result in a work-loss day. We calculated this value by multiplying the proportion of households with school-age children by a measure of lost wages.

We used this method in the absence of a preferable WTP method. However, this approach suffers from several uncertainties. First, it omits willingness to pay to avoid the symptoms/illness that resulted in the school absence; second, it effectively gives zero value to school absences that do not result in work-loss days; and third, it uses conservative assumptions about the wages of the parent staying home with the child. Finally, this method assumes that parents are unable to work from home. If this is not a valid assumption, then there would be no lost wages.

For this valuation approach, we assumed that in a household with two working parents, the female parent will stay home with a sick child. From the Statistical Abstract of the United States (U.S. Census Bureau, 2001), we obtained: (1) the numbers of single, married and “other” (widowed, divorced or separated) working women with children; and (2) the rates of participation in the workforce of single, married and “other” women with children. From these two sets of statistics, we calculated a weighted average participation rate of 72.85 percent.

Our estimate of daily lost wage (wages lost if a mother must stay at home with a sick child) is based on the year 2000 median weekly wage among women ages 25 and older (U.S. Census Bureau, 2001). This median weekly wage is $551. Dividing by five gives an estimated median daily wage of $103. To estimate the expected lost wages on a day when a mother has to stay home with a school-age child, we first estimated the probability that the mother is in the workforce then multiplied that estimate by the daily wage she would lose by missing a work day: 72.85 percent times $103, for a total loss of $75. Using the CPI-U for all items to adjust to 2005$, the value equals approximately $85. This valuation approach is similar to that used by Hall et al. (2003).

Table 8.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2005$)[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): $PM_{2.5}$- and Ozone-related	$6,200,000	$7,500,000	$7,700,000	Point estimate is the mean of a normal distribution with a 95 percent confidence interval between $1 and $10 million (in 2000$). 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)[52] meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003)[53] meta-analysis. Adjusted for 2005$, the mean equals approximately $6.2 million. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$380,000	$470,000	$490,000	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][54]) 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).[55] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[56] and Wittels et al. (1990).[57] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25-44 $10,880 $9,740 45-54 $16,036 $14,357 55-65 $92,685 $82,958 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($127,296—no discounting) 2. Russell et al. (1998), 5-year period ($27,690 at 3% discount rate; $26,180 at 7% discount rate)
3% discount rate				
Age 0–24	$82,958	$82,958	$82,958	
Age 25–44	$92,598	$92,598	$92,598	
Age 45–54	$97,754	$97,754	$97,754	
Age 55–65	$174,405	$174,405	$174,405	
Age 66 and over	$82,958	$82,958	$82,958	
7% discount rate				
Age 0–24	$80,963	$80,963	$80,963	
Age 25–44	$90,705	$90,705	$90,705	
Age 45–54	$95,320	$95,320	$95,320	
Age 55–65	$163,945	$163,945	$163,945	
Age 66 and over	$80,963	$80,963	$80,963	

(continued)

Table 8.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2005$)[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)	$15,345	$15,345	$15,345	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)[58] (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$18,219	$18,219	$18,219	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	$8,226	$8,226	$8,226	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)	$22,800	$22,800	$22,800	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	$355	$355	$355	Simple average of two unit COI values: (1) $386.32, from Smith et al. (1997)[59] and (2) $323.23, from Stanford et al. (1999).[60]

(continued)

Table 8.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2005$)[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)	$28	$30	$30	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)[61] 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)	$18	$19	$19	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	$47	$51	$51	Asthma exacerbations are valued at $47 per incidence (2005$), based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[62] 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	$407	$434	$438	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).[63]

(continued)

Table 8.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2005$)[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.
School Absence Days	$85	$85	$85	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103.. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75 ($85 in 2005$)
Worker Productivity	$1.07 per worker per 10% change in ozone per day	$1.07 per worker per 10% change in ozone per day	$1.07 per worker per 10% change in ozone per day	Based on $68 ($77 in 2005$) – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States ("Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$58	$61	$62	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[64]

[a] All annual benefit estimates associated with the final 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.[65] 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 the PM NAAQS regulatory impact analysis. 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.

8.6 Benefits Analysis Results for the Final Standards

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ and ozone associated with the final standards results in estimates of the changes in health damages (e.g., premature mortalities, cases, admissions) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 8.6-1. Monetized values for those health endpoints are presented in Table 8.6-2. Total aggregate monetized benefits are presented in Table 8.6-3 and Table 8.6-4 using either a 3 percent or 7 percent discount rate, respectively. All of the monetary benefits are in constant-year 2005 dollars. For each endpoint presented in Tables 8.6-1 and 8.6-2, we provide both the mean estimate and the 90% confidence interval.

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health benefits of the final standards is thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health benefits we are able to quantify plus the sum of the nonmonetized health and welfare benefits. We believe the total benefits are therefore likely underestimated.

Total monetized benefits are dominated by benefits of mortality risk reductions. We provide results for particulate matter based on $PM_{2.5}$ concentration response functions from the American Cancer Society Study (ACS), Six Cities, and Expert Elicitation to give an indication of the sensitivity of the benefits estimates to alternative assumptions. Following the recommendations of the NRC report (NRC, 2002), we identify those estimates which are based on empirical data, and those which are based on expert judgments. EPA recently asked its Science Advisory Board (SAB) to evaluate how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies. EPA has not yet had a chance to incorporate the results of the SAB's July 11, 2008 report (EPA-COUNCIL-08-002).

Using the ACS and Six-Cities results, we estimate that the final standards would result in between 150 and 340 cases of avoided $PM_{2.5}$-related premature deaths annually in 2020 and between 230 and 510 avoided premature deaths annually in 2030. When the range of expert opinion is used, we estimate between 80 and 840 fewer premature mortalities in 2020 and between 120 and 1,300 fewer premature mortalities in 2030. Note that in the case of the premature mortality estimates derived from the expert elicitation, we report the 90% credible interval, which encompasses a broader representation of uncertainty relative to the statistical confidence intervals provided for the effect estimates derived from the epidemiology literature.

The range of ozone benefits associated with the final standards is based on risk reductions estimated using several sources of ozone-related mortality effect estimates. This analysis presents four alternative estimates for the association based upon different functions reported in the scientific literature, derived from both the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Bell et al., 2004) and from a series of recent meta-analyses (Bell et al., 2005, Ito et al., 2005, and Levy et al., 2005). This approach is not inconsistent with recommendations provided by the NRC in their recent report (NRC, 2008) on the estimation of ozone-related mortality risk reductions, "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously published studies."

Prior to the publication of the NRC ozone mortality report, EPA considered the possibility that the observed associations between ozone and mortality may not be causal in nature. The report, however, recommended that EPA give "little or no weight to the assumption that there is no causal association between ozone exposure and premature mortality." Because EPA has yet to develop a coordinated response to the NRC report's findings and recommendations, we have retained the approach to estimating ozone-related premature mortality used in RIA for the final Ozone NAAQS. EPA will specifically address the report's findings and recommendations in future rulemakings.

For ozone-related premature mortality, we estimate a range of between 46 to 210 fewer premature mortalities as a result of the final rule in 2020 and between 77 to 350 in 2030, assuming that there is a causal relationship between ozone exposure and mortality. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from the final 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 final standards, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between \$1.2 billion and \$4.0 billion, assuming a 3 percent discount rate, or between \$1.1 billion and \$3.8 billion, assuming a 7 percent discount rate. In 2030, we estimate the monetized benefits to be between \$1.8 billion and \$6.4 billion, assuming a 3 percent discount rate, or between \$1.6 billion and \$6.1 billion, assuming a 7 percent discount rate. The monetized benefit associated with reductions in the risk of both ozone- and $PM_{2.5}$-related premature mortality ranges between 90 to 98 percent of total monetized health benefits, in part because we are unable to quantify a number benefits categories (see Table 8.4-1). These unquantified benefits may be substantial, although their magnitude is highly uncertain.

The next largest benefit is for reductions in chronic illness (chronic bronchitis 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 PM-related premature mortalities (based on the ACS study), 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). As such, the true value of these effects may be higher than that reported in Table 8.6-2.

Following these tables, we also provide a more comprehensive presentation of the distributions of incidence generated using the available information from empirical studies and expert elicitation. Tables 8.6-5 and 8.6-6 present the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-cities study (Laden et al., 2006). The 90% confidence interval for each separate estimate of PM-related mortality is also provided.

The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in these tables, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

Table 8.6-1. Estimated Reduction in Incidence of Adverse Health Effects Related to the Final Standards[a]

		2020	2030
Health Effect		Mean Incidence Reduction (5th – 95th %ile)	
PM-Related Endpoints			
Premature Mortality – Derived from Epidemiology Literature	Adult, age 30+ - ACS cohort study (Pope et al., 2002)	150 (60 - 240)	230 (88 – 360)
	Adult, age 25+ - Six-Cities study (Laden et al., 2006)	340 (190 – 500)	510 (280 – 740)
	Infant, age <1 year – Woodruff et al. 1997	0 (0 – 1)	1 (0 – 1)
Premature Mortality – Derived from Expert Elicitation[b]	Adult, age 25+ - Lower Bound (Expert K)	81 (0 – 380)	120 (0 – 580)
	Adult, age 25+ - Upper Bound (Expert E)	840 (420 – 1,300)	1,300 (650 – 1,900)
Chronic bronchitis (adult, age 26 and over)		150 (28 – 270)	220 (40 – 400)
Acute myocardial infarction (adults, age 18 and older)		330 (180 – 480)	530 (280 – 770)
Hospital admissions—respiratory (all ages)[c]		40 (20 – 59)	61 (30 – 88)
Hospital admissions—cardiovascular (adults, age >18)[d]		81 (50 – 110)	130 (82 – 180)
Emergency room visits for asthma (age 18 years and younger)		150 (85 – 210)	210 (120 – 300)
Acute bronchitis (children, age 8–12)		400 (-14 – 810)	580 (-20 – 1,200)
Lower respiratory symptoms (children, age 7–14)		2,700 (1,300 – 4,000)	3,800 (1,800 – 5,800)
Upper respiratory symptoms (asthmatic children, age 9–18)		1,900 (610 – 3,300)	2,800 (880 – 4,700)
Asthma exacerbation (asthmatic children, age 6–18)		2,400 (270 – 7,000)	3,500 (380 – 10,000)
Work loss days (adults, age 18–65)		17,000 (15,000 – 19,000)	23,000 (20,000 – 26,000)
Minor restricted-activity days (adults, age 18–65)		100,000 (86,000 – 120,000)	140,000 (120,000 – 160,000)
Ozone-Related Endpoints			
Premature Mortality, All ages – Derived from NMMAPS	Bell et al., 2004	46 (20 – 72)	77 (34 – 120)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	150 (84 – 210)	250 (140 – 360)
	Ito et al., 2005	200 (140 – 270)	340 (230 – 450)
	Levy et al., 2005	210 (160 – 260)	350 (260 - 440)
Premature Mortality – Assumption that association between ozone and mortality is not causal[e]		0	0
Hospital admissions- respiratory causes (children, under 2;		540	1,000

adult, 65 and older)[f]	(170 – 900)	(290 – 1,700)
Emergency room visit for asthma (all ages)	200 (0 – 510)	320 (0 - 810)
Minor restricted activity days (adults, age 18-65)	310,000 (160,000 – 460,000)	450,000 (230,000 – 670,000)
School absence days	110,000 (40,000 – 200,000)	180,000 (62,000 – 320,000)

[a] Incidence is rounded to two significant digits. PM and ozone estimates represent impacts from the final standards nationwide.

[b] Based on effect estimates derived from the full-scale expert elicitation assessing the uncertainty in the concentration-response function for PM-related premature mortality (IEc, 2006).[66] The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia, and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[e] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

[f] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 8.6-2. Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2005$)[a,b]

		2020	2030
$PM_{2.5}$-Related Health Effect		Estimated Mean Value of Reductions (5th and 95th %ile)	
Premature Mortality – Derived from Epidemiology Studies[c,d,]	Adult, age 30+ - ACS study (Pope et al., 2002)		
	3% discount rate	$1,000 ($240 - $2,100)	$1,600 ($370 - $3,200)
	7% discount rate	$910 ($220 - $1,900)	$1,400 ($330 - $2,800)
	Adult, age 25+ - Six-cities study (Laden et al., 2006)		
	3% discount rate	$2,300 ($630 - $4,400)	$3,500 ($970 - $6,700)
	7% discount rate	$2,100 ($570 - $3,900)	$3,200 ($870 - $6,000)
	Infant Mortality, <1 year – (Woodruff et al. 1997)		
	3% discount rate	$3.2 ($0.8 - $6.2)	$3.9 ($1.0 - $7.7)
	7% discount rate	$2.9 ($0.8 - $5.6)	$3.5 ($0.9 - $6.9)
Premature mortality – Derived from Expert Elicitation[c,d,e]	Adult, age 25+ - Lower bound (Expert K)		
	3% discount rate	$540 ($0 - $2,600)	$850 ($0 - $4,100)
	7% discount rate	$490 ($0 - $2,400)	$760 ($0 - $3,700)
	Adult, age 25+ - Upper bound (Expert E)		
	3% discount rate	$5,600 ($1,500 - $11,000)	$8,800 ($2,400 - $17,000)
	7% discount rate	$5,100 ($1,400 - $10,000)	$8,000 ($2,100 - $16,000)
Chronic bronchitis (adults, 26 and over)		$70 ($5.7 - $230)	$110 ($8.6 - $350)
Non-fatal acute myocardial infarctions			
3% discount rate		$34 ($10 - $72)	$52 ($15 - $110)
7% discount rate		$33 ($10 - $70)	$51 ($14 - $110)
Hospital admissions for respiratory causes		$0.8 ($0.4 - $1.2)	$1.3 ($0.6 - $1.8)
Hospital admissions for cardiovascular causes		$2.2 ($1.3 - $2.9)	$3.5 ($2.2 - $4.7)
Emergency room visits for asthma		$0.05 ($0.03 - $0.08)	$0.07 ($0.04 - $0.1)
Acute bronchitis (children, age 8–12)		$0.2 ($0 - $0.4)	$0.2 ($0 - $0.6)
Lower respiratory symptoms (children, 7–14)		$0.05 ($0.02 - $0.09)	$0.07 ($0.03 - $0.1)
Upper respiratory symptoms (asthma, 9–11)		$0.06	$0.08

		($0.02 - $0.1)	($0.02 - $0.2)
Asthma exacerbations		$0.1 ($0.01 - $0.4)	$0.2 ($0.02 - $0.5)
Work loss days		$2.5 ($2.2 - $2.8)	$3.4 ($3.0 - $3.8)
Minor restricted-activity days (MRADs)		$2.9 ($0.3 – $5.7)	$4.0 ($0.4 - $7.7)
Recreational Visibility, 86 Class I areas		$17 (na)[f]	$7 (na)
Ozone-related Health Effect			
Premature Mortality, All ages – Derived from NMMAPS	Bell et al., 2004	$340 ($86 - $680)	$590 ($150 - $1,200)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	$1,100 ($310 - $2,100)	$1,900 ($530 - $3,600)
	Ito et al., 2005	$1,500 ($450 - $2,800)	$2,600 ($760 - $4,700)
	Levy et al., 2005	$1,600 ($470 - $2,700)	$2,600 ($800 - $4,700)
Premature Mortality – Assumption that association between ozone and mortality is not causal[f]		$0	$0
Hospital admissions- respiratory causes (children, under 2; adult, 65 and older)		$8.7 ($2.1 - $15)	$17 ($3.8 - $31)
Emergency room visit for asthma (all ages)		$0.07 ($0 - $0.2)	$0.1 ($0 - $0.3)
Minor restricted activity days (adults, age 18-65)		$19 ($8.5 - $31)	$27 ($13 - $46)
School absence days		$9.7 ($3.4 - $17)	$15 ($5.4 - $27)
Worker Productivity		$3.1 (na)[g]	$5.1 (na)[g]

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone 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] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. 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).

[d] The valuation of adult premature mortality, derived either from the epidemiology literature or the expert elicitation, is not additive. Rather, the valuations represent a range of possible mortality benefits.

[e] Based on effect estimates derived from the full-scale expert elicitation assessing the uncertainty in the concentration-response function for PM-related premature mortality (IEc, 2006). The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[f] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

[g] We are unable at this time to characterize the uncertainty in the estimate of benefits of worker productivity and improvements in visibility at Class I areas. As such, we treat these benefits as fixed and add them to all percentiles of the health benefits distribution.

Table 8.6-3 Total Monetized Benefits of the Final Small SI and Marine SI Engine Rule – 3% Discount Rate

Total Ozone and PM Benefits (billions, 2005$) – PM Mortality Derived from the ACS and Six Cities Studies					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$1.5 - $2.8	NMMAPS	Bell et al., 2004	$2.4 - $4.3
Meta-analysis	Bell et al., 2005	$2.3 - $3.6	Meta-analysis	Bell et al., 2005	$3.7 - $5.6
	Ito et al., 2005	$2.7 - $4.0		Ito et al., 2005	$4.4 - $6.4
	Levy et al., 2005	$2.7 - $4.0		Levy et al., 2005	$4.4 - $6.4
Assumption that association is not causal[a]		$1.2 - $2.5	Assumption that association is not causal[a]		$1.8 - $3.8
Total Ozone and PM Benefits (billions, 2005$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$1.1 - $6.1	NMMAPS	Bell et al., 2004	$1.7 - $9.7
Meta-analysis	Bell et al., 2005	$1.8 - $6.9	Meta-analysis	Bell et al., 2005	$3.0 - $11
	Ito et al., 2005	$2.2 - $7.3		Ito et al., 2005	$3.7 - $12
	Levy et al., 2005	$2.3 - $7.4		Levy et al., 2005	$3.7 - $12
Assumption that association is not causal[a]		$0.7 - $5.8	Assumption that association is not causal[a]		$1.1 - $9.1

[a] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

Table 8.6-4 Total Monetized Benefits of the Final Small SI and Marine SI Engine Rule – 7% Discount Rate

Total Ozone and PM Benefits (billions, 2005$) – PM Mortality Derived from the ACS and Six Cities Studies					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$1.4 - $2.6	NMMAPS	Bell et al., 2004	$2.2 - $4.0
Meta-analysis	Bell et al., 2005	$2.2 - $3.4	Meta-analysis	Bell et al., 2005	$3.5 - $5.3
	Ito et al., 2005	$2.6 - $3.7		Ito et al., 2005	$4.2 - $6.0
	Levy et al., 2005	$2.6 - $3.8		Levy et al., 2005	$4.3 - $6.1
Assumption that association is not causal[a]		$1.1 - $2.2	Assumption that association is not causal[a]		$1.6 - $3.4
Total Ozone and PM Benefits (billions, 2005$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$1.0 - $5.6	NMMAPS	Bell et al., 2004	$1.6 - $8.8
Meta-analysis	Bell et al., 2005	$1.8 - $6.4	Meta-analysis	Bell et al., 2005	$2.9 - $10
	Ito et al., 2005	$2.2 - $6.8		Ito et al., 2005	$3.6 - $11
	Levy et al., 2005	$2.2 - $6.8		Levy et al., 2005	$3.7 - $11
Assumption that association is not causal[a]		$0.7 - $5.2	Assumption that association is not causal[a]		$1.0 - $8.2

[a] A recent report published by the National Research Council (NRC, 2008) recommended that EPA "give little or no weight to the assumption that there is no causal association between estimated reductions in premature mortality and reduced ozone exposure."

Table 8.6-5. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with the Final Standards

Source of Mortality Estimate	2020 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	59	150	240
Laden et al. (2006)	190	340	500
Expert A	120	670	1,200
Expert B	64	510	1,100
Expert C	92	510	1,100
Expert D	74	350	580
Expert E	420	840	1,300
Expert F	320	460	670
Expert G	0	300	550
Expert H	1	380	870
Expert I	80	500	900
Expert J	120	410	900
Expert K	0	81	380
Expert L	45	350	690

Table 8.6-6. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Final Standards

Source of Mortality Estimate	2030 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	88	230	360
Laden et al. (2006)	280	510	740
Expert A	190	1,000	1,900
Expert B	97	780	1,700
Expert C	140	780	1,700
Expert D	110	540	890
Expert E	650	1,300	1,900
Expert F	490	700	1,000
Expert G	0	450	840
Expert H	2	580	1,300
Expert I	120	770	1,400
Expert J	190	620	1,400
Expert K	0	120	580
Expert L	67	530	1,100

8.7 Comparison of Costs and Benefits

In estimating the net benefits of the final standards, the appropriate cost measure is 'social costs.' Social costs represent the welfare costs of a rule to society. These costs do not consider transfer payments (such as taxes) that are simply redistributions of wealth. Table 8.7-1 contains the estimates of monetized benefits and estimated social welfare costs for the final rule and each of the final control programs. The annual social welfare costs of all provisions of this final rule are described more fully in Chapter 9 of this RIA.

The results in Table 8.7-1 suggest that the 2020 monetized benefits of the final standards are greater than the expected social welfare costs. Specifically, the annual benefits of the total program will range between $1.2 to $4.0 billion annually in 2020 using a three percent discount rate, or between $1.1 to $3.8 billion assuming a 7 percent discount rate, compared to estimated social costs of approximately $210 million in that same year. These benefits are expected to increase to between $1.8 and $6.4 billion annually in 2030 using a three percent discount rate, or between $1.6 and $6.1 billion assuming a 7 percent discount rate, while the social costs are estimated to be approximately $190 million. Though there are a number of health and environmental effects associated with the final standards that we are unable to quantify or monetize (see Table 8.4-1), the benefits of the final standards far outweigh the projected costs. When we examine the benefit-to-cost comparison for the rule standards separately, we also find that the benefits of the specific engine standards outweigh their projected costs.

Using a conservative benefits estimate, the 2020 benefits outweigh the costs by a factor of 5. Using the upper end of the benefits range, the benefits could outweigh the costs by a factor of 19. Likewise, in 2030 benefits outweigh the costs by at least a factor of 8 and could be as much as a factor of 34. Thus, even taking the most conservative benefits assumptions, benefits of the final standards clearly outweigh the costs.

Table 8.7-1. Summary of Annual Benefits and Costs of the Final Standards[a] (Millions of 2005 dollars)

Description	2020	2030
Estimated Social Costs[b]		
Small SI	$163	$185
Marine SI	$44	$0.8
Total Social Costs	$210	$190
Estimated Health Benefits of the Final Standards[c,d,e,f]		
Small SI		
3 percent discount rate	$860 to $2,600	$820 to $2,900
7 percent discount rate	$790 to $2,500	$710 to $2,800
Marine SI		
3 percent discount rate	$340 to $1,400	$980 to $3,500
7 percent discount rate	$310 to $1,300	$890 to $3,300
Total Benefits		
3 percent discount rate	$1,200 to $4,000	$1,800 to $6,400
7 percent discount rate	$1,100 to $3,800	$1,600 to $6,100
Annual Net Benefits (Total Benefits – Total Costs)		
3 percent discount rate	$990 to $3,800	$1,600 to $6,200
7 percent discount rate	$890 to $3,600	$1,400 to $5,900

[a] All estimates represent annualized benefits and costs anticipated for the years 2020 and 2030. Totals may not sum due to rounding.

[b] The calculation of annual costs does not require amortization of costs over time. Therefore, the estimates of annual cost do not include a discount rate or rate of return assumption (see Chapter 9 of the RIA). 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).

[c] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function, including an assumption that the association is not causal, to $PM_{2.5}$-related premature mortality derived from the ACS (Pope et al., 2002) and Six Cities (Laden et al., 2006) studies.

[d] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).

[e] Valuation of premature mortality based on long-term PM exposure assumes discounting over the SAB recommended 20-year segmented lag structure described in the Regulatory Impact Analysis for the Final Clean Air Interstate Rule (March, 2005).

[f] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 8.4-1.

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Appendix 8A: Sensitivity Analyses of Key Parameters in the Benefits Analysis

The primary analysis presented in Chapter 8 is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies and the assumptions that are most appropriate to adopt in the face of important uncertainties and resource limitations. The majority of the analytical assumptions used to develop the primary estimates of benefits have been used to support similar rulemakings and approved by EPA's Science Advisory Board (SAB). Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions. This appendix supplements our primary estimates of benefits with a series of sensitivity calculations that use other sources of health effect estimates and valuation data for key benefits categories. The supplemental estimates examine sensitivity to both valuation issues and for physical effects issues. These supplemental estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commenters as likely to have a significant impact on total benefits. The individual adjustments in the tables should not simply be added together because: 1) there may be overlap among the alternative assumptions; and 2) the joint probability among certain sets of alternative assumptions may be low.

8.A.1 Premature Mortality – Alternative Threshold Analysis

To consider the impact of a threshold in the response function for the chronic mortality endpoint, we have 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, we have adjusted the mortality function slopes accordingly.[A] Five cutpoints (including the base case assumption) were included in the sensitivity analysis: (a) 14 µg/m3 (assumes no impacts below the alternative annual NAAQS), (b) 12 µg/m3 (c) 10 µg/m3 (reflects comments from CASAC, 2005) [1], (d) 7.5 µg/m3 (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the Pope 2002 study used as the basis for modeling chronic mortality) [2] and (e) background or 3 µg/m3 (reflects NRC recommendation to consider effects all the way to background).[3] We repeat this sensitivity analysis for the RIA of the final standards, the results of which can be found in Table 8A-1.

[A] Note that this analysis only adjusted the mortality slopes for the 10 µg/m^3, 12 µg/m^3 and 14 µg/m^3 cutpoints since the 7.5 µg/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.

Table 8A-1. PM-Related Mortality Benefits of the Final Standards: Cutpoint Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Certainty that Benefits are At Least Specified Value	Level of Assumed Threshold	PM Mortality Incidence	
		2020	2030
More Certain that Benefits Are at Least as Large	14 µg/m3 [b]	6	7
↓	12 µg/m3	29	40
	10 µg/m3 [c]	150	230
	7.5 µg/m3 [d]	220	340
Less Certain that Benefits Are at Least as Large	3 µg/m3 [e]	250	380

[a] Note that this table only presents the effects of a cutpoint on PM-related mortality incidence.
[b] Alternative annual PM NAAQS.
[c] Primary threshold assumption based on CASAC (2005).[85]
[d] SAB-HES (2004)[86]
[e] NAS (2002)[87]

8.A.2 Premature Mortality - Alternative Lag Structures

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient $PM_{2.5}$ will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question.

The SAB-HES has recognized this lack of direct evidence. However, in early advice, they also note that “although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population,” (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9).[4]

In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using "a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions," (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that "an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate," (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its follow-up advice provided in December 2004, the SAB suggested 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 $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004).[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. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). The 0-year lag is representative of EPA's assumption in previous RIAs. The 8- and 15-year lags are based on the study periods from the Pope et al. (1995)[6] and Dockery et al. (1993)[7] studies, respectively.[B] However, neither the Pope et al. nor Dockery et al. studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope et al. and Dockery et al. analyses do not support or refute the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8- and 15-year lags implicitly

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[FF] Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

assume that all premature mortalities occur at the end of the study periods (i.e., at 8 and 15 years).

In addition to the simple 8- and 15-year lags, we have added two additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 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 30 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table 8A-2. These estimates are based on the value of statistical lives saved approach (i.e., $5.5 million per incidence) and are presented using both a 3 percent and 7 percent discount rate over the lag period.

Table 8A-2. Sensitivity of Benefits of Premature Mortality Reductions to Alternative Lag Assumptions (Relative to Primary Benefits Estimates of the Final Standards)

		Avoided Incidences (ACS; Pope et al., 2002)[a]		Value (million 2006$)[b]	
	Description of Sensitivity Analysis	2020	2030	2020	2030
Alternative Lag Structures for PM-Related Premature Mortality					
Primary	30 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 20 percent in years 6 to 20				
	3% Discount Rate	150	230	$1,000	$1,600
	7% Discount Rate	150	230	$900	$1,400
None	Incidences all occur in the first year	150	230	$1,100	$1,700
8-year	Incidences all occur in the 8th year				
	3% Discount Rate	150	230	$910	$1,400
	7% Discount Rate	150	230	$690	$1,100
15-year	Incidences all occur in the 15th year				
	3% Discount Rate	150	230	$740	$1,100
	7% Discount Rate	150	230	$430	$660
Alternative Segmented	20 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20				
	3% Discount Rate	150	230	$1,100	$1,500
	7% Discount Rate	150	230	$1,000	$1,300
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5				
	3% Discount Rate	150	230	$980	$1,600
	7% Discount Rate	150	230	$850	$1,500

[a] Incidences rounded to two significant digits.

[b] Dollar values rounded to two significant digits. The alternative lag structure analysis presents benefits calculated using both a 3 percent and 7 percent discount rate.

The results of the scaled alternative lag sensitivity analysis demonstrate that choice of lag structure can have a large impact on benefits. Because of discounting of delayed benefits, the lag structure may have a large downward impact on monetized benefits if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits.

8.A.3 Visibility Benefits in Additional Class I Areas

The Chestnut and Rowe (1990)[viii] study from which the primary visibility valuation estimates are derived only examined WTP for visibility changes in Class I areas (national parks and wilderness areas) in the southeast, southwest, and California. To obtain estimates of WTP for visibility changes at national parks and wilderness areas in the northeast, northwest, and central regions of the U.S., we have to transfer WTP values from the studied regions. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions.

Based on this benefits transfer methodology (implemented within the preference calibration framework discussed in Chapter 5 and Appendix I of the final PM NAAQS RIA), estimated additional visibility benefits in the northwest, central, and northeastern U.S. are provided in Table 8.A-3.

Table 8.A-3: Monetary Benefits Associated with Improvements in Visibility in Additional Federal Class I Areas in 2020 and 2030 (in millions of 2006$)[a]

Year	*Northwest*[b]	*Central*[c]	*Northeast*[d]	*Total*
2020	$3.9	$1.7	$9.2	$15
2030	$15	$17	$12	$44

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns

[b] Northwest Class I areas include Crater Lake, Mount Rainier, North Cascades, and Olympic national parks, and Alpine Lakes, Diamond Peak, Eagle Cap, Gearhart Mountain, Glacier Peak, Goat Rocks, Hells Canyon, Kalmiopsis, Mount Adams, Mount Hood, Mount Jefferson, Mount Washington, Mountain Lakes, Pasayten, Strawberry Mountain, and Three Sisters wilderness areas.

[c] Central Class I areas include Craters of the Moon, Glacier, Grand Teton, Theodore Roosevelt, Badlands, Wind Cave, and Yellowstone national parks, and Anaconda-Pintlar, Bob Marshall, Bridger, Cabinet Mountains, Fitzpatrick, Gates of the Mountain, Lostwood, Medicine Lake, Mission Mountain, North Absaroka, Red Rock Lakes, Sawtooth, Scapegoat, Selway-Bitterroot, Teton, U.L. Bend, and Washakie wilderness areas.

[d] Northeast Class I areas include Acadia, Big Bend, Guadalupe Mountains, Isle Royale, Voyageurs, and Boundary Waters Canoe national parks, and Brigantine, Caney Creek, Great Gulf, Hercules-Glades, Lye Brook, Mingo, Moosehorn, Presidential Range-Dry Roosevelt Campobello, Seney, Upper Buffalo, and Wichita Mountains wilderness areas.

Appendix 8B: Health-Based Cost-Effectiveness of Reductions in Ambient O_3 and $PM_{2.5}$ Associated with the Final Small SI and Recreational Marine Engine Rule

8B.1 Introduction

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. Analyses of environmental regulations have typically used benefit-cost analysis to characterize impacts on social welfare. Benefit-cost analyses allow for aggregation of the benefits of reducing mortality risks with other monetized benefits of reducing air pollution, including reduced risk of acute and chronic morbidity, and non-health benefits. One of the great advantages of the benefit-cost paradigm is that a wide range of quantifiable benefits can be compared to costs to evaluate the economic efficiency of particular actions. However, alternative paradigms such as CEA and CUA analyses may also provide useful insights. CEA involves estimation of the costs per unit of benefit (e.g., lives or life years saved). CUA is a special type of CEA using preference-based measures of effectiveness, such as quality-adjusted life years (QALYs).

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA for 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 non-health benefits.

The Office of Management and Budget (OMB) recently 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, however, making application of CEA more difficult and less straightforward.

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). 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.

CEA and CUA are most useful for comparing programs that have similar goals, for example, alternative medical interventions or treatments that can save a life or cure a disease. They are less readily applicable to programs with multiple categories of benefits, such as those reducing ambient air pollution, because the cost-effectiveness calculation is based on the quantity of a single benefit category. In other words, we cannot readily convert non-health benefits, such as visibility improvements associated with reductions in $PM_{2.5}$ or increases in worker productivity associated with reductions in O_3, to a health metric such as life years saved. For these reasons, environmental economists prefer to present results in terms of monetary benefits and net benefits.

However, QALY-based CUA has been widely adopted within the health economics literature (Neumann, 2003; Gold et al., 1996) and in the analysis of public health interventions (US FDA, 2004). QALY-based analyses have not been as accepted in the environmental economics literature because of concerns about the theoretical consistency of QALYs with individual preferences (Hammitt, 2002), treatment of nonhuman health benefits, and a number of other factors (Freeman, Hammitt, and De Civita, 2002). For environmental regulations, benefit-cost analysis has been the preferred method of choosing among regulatory alternatives in terms of economic efficiency. Recently several academic analyses have proposed the use of life years-based benefit-cost or CEAs of air pollution regulations (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003; Rabl, 2003; Carrothers, Evans, and Graham, 2002). In addition, the World Health Organization has adopted the use of disability-adjusted life years, a variant on QALYs, to assess the global burden of disease due to different causes, including environmental pollution (Murray et al., 2002; de Hollander et al., 1999).

One of the ongoing controversies in health impact assessment regards whether reductions in mortality risk should be reported and valued in terms of statistical lives saved or in terms of statistical life years saved. Life years saved measures differentiate among premature mortalities based on the remaining life expectancy of affected individuals. In general, under the life years approach, older individuals will gain fewer life years than younger individuals for the same reduction in mortality risk during a given time period, making interventions that benefit older individuals seem less beneficial relative to similar interventions benefiting younger individuals. A further complication in the debate is whether to apply quality adjustments to life years lost. Under this approach, individuals with preexisting health conditions would have fewer QALYs lost relative to healthy individuals for the same loss in life expectancy, making interventions that primarily benefit individuals with poor health seem less beneficial than similar interventions affecting primarily healthy individuals.

In this CEA, based largely on a report prepared under contract with Abt Associates,[3] we calculated both life years saved and statistical lives saved. Following the methodology used in the CEAs for the PM and O_3 NAAQS RIAs, we did not assign QALY weights to the life years saved – i.e., we calculated life years saved, rather than QALYs gained from mortality avoided. Put another way, we assumed weights of 1.0 for all life years saved. Life years saved in the future, however, were discounted to reflect people's time preference (i.e., a benefit received now

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[3] The full report prepared by Abt Associates is included in the docket for the Final Small SI and Recreational Marine Engine Rule (EPA-HQ-OAR-2004-0008).

is worth more than the same benefit received in the future). We used discount rates of 3 percent and 7 percent.

Where possible, benefits that could not be quantified in the denominator of our cost-effectiveness ratios were monetized and subtracted from the cost of the regulation in the numerator. For example, developing QALYs for acute health effects is problematic (Bala and Zarkin, 2000). Therefore, rather than try to derive QALYs for the acute morbidity endpoints, we instead applied valuation estimates and subtracted the total monetized value of all avoided acute morbidity effects from the cost of the regulation, in the numerator of the cost-effectiveness ratios. The monetized benefits of non-health improvements, where they were estimated, were similarly subtracted from the cost of the regulation. Finally, although QALY estimates were derived for the ($PM_{2.5}$-related) chronic morbidity endpoints, the medical and opportunity costs associated with these chronic illnesses were also subtracted from the cost of the regulation.

$PM_{2.5}$-related benefits derive not only from avoided cases of premature mortality and acute morbidity, but from avoided cases of chronic morbidity (chronic bronchitis and non-fatal myocardial infarction) as well. In the CEAs for the PM and O_3 NAAQS RIAs, EPA derived QALYs for these two chronic morbidity endpoints (see, for example, Appendix G of the PM NAAQS RIA, http://www.epa.gov/ttn/ecas/regdata/RIAs/Appendix%20G--Health%20Based%20Cost%20Effectiveness%20Analysis.pdf) and used an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILYs), to address some of the concerns about aggregation of life extension and quality-of-life impacts. MILYs represent the sum of life years gained due to reductions in premature mortality and the QALYs gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy.

For this analysis, we present several metrics: lives saved, life years saved, cost of the regulation (net of the monetized benefits not included in the denominator) per life saved and per life year saved, and MILYs gained and the cost of the regulation (net of the monetized benefits not included in the denominator) per MILY gained.

Note that, like future life years saved, future QALYs gained from avoided cases of chronic bronchitis and myocardial infarction are discounted. All costs and monetized benefits are in 2005 dollars.

Monte Carlo simulation methods as implemented in the Crystal Ball™ software program were used to propagate uncertainty in several of the model parameters throughout the analysis. In particular, we incorporated uncertainty surrounding the coefficients in the concentration-response (C-R) functions, the unit values for the various morbidity endpoints included in the analysis, and the quality of life weights for the two chronic morbidity endpoints for which we developed QALYs.

We characterized overall uncertainty in the results with 95 percent credible or confidence intervals based on the Monte Carlo simulations. In addition, we examined the impacts on the cost effectiveness metrics of changing key parameters and/or assumptions, including

- the discount rate (for the cost of the regulation in the numerator and future lives or life years saved and QALYs gained in the denominator);
- the C-R functions for O_3-related and $PM_{2.5}$-related mortality ; and
- the life expectancies (and therefore years of potential life lost) of individuals who die as a result of exposure to O_3 (as explained in Section 8B.4 below).

The methodology presented in this appendix is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations where it may be inappropriate. It is intended solely to demonstrate one particular approach to estimating the cost-effectiveness of reductions in ambient $PM_{2.5}$ and O_3 in achieving improvements in public health. Reductions in ambient $PM_{2.5}$ and O_3 are estimated to have other health and environmental benefits that will not be reflected in this CEA. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar health-based CEAs. A number of additional methodological issues must be considered when conducting CEAs for environmental policies, including treatment of non-health effects, aggregation of acute and long-term health impacts, and aggregation of life extensions and quality-of-life improvements in different populations. The appropriateness of health-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models, among other factors.

The remainder of this appendix provides an overview of the methods used to derive the cost effectiveness metrics developed for this CEA and presents the resulting metrics. Section 8B.2 provides an overview of effectiveness measures. Section 8B.3 discusses general issues in constructing cost-effectiveness ratios. Section 8B.4 presents methods and results. Finally, Section 8B.5 presents concluding remarks.

8B.2 Effectiveness Measures

For the purposes of CEA, we focus the effectiveness measures on the quantifiable health impacts of the reductions in $PM_{2.5}$ and O_3 estimated to occur as a result of this rule. If the main impact of interest is reductions in mortality risk from air pollution, the effectiveness measures are relatively straightforward to develop. Mortality impacts can be characterized similar to the benefits analysis, by counting the number of premature deaths avoided, or can be characterized in terms of increases in life expectancy or life years.[4] Estimates of premature mortality have the benefit

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[4] Life expectancy is an *ex ante* concept, indicating the impact on an entire population's expectation of the number of life years they have remaining, before knowing which individuals will be affected. Life expectancy thus incorporates both the probability of an effect and the impact of the effect if realized. Life years is an *ex post* concept, indicating the impact on individuals who actually die from exposure to air pollution. Changes in population life expectancy will always be substantially smaller than changes in life years per premature mortality avoided, although the total life years gained in the population will be the same. This is

of being relatively simple to calculate, are consistent with the benefit-cost analysis, and do not impose additional assumptions on the degree of life shortening. However, some have argued that counts of premature deaths avoided are problematic because a gain in life of only a few months would be considered equivalent to a gain of many life years, and the true effectiveness of an intervention is the gain in life expectancy or life years (Rabl, 2003; Miller and Hurley, 2003).

Calculations of changes in life years and life expectancy can be accomplished using standard life table methods (Miller and Hurley, 2003). However, the calculations require assumptions about the baseline mortality risks for each age cohort affected by air pollution. A general assumption may be that air pollution mortality risks affect the general mortality risk of the population in a proportional manner. However, some concerns have been raised that air pollution affects mainly those individuals with preexisting cardiovascular and respiratory disease, who may have reduced life expectancy relative to the general population. This issue is explored in more detail below.

Air pollution is also associated with a number of significant chronic and acute morbidity endpoints. Failure to consider these morbidity effects may understate the cost-effectiveness of air pollution regulations or give too little weight to reductions in particular pollutants that have large morbidity impacts but no effect on life expectancy. The QALY approach explicitly incorporates morbidity impacts into measures of life years gained and is often used in health economics to assess the cost-effectiveness of medical spending programs (Gold et al., 1996). Using a QALY rating system, health quality ranges from 0 to 1, where 1 may represent full health, 0 death, and some number in between (e.g., 0.8) an impaired condition. QALYs thus measure morbidity as a reduction in quality of life over a period of life. QALYs assume that duration and quality of life are equivalent, so that 1 year spent in perfect health is equivalent to 2 years spent with quality of life half that of perfect health. QALYs can be used to evaluate environmental rules under certain circumstances, although some very strong assumptions (detailed below) are associated with QALYs. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommended using QALYs when evaluating medical and public health programs that primarily reduce both mortality and morbidity (Gold et al., 1996). Although there are significant non-health benefits associated with air pollution regulations, over 90 percent of quantifiable monetized benefits are health-related. Thus, it can be argued that QALYs are more applicable for these types of regulations than for other environmental policies. However, the value of non-health benefits should not be ignored. As discussed below, we have chosen to subtract the value of non-health benefits from the costs in the numerator of the cost-effectiveness ratio.

The use of QALYs is predicated on the assumptions embedded in the QALY analytical framework. As noted in the QALY literature, QALYs are consistent with the utility theory that underlies most of economics only if one imposes several restrictive assumptions, including independence between longevity and quality of life in the utility function, risk neutrality with respect to years of life (which implies that the utility function is linear), and constant proportionality in trade-offs between quality and quantity of life (Pliskin, Shepard, and Weinstein, 1980; Bleichrodt, Wakker, and Johannesson, 1996). To the extent that these assumptions do not represent actual preferences, the QALY approach will not provide results

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because life expectancy gains average expected life years gained over the entire population, while life years gained measures life years gained only for those experiencing the life extension.

that are consistent with a benefit-cost analysis based on the Kaldor-Hicks criterion.[5] Even if the assumptions are reasonably consistent with reality, because QALYs represent an average valuation of health states rather than the sum of societal WTP, there are no guarantees that the option with the highest QALY per dollar of cost will satisfy the Kaldor-Hicks criterion (i.e., generate a potential Pareto improvement [Garber and Phelps, 1997]).

Benefit-cost analysis based on WTP is not without potentially troubling underlying structures as well, incorporating ability to pay (and thus the potential for equity concerns) and the notion of consumer sovereignty (which emphasizes wealth effects). Table 8B-1 compares the two approaches across a number of parameters. For the most part, WTP allows parameters to be determined empirically, while the QALY approach imposes some conditions *a priori*.

Table 8B-1. Comparison of QALY and WTP Approaches

Parameter	*QALY*	*WTP*
Risk aversion	Risk neutral	Empirically determined
Relation of duration and quality	Independent	Empirically determined
Proportionality of duration/ quality trade-off	Constant	Variable
Treatment of time/age in utility function	Utility linear in time	Empirically determined
Preferences	Community/Individual	Individual
Source of preference data	Stated	Revealed and stated
Treatment of income and prices	Not explicitly considered	Constrains choices

8B.3 Construction of Cost-Effectiveness Ratios: General Issues

8B.3.1 Dealing with Morbidity Health Effects and Non-health Effects

Health effects from exposure to $PM_{2.5}$ and O_3 air pollution encompass a wide array of chronic and acute conditions in addition to premature mortality. EPA's Ozone and PM Criteria Documents outline numerous health effects known or suspected to be linked to exposure to ambient ozone and PM (US EPA, 2006; US EPA, 2005; Anderson et al., 2004). Although chronic conditions and premature mortality generally account for the majority of monetized benefits, acute symptoms can affect a broad population or sensitive populations (e.g., asthma-related emergency room visits among asthmatics). In addition, reductions in air pollution may result in a broad set of non-health environmental benefits, including improved worker productivity, improved visibility in national parks, increased agricultural and forestry yields, reduced acid damage to buildings, and a host of other impacts. Lives saved, life years saved, and

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[5] The Kaldor-Hicks efficiency criterion requires that the "winners" in a particular case be potentially able to compensate the "losers" such that total societal welfare improves. In this case, it is sufficient that total benefits exceed total costs of the regulation. This is also known as a potential Pareto improvement, because gains could be allocated such that at least one person in society would be better off while no one would be worse off.

QALYs gained address only health impacts, and the OMB guidance notes that "where regulation may yield several different beneficial outcomes, a cost-effectiveness comparison becomes more difficult to interpret because there is more than one measure of effectiveness to incorporate in the analysis."

With regard to acute health impacts, Bala and Zarkin (2000) suggest that QALYs are not appropriate for valuing acute symptoms, because of problems with both measuring utility for acute health states and applying QALYs in a linear fashion to very short duration health states. Johnson and Lievense (2000) suggest using conjoint analysis to get healthy-utility time equivalences that can be compared across acute effects, but it is not clear how these can be combined with QALYs for chronic effects and loss of life expectancy. There is also a class of effects that EPA has traditionally treated as acute, such as hospital admissions, which may also result in a loss of quality of life for a period of time following the effect. For example, life after asthma hospitalization has been estimated with a utility weight of 0.93 (Bell et al., 2001; Kerridge, Glasziou, and Hillman, 1995).

How should these effects be combined with QALYs for chronic and mortality effects? One method would be to convert the acute effects to QALYs; however, as noted above, there are problems with the linearity assumption (i.e., if a year with asthma symptoms is equivalent to 0.7 year without asthma symptoms, then 1 day without asthma symptoms is equivalent to 0.0019 QALY gained). This is troubling from both a conceptual basis and a presentation basis. An alternative approach is simply to treat acute health effects like non-health benefits and subtract the dollar value (based on WTP or COI) from compliance costs in the CEA.

To address the issues of incorporating acute morbidity and non-health benefits, OMB suggests that agencies "subtract the monetary estimate of the ancillary benefits from the gross cost estimate to yield an estimated net cost." As with benefit-cost analysis, any unquantified benefits and/or costs should be noted and an indication of how they might affect the cost-effectiveness ratio should be described. We followed this recommended "net cost" approach, specifically in netting out the benefits of health improvements other than reduced mortality and improved quality of life from avoided chronic illness – in particular, the monetized benefits of acute morbidity avoided, the medical and opportunity costs ("cost of illness") of avoided chronic illness, and the benefits of non-health improvements, including increases in worker productivity associated with reductions in O_3 and visibility improvements at national parks associated with reductions in $PM_{2.5}$ (see Chapter 8 for more details on these benefit categories).

8B.3.2 Should Life Years Gained Be Adjusted for Initial Health Status?

The methods outlined below in Section 8B.4 provide estimates of the total number of life years gained in a population, regardless of the quality of those life years, or equivalently, assuming that all life years gained are in perfect health. In some CEAs (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003), analysts have adjusted the number of life years gained to reflect the fact that 1) the general public is not in perfect health and thus "healthy" life years are less than total life years gained and 2) those affected by air pollution may be in a worse health state than the general population and therefore will not gain as many "healthy" life years adjusted for quality, from an air pollution reduction. This adjustment, which converts life years gained into QALYs, raises a number of serious ethical issues. Proponents of QALYs have promoted the nondiscriminatory nature of QALYs in evaluating improvements in quality of life (e.g., an improvement from a score of 0.2 to 0.4 is equivalent to an improvement from 0.8 to 1.0), so the starting health status does not affect the evaluation of interventions that improve quality of life. However, for life-extending interventions, the gains in QALYs will be directly proportional to the baseline health state (e.g., an individual with a 30-year life expectancy and a starting health status of 0.5 will gain exactly half the QALYs of an individual with the same life expectancy and a starting health status of 1.0 for a similar life-extending intervention). This is troubling because it imposes an additional penalty for those already suffering from disabling conditions. Brock (2002) notes that "the problem of disability discrimination represents a deep and unresolved problem for resource prioritization."

OMB (2003) has recognized this issue in their Circular A-4 guidance, which includes the following statement:

> *When CEA is performed in specific rulemaking contexts, you should be prepared to make appropriate adjustments to ensure fair treatment of all segments of the population. Fairness is important in the choice and execution of effectiveness measures. For example, if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves the lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimated number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts. More generally, when numeric adjustments are made for life expectancy or quality of life, analysts should prefer use of population averages rather than information derived from subgroups dominated by a particular demographic or income group. (p. 13)*

This suggests two adjustments to the standard QALY methodology: one adjusting the relevant life expectancy of the affected population, and the other affecting the baseline quality of life for the affected population.

In addition to the issue of fairness, potential measurement issues are specific to the air pollution context that might argue for caution in applying quality-of-life adjustments to life years gained due to air pollution reductions. A number of epidemiological and toxicological studies link exposure to air pollution with chronic diseases, such as CB and atherosclerosis (Abbey et al., 1995; Schwartz, 1993; Suwa et al., 2002). If these same individuals with chronic disease caused by exposure to air pollution are then at increased risk of premature death from air pollution, there is an important dimension of "double jeopardy" involved in determining the correct baseline for assessing QALYs lost to air pollution (see Singer et al. [1995] for a broader discussion of the double-jeopardy argument).

Analyses estimating mortality from acute exposures that ignore the effects of long-term exposure on morbidity may understate the health impacts of reducing air pollution. Individuals exposed to chronically elevated levels of air pollution may realize an increased risk of death and chronic disease throughout life. If at some age they contract heart (or some other chronic) disease as a result of the exposure to air pollution, they will from that point forward have both reduced life expectancy and reduced quality of life. The benefit to that individual from reducing lifetime exposure to air pollution would be the increase in life expectancy plus the increase in quality of life over the full period of increased life expectancy. If the QALY loss is determined based on the underlying chronic condition and life expectancy without regard to the fact that the person would never have been in that state without long-term exposure to elevated air pollution, then the person is placed in double jeopardy. In other words, air pollution has placed more people in the susceptible pool, but then we penalize those people in evaluating policies by treating their subsequent deaths as less valuable, adding insult to injury, and potentially downplaying the importance of life expectancy losses due to air pollution. If the risk of chronic disease and risk of death are considered together, then there is no conceptual problem with measuring QALYs, but this has not been the case in recent applications of QALYs to air pollution (Carrothers, Evans, and Graham, 2002; Coyle et al., 2003). The use of QALYs thus highlights the need for a better understanding of the relationship between chronic disease and long-term exposure and suggests that analyses need to consider morbidity and mortality jointly, rather than treating each as a separate endpoint (this is an issue for current benefit-cost approaches as well).

Because of the fairness and measurement concerns discussed above, for the purposes of this analysis, we do not reduce the number of life years gained to reflect any differences in underlying health status that might reduce quality of life in remaining years. Thus, we maintain the assumption that all direct gains in life years resulting from mortality risk reductions will be assigned a weight of 1.0. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that “since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY” (Gold et al., 1996). However, for the purposes of this analysis, we propose an alternative to the traditional aggregate QALY metric that keeps separate quality adjustments to life expectancy and gains in life expectancy. As such, we do not make any adjustments to life years gained to reflect the less than perfect health of the general population. Gains in quality of life will be addressed as they accrue because of reductions in the incidence of chronic diseases. This is an explicit equity choice in the treatment of issues associated with quality-of-life adjustments for increases in life expectancy that still capitalizes on the ability of QALYs to capture both morbidity and mortality impacts in a single effectiveness measure.

8B.3.3 Constructing Cost-Effectiveness Ratios

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. The estimate of costs in the numerator should include both the direct costs of the controls necessary to achieve the reduction in ambient concentrations of the air pollutant and the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). In general, because reductions in air pollution do not require direct actions by the affected populations, there are no specific costs to affected individuals (aside from the overall increases in prices that might be expected to occur as control costs are passed on by affected industries). Likewise, because individuals do not engage in any specific actions to realize the health benefit of the pollution reduction, there are no decreases in utility (as might occur from a medical intervention) that need to be adjusted for in the denominator. Thus, the elements of the numerator are direct costs of controls minus the avoided costs of illness (COI) associated with chronic illnesses. In addition, as noted above, to account for the value of reductions in acute health impacts and non-health benefits, we netted out the monetized value of these benefits from the numerator to yield a “net cost” estimate.

The denominators of the cost-effectiveness ratios we calculated are either lives saved, life years saved, or MILYs gained. For the MILY aggregate effectiveness measure, the denominator is simply the sum of life years gained from increased life expectancy and QALYs gained from the reductions in incidence of chronic illnesses associated with $PM_{2.5}$ – chronic bronchitis (CB) and nonfatal acute myocardial infarction (AMI).

8B.4 Cost Effectiveness Metrics

In this section we describe the development of cost effectiveness metrics. To generate health outcomes, we used the same framework as for the benefit-cost analysis described in Chapter 8. For convenience, we summarize the basic methodologies here. For more details, see Chapter 8 and the Environmental Benefits Mapping and Analysis Program (BenMAP) user’s manual (http://www.epa.gov/ttn/ecas/benmodels.html).

BenMAP uses health impact functions to generate changes in the incidence of health effects. Health impact functions are derived from the C-R functions reported in the epidemiology literature. A standard health impact function has four components: an effect estimate from a particular epidemiological study, a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics, such as CDC), the affected population, and the estimated change in the relevant pollutant summary measure.

A typical health impact function might look like this:

$$\Delta y = y_0 \cdot (e^{\beta \cdot \Delta x} - 1) ,$$

where y_0 is the baseline incidence, equal to the baseline incidence rate times the potentially affected population; β is the effect estimate; Δx is the estimated change in the pollutant (e.g., $PM_{2.5}$ or O_3) and Δy is the estimated change in incidence of the health effect (e.g., the number of deaths avoided) associated with the change in the pollutant, Δx. There are other functional forms, but the basic elements remain the same.

8B.4.1 Reductions in O_3-Related Premature Deaths

To calculate O_3-related life years saved under the Final Small SI and Recreational Marine Engine Rule (hereafter, Final SSI & RME Rule), we first calculated the numbers of O_3-related statistical lives saved within 5-year age groups, using BenMAP. (For more details on the calculation of statistical lives saved using BenMAP, see Chapter 8 or the BenMAP user’s manual (http://www.epa.gov/ttn/ecas/benmodels.html). We used two studies used in the benefit analysis for the Final SSI & RME Rule RIA – Bell et al. (2004) and Levy et al. (2005). Both studies report estimated C-R functions of the association between premature mortality and short-term exposures to ambient O_3. Bell et al. (2004) is a multi-city study of 95 cities, and as such may avoid the potential for publication bias that may be inherent in single-city studies or meta-analyses of single-city studies. This study provides the lowest estimate of O_3-related premature deaths among the mortality studies included in the Final SSI & RME Rule RIA benefit analysis. An upper bound estimate of O_3-related premature deaths in the Final SSI & RME Rule RIA benefit analysis was provided by Levy et al. (2005). More extensive discussions of these studies are given in Chapter 8.

We checked to confirm that the total number of O_3-related statistical lives saved, summed across all age groups, equals the corresponding number calculated in the Final SSI & RME Rule RIA benefit analysis. Age group-specific O_3-related premature deaths avoided under the Final SSI & RME Rule in 2020 and in 2030 are given in Table 8B-2.

Table 8B-2. Estimated Reduction in Incidence of O_3-Related Premature Mortality Under the Final SSI & RME Rule in 2020 and 2030

	Reduction in O_3-Related Premature Mortality (95% CI)*			
Age Interval	2020		2030	
	Bell et al. (2004)	Levy et al. (2005)	Bell et al. (2004)	Levy et al. (2005)
0 - 4	0 (0 - 0)	1 (1 - 1)	0 (0 - 0)	1 (1 - 2)
5 - 9	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)	1 (0 - 1)
10 - 14	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)	1 (0 - 1)
15 - 19	0 (0 - 0)	1 (0 - 1)	0 (0 - 0)	1 (1 - 1)
20 - 24	0 (0 - 0)	1 (1 - 2)	0 (0 - 0)	2 (1 - 2)
25 - 29	0 (0 - 0)	2 (1 - 2)	0 (0 - 0)	2 (2 - 3)
30 - 34	0 (0 - 0)	2 (1 - 2)	0 (0 - 0)	2 (1 - 3)
35 - 39	0 (0 - 1)	3 (2 - 3)	1 (0 - 1)	4 (3 - 5)
40 - 44	0 (0 - 1)	2 (2 - 3)	1 (0 - 1)	3 (2 - 4)
45 - 49	1 (0 - 2)	5 (3 - 6)	1 (0 - 2)	7 (5 - 9)
50 - 54	1 (0 - 2)	5 (4 - 7)	1 (0 - 2)	5 (4 - 7)
55 - 59	3 (1 - 5)	13 (9 - 18)	3 (1 - 6)	16 (11 - 20)
60 - 64	3 (1 - 5)	13 (9 - 17)	4 (1 - 6)	16 (11 - 21)
65 - 69	6 (2 - 9)	25 (17 - 33)	9 (3 - 16)	42 (29 - 54)
70 - 74	4 (1 - 7)	20 (14 - 26)	8 (3 - 13)	35 (24 - 46)
75 - 79	7 (2 - 12)	31 (22 - 41)	15 (5 - 26)	67 (46 - 88)
80 - 84	5 (2 - 8)	20 (14 - 26)	9 (3 - 15)	39 (27 - 51)
85+	15 (5 - 25)	65 (45 - 85)	24 (8 - 40)	100 (72 - 140)
Total:	46 (15 - 77)	210 (140 - 270)	77 (25 - 130)	350 (240 - 460)

*95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

8B.4.2 Life Years Saved as a Result of Reductions in O_3-Related Mortality Risk

The number of life years saved depends not only on the number of statistical lives saved, but also on the life expectancies associated with those statistical lives. As was pointed out in the CEAs for the PM and O_3 NAAQS RIAs, age-specific life expectancies for the general population are calculated from mortality rates for the general population, and these reflect the prevalence of chronic disease, which shortens life expectancies. The only reason one might use lower life expectancies than those for the general population in the CEA for the Final SSI & RME Rule RIA is if the population at risk from exposure to O_3 was limited solely or disproportionately to individuals with preexisting chronic illness, whose life expectancies were, on average, shorter than those of the general population (unless all of those individuals had preexisting chronic illness because of long-term exposure to O_3).

It is reasonable to assume that someone who dies from exposure to an air pollutant is already in a compromised state. However, there are both acute and chronic compromised states. If an individual has an acute illness (e.g., pneumonia) that puts him at risk of mortality when exposed to a high concentration of an air pollutant, then in the absence of that high concentration he could be expected to recover from the illness and go on to live the expected number of years for someone his age – i.e., he would have the age-specific life expectancy of the general population.

If an individual has a chronic illness that makes him vulnerable to a high concentration of an air pollutant, then an important question is whether or not he would have had that chronic illness if he had not been exposed over the long term to high levels of the air pollutant.

We can categorize individuals who are at risk of dying because of exposure to an air pollutant into three groups:

- those who are vulnerable because of a preexisting acute condition;
- those who are vulnerable because of a preexisting chronic condition that they would *not* have had, had they not been exposed over the long term to high levels of the air pollutant; and
- those who are vulnerable because of a preexisting chronic condition that they would have had even in the absence of long term exposure to high levels of the air pollutant.

The age-specific life expectancies of the general population should apply to the first two groups, and the age-specific life expectancies of the subpopulation with the relevant chronic condition(s) should apply to the third group. If we knew the proportions of people who die from exposure to O_3 who are in each group, and the life expectancies of people in the third group, we could calculate the number of life years saved as follows:

$$\textit{Total life years saved} = \sum_i M_i * (p_{1i} * LE_i + p_{2i} * LE_i + p_{3i} * LE_i^*)$$

where

M_i denotes the number of O_3-related deaths of individuals age *i*,

LE_i denotes the general population life expectancy for age *i*,

LE_i^* denotes the life expectancy for age i of the subpopulation with the relevant chronic condition(s) – i.e., the third group;

p_{1i} denotes the proportion of the M_i O_3-related deaths that are in the first group;

p_{2i} denotes the proportion of the M_i O_3-related deaths that are in the second group; and

p_{3i} denotes the proportion of the M_i O_3-related deaths that are in the third group.

Unlike for $PM_{2.5}$ (discussed below), we currently lack information that would allow us to estimate the relevant proportions necessary to estimate the set of life expectancies that would be appropriate to apply to O_3-related deaths. Although there is substantial evidence linking premature mortality to short-term exposures to O_3, there is currently not similar evidence for long-term exposures. We therefore do not know if the second group above is relevant in the case of O_3-related mortality. Nor do we know what proportion of O_3-related deaths can be attributed to preexisting acute conditions (the first group) versus preexisting chronic conditions that these individuals would have had even in the absence of long term exposure to O_3 (the third group).

Because we currently lack the necessary information to determine the appropriate set of life expectancies to use in calculating life years saved associated with O_3-related premature mortality avoided, we calculated life years saved based on four different underlying assumptions:

- A lower bound assumption of zero life years saved, based on the hypothesis that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship;
- An upper bound assumption that an O_3-related premature death of an individual of a given age will result in a loss of life years equal to the life expectancy in the general population of that age;
- Two intermediate assumptions: That the proportions of O_3-related premature deaths in the three groups delineated above (p_{1i}, p_{2i}, and p_{3i}) are such that, on average, the age-specific life expectancies among people who die O_3-related premature deaths are those of
    - people with severe preexisting chronic conditions, whose life expectancies are substantially shorter than those of the general population; and
    - people with preexisting chronic conditions of a range of severities, whose life expectancies are somewhat shorter than those of the general population.

Life years saved based on the upper bound assumption were calculated from age-specific mortality probabilities for the general population taken from the Centers for Disease Control (CDC) National Vital Statistics Reports, Vol. 56, No. 9, December 28, 2007, Table 1. Life table for the total population: United States, 2004.[6] We used a simplified method of calculating life expectancies from these age-specific mortality probabilities that yielded life expectancies that were close to the life expectancies derived using the more complicated method employed by the

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[6] http://www.cdc.gov/nchs/data/nvsr/nvsr56/nvsr56_09.pdf

CDC.[7] In particular, starting with a cohort of size 1,000,000 at birth, we calculated the life-years lived between ages x and $(x+1)$, for $x = 0, 1, 2, \ldots, 99$, using the age-specific mortality probabilities taken from the CDC Vital Statistics Report (see above) and assuming that all deaths that occurred between ages x and $(x+1)$ occurred midway through the year (i.e., we assigned 0.5 life-year to each year of death). The life expectancy at age n was then calculated as the sum of the life-years lived from age n through age 100 divided by the cohort size at age n. The life expectancy at age n is the number of life years lost due to an O_3-related premature mortality of an individual age n.

To estimate life years saved under the two intermediate assumptions about the life years lost as a result of O_3-related premature mortality, we turned to the epidemiological evidence of a statistically significant association between short-term exposures to O_3 and respiratory hospital admissions. This evidence suggests that these short-term exposures may exacerbate respiratory conditions that were preexisting. It is reasonable to suppose that some of these hospitalizations for respiratory illnesses on days of relatively high O_3 concentrations might result in death. It may also be the case that some individuals who did not go to the hospital might also die. We therefore looked for information on life expectancies of people with chronic respiratory conditions.

While there is information readily available in vital statistics sources on rates of death *from* chronic respiratory diseases, there is not similarly available information on rates of death *among that subpopulation who suffer from those diseases*. It is the latter rate – the rate of death among that subpopulation who suffers from those diseases – that is of interest.

A recent study of people with and without chronic obstructive pulmonary disease (COPD) provided data from which we were able to construct estimates of the mortality rates of interest. Mannino et al. (2006) followed a cohort of 15,440 subjects ages 43 to 66 for up to 11 years. The cohort subjects were selected from the larger cohort of the Atherosclerosis Risk in Communities (ARIC) study, which selected its subjects from the population of four U.S. communities by probability sampling.[8] The subjects in the Mannino study were limited to the ARIC participants who provided baseline information on respiratory symptoms and diagnoses, who underwent pulmonary function testing, and for whom follow-up data were available.

Using a modification of the criteria developed by the Global Initiative on Obstructive Lung Disease (GOLD), Mannino et al. (2006) classified the study subjects into COPD severity groups (or stages), with GOLD stage 0 (presence of respiratory symptoms in the absence of any lung function abnormality) being the least severe COPD group, and GOLD stages 3 and 4 being the most severe. The unadjusted death rates of the study participants (taken from Table 1 of Mannino et al., 2006), ratios of (unadjusted) death rates, and hazard ratios, based on Cox

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[7] We calculated life expectancies from the mortality probabilities rather than using the life expectancies given in the CDC table because we were going to also calculate life expectancies for the subpopulations with severe COPD and with "average" COPD by adjusting the age-specific mortality probabilities and then calculating life expectancies using these adjusted probabilities.

[8] In one of the four communities probability sampling was used to select African-Americans only.

proportional hazard regressions, which took into account several covariates (including, among others, age, sex, race, smoking status, and education level) are shown in the table below. In addition, the right-most column of the table below shows the proportion of COPD subjects in the study in each GOLD category.

Table 8B-3. Death Rates and Hazard Ratios for Subjects with Varying Degrees of Severity of COPD (from Mannino et al., 2006)

GOLD* Category	N	Deaths	(%)	Person-Years	Death Rate per 1,000 Person-Years	Ratio of Death Rate to Death Rate for Normal Population	Hazard Ratio**	Proportion of COPD Subjects in GOLD Category
GOLD 3 or 4	271	92	33.9%	2,143	42.9	7.97	5.7	4.77%
GOLD 2	1,484	232	15.6%	12,852	18.1	3.35	2.4	26.14%
GOLD 1	1,679	137	8.2%	15,031	9.1	1.69	1.4	29.57%
GOLD 0	2,244	204	9.1%	20,191	10.1	1.88	1.5	39.52%
Restricted	1,101	150	13.6%	9,644	15.6	2.89	2.3	
Normal	8,661	427	4.9%	79,317	5.4	1.00	1.0	
Total	15,440	1,242	8.0%	139,178	8.9			

*Global Inititative on Obstructive Lung Disease (GOLD) guidelines for the staging of COPD severity.
**See Mannino et al. (2006), p. 117.

The ratios of unadjusted death rates are somewhat larger than the corresponding hazard ratios because these ratios were not adjusted for age. COPD is a progressive disease, so it would be expected that the proportion of older individuals would increase as the stages (and severity) increased, and this was indeed the case in the Mannino study. The hazard ratios, being based on regressions that took age into account, avoid this problem. We therefore used the hazard ratios to derive age-specific mortality rates for individuals with (1) severe COPD and (2) COPD of “average” severity. In particular, to derive age-specific mortality probabilities for the subpopulation with severe COPD, we multiplied each age-specific mortality probability for the general population by 5.7 (the hazard ratio for GOLD 3 or 4); to derive age-specific mortality probabilities for the subpopulation with “average” COPD, we multiplied each age-specific mortality probability for the general population by a weighted average of the GOLD category-specific hazard ratios, where the weight for a GOLD category was the proportion of COPD subjects in that GOLD category (given in the right-most column of Table 1 above). The weighted average hazard ratio was 1.906. Age-specific life expectancies were then derived for the severe COPD and “average” COPD subpopulations using these adjusted mortality probabilities and the method for calculating life expectancies described above.

Once an appropriate set of life expectancies has been determined (e.g., life expectancies for the general population or life expectancies for a subpopulation with severe COPD), these then provide the number of life years lost for an individual who dies at a given age. This information can then be combined with the estimated number of O_3-related premature deaths at each age calculated with BenMAP (see previous subsection). Because BenMAP calculates numbers of premature deaths avoided within age intervals, we can either allocate the premature deaths avoided within an age interval uniformly to the ages within the interval or, alternatively, we can calculate average life expectancies for the age intervals. We illustrate the first approach in calculating O_3-related life years saved and the second approach in calculating $PM_{2.5}$-related life years saved (see Section 8B.4.4).

Total O_3-related life years gained was calculated as the sum of life years gained at each age:

$$Total\ life\ years\ gained = = \sum_{i=0}^{N} LE_i \times M_i$$

where LE_i is the remaining life expectancy for age i, M_i is the number of premature deaths avoided among individuals age i, and N is the oldest age considered.

For the purposes of determining cost effectiveness, it is also necessary to consider the time-dependent nature of the gains in life years. Standard economic theory suggests that benefits occurring in future years should be discounted relative to benefits occurring in the present. OMB and EPA guidance suggest discount rates of three and seven percent. Selection of a 3 percent discount rate is also consistent with recommendations from the U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine (Gold et al., 1996).

Discounted total life years gained is calculated as follows:

$$Discounted\ LY = \int_0^{LE} e^{-rt} \boldsymbol{dt},$$

where r is the discount rate, t indicates time, and LE is the life expectancy at the time when the premature death would have occurred. Because O_3-related premature mortality is associated only with short-term exposures, all O_3-related premature deaths are assumed to occur in the year of exposure. We therefore did not discount O_3-related premature deaths avoided.

Undiscounted age-specific life expectancies, and age-specific life expectancies using discount rates of 3 percent and 7 percent are given for the general population, the subpopulation of individuals with severe COPD, and the subpopulation of individuals with COPD of average severity in Tables 8B-4, 8B-5, and 8B-6, respectively. The O_3-related (discounted) life years saved, based on each of the two O_3-mortality studies and each of the assumptions about relevant life expectancies, are given, using 3 percent and 7 percent discount rates, in Tables 8B-7 and 8B-8, respectively. The O_3-related (discounted) life years saved, under the first assumption – that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship – is zero in all cases (i.e., regardless of the mortality study used and the scenario considered), and is therefore not shown in these Tables.

Table 8B-4. Undiscounted and Discounted Age-Specific Life Expectancies for the General Population

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.006799	1,000,000	6,799	996,600	77.8	30.9	15.2
1	0.000483	993,201	480	992,961	77.3	30.8	15.2
2	0.000297	992,721	295	992,574	76.4	30.7	15.2
3	0.000224	992,427	222	992,315	75.4	30.6	15.2
4	0.000188	992,204	187	992,111	74.4	30.5	15.2
5	0.000171	992,017	170	991,932	73.4	30.4	15.2
6	0.000161	991,847	159	991,768	72.4	30.3	15.2
7	0.000151	991,688	149	991,613	71.4	30.2	15.2
8	0.000136	991,538	135	991,471	70.4	30.1	15.2
9	0.000119	991,403	118	991,345	69.5	29.9	15.1
10	0.000106	991,286	105	991,233	68.5	29.8	15.1
11	0.000112	991,180	111	991,125	67.5	29.7	15.1
12	0.000149	991,070	148	990,996	66.5	29.5	15.1
13	0.000227	990,922	225	990,809	65.5	29.4	15.1
14	0.000337	990,697	333	990,530	64.5	29.2	15.1
15	0.000460	990,363	456	990,135	63.5	29.1	15.1
16	0.000579	989,907	573	989,621	62.5	28.9	15.1
17	0.000684	989,334	677	988,996	61.6	28.8	15.0
18	0.000763	988,657	755	988,280	60.6	28.6	15.0
19	0.000819	987,902	809	987,498	59.7	28.4	15.0
20	0.000873	987,093	862	986,662	58.7	28.3	15.0
21	0.000926	986,231	913	985,775	57.8	28.1	15.0
22	0.000960	985,318	946	984,845	56.8	27.9	15.0
23	0.000972	984,372	957	983,893	55.9	27.8	14.9
24	0.000969	983,415	953	982,939	54.9	27.6	14.9
25	0.000960	982,462	943	981,991	54.0	27.4	14.9
26	0.000954	981,519	936	981,051	53.0	27.2	14.9
27	0.000952	980,583	933	980,117	52.1	27.0	14.8
28	0.000958	979,650	939	979,181	51.1	26.8	14.8
29	0.000973	978,712	952	978,235	50.2	26.5	14.8
30	0.000994	977,759	972	977,273	49.2	26.3	14.7
31	0.001023	976,787	999	976,287	48.3	26.1	14.7
32	0.001063	975,788	1,038	975,269	47.3	25.9	14.7
33	0.001119	974,750	1,091	974,205	46.4	25.6	14.6
34	0.001192	973,659	1,160	973,079	45.4	25.4	14.6
35	0.001275	972,499	1,240	971,879	44.5	25.1	14.5
36	0.001373	971,259	1,334	970,592	43.5	24.9	14.5
37	0.001493	969,925	1,448	969,201	42.6	24.6	14.4
38	0.001634	968,477	1,582	967,686	41.7	24.3	14.4
39	0.001788	966,895	1,729	966,031	40.7	24.0	14.3
40	0.001945	965,166	1,877	964,228	39.8	23.7	14.3
41	0.002107	963,290	2,029	962,275	38.9	23.5	14.2
42	0.002287	961,260	2,198	960,161	38.0	23.2	14.1
43	0.002494	959,062	2,392	957,866	37.0	22.8	14.0
44	0.002727	956,670	2,609	955,366	36.1	22.5	14.0
45	0.002982	954,061	2,845	952,639	35.2	22.2	13.9
46	0.003246	951,216	3,088	949,672	34.3	21.9	13.8

Table 8B-4. Undiscounted and Discounted Age-Specific Life Expectancies for the General Population (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.003520	948,129	3,337	946,460	33.5	21.6	13.7
48	0.003799	944,792	3,589	942,997	32.6	21.2	13.6
49	0.004088	941,203	3,848	939,279	31.7	20.9	13.5
50	0.004404	937,355	4,128	935,291	30.8	20.5	13.4
51	0.004750	933,227	4,433	931,010	30.0	20.2	13.3
52	0.005113	928,794	4,749	926,419	29.1	19.8	13.2
53	0.005488	924,045	5,071	921,510	28.2	19.4	13.0
54	0.005879	918,974	5,403	916,273	27.4	19.1	12.9
55	0.006295	913,571	5,751	910,696	26.6	18.7	12.7
56	0.006754	907,820	6,131	904,755	25.7	18.3	12.6
57	0.007280	901,689	6,564	898,407	24.9	17.9	12.4
58	0.007903	895,125	7,074	891,588	24.1	17.5	12.3
59	0.008633	888,051	7,667	884,217	23.3	17.1	12.1
60	0.009493	880,384	8,357	876,205	22.5	16.7	11.9
61	0.010449	872,027	9,112	867,471	21.7	16.2	11.8
62	0.011447	862,915	9,878	857,976	20.9	15.8	11.6
63	0.012428	853,037	10,601	847,736	20.1	15.4	11.4
64	0.013408	842,435	11,295	836,788	19.4	15.0	11.2
65	0.014473	831,140	12,029	825,126	18.6	14.5	11.0
66	0.015703	819,111	12,863	812,680	17.9	14.1	10.7
67	0.017081	806,249	13,771	799,363	17.2	13.7	10.5
68	0.018623	792,477	14,758	785,098	16.5	13.2	10.3
69	0.020322	777,719	15,805	769,817	15.8	12.8	10.0
70	0.022104	761,915	16,841	753,494	15.1	12.3	9.8
71	0.024023	745,073	17,899	736,124	14.4	11.9	9.5
72	0.026216	727,174	19,064	717,642	13.7	11.5	9.3
73	0.028745	708,110	20,355	697,933	13.1	11.0	9.0
74	0.031561	687,756	21,706	676,903	12.5	10.6	8.7
75	0.034427	666,050	22,930	654,585	11.9	10.2	8.4
76	0.037379	643,120	24,039	631,100	11.3	9.7	8.2
77	0.040756	619,080	25,231	606,465	10.7	9.3	7.9
78	0.044764	593,849	26,583	580,558	10.1	8.9	7.6
79	0.049395	567,266	28,020	553,256	9.6	8.5	7.3
80	0.054471	539,246	29,373	524,560	9.0	8.1	7.0
81	0.059772	509,873	30,476	494,635	8.5	7.7	6.7
82	0.065438	479,397	31,371	463,712	8.1	7.3	6.4
83	0.071598	448,026	32,078	431,987	7.6	6.9	6.1
84	0.078516	415,949	32,659	399,619	7.1	6.5	5.8
85	0.085898	383,290	32,924	366,828	6.7	6.2	5.6
86	0.093895	350,366	32,897	333,917	6.3	5.8	5.3
87	0.102542	317,468	32,554	301,192	5.9	5.5	5.0
88	0.111875	284,915	31,875	268,977	5.5	5.1	4.7
89	0.121928	253,040	30,853	237,613	5.1	4.8	4.5
90	0.132733	222,187	29,492	207,441	4.8	4.5	4.2
91	0.144318	192,695	27,809	178,791	4.4	4.2	3.9
92	0.156707	164,886	25,839	151,967	4.1	3.9	3.7
93	0.169922	139,047	23,627	127,234	3.7	3.6	3.4
94	0.183975	115,420	21,234	104,803	3.4	3.3	3.1
95	0.198875	94,186	18,731	84,820	3.0	3.0	2.8
96	0.214620	75,454	16,194	67,357	2.7	2.6	2.5
97	0.231201	59,260	13,701	52,410	2.3	2.2	2.2
98	0.248600	45,559	11,326	39,896	1.8	1.8	1.8
99	0.266786	34,233	9,133	29,667	1.2	1.2	1.2
100	1.000000	25,100	25,100	12,550	0.5	0.5	0.5

*Mortality probabilities for the general population taken from Table 1. Life table for the total population: United States, 2004. CDC National Vital Statistics Reports, Vol. 56, No. 9, December 28, 2007 http://www.cdc.gov/nchs/data/nvsr/nvsr56/nvsr56_09.pdf

Table 8B-5. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with Severe COPD

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.038755	1,000,000	38,755	980,622	54.5	27.5	14.9
1	0.002752	961,245	2,646	959,922	55.7	27.7	14.9
2	0.001692	958,599	1,622	957,788	54.9	27.5	14.9
3	0.001277	956,977	1,222	956,366	53.9	27.4	14.9
4	0.001074	955,755	1,026	955,242	53.0	27.2	14.9
5	0.000978	954,729	933	954,263	52.1	27.0	14.8
6	0.000916	953,796	873	953,359	51.1	26.8	14.8
7	0.000859	952,923	819	952,513	50.2	26.5	14.8
8	0.000777	952,104	739	951,734	49.2	26.3	14.7
9	0.000677	951,365	644	951,043	48.2	26.1	14.7
10	0.000606	950,721	576	950,433	47.3	25.8	14.7
11	0.000636	950,145	605	949,842	46.3	25.6	14.6
12	0.000850	949,540	807	949,137	45.3	25.3	14.6
13	0.001295	948,733	1,229	948,119	44.4	25.1	14.5
14	0.001918	947,505	1,818	946,596	43.4	24.8	14.5
15	0.002625	945,687	2,482	944,446	42.5	24.6	14.4
16	0.003301	943,205	3,113	941,648	41.6	24.3	14.4
17	0.003901	940,092	3,667	938,258	40.8	24.0	14.3
18	0.004351	936,424	4,075	934,387	39.9	23.8	14.3
19	0.004671	932,350	4,355	930,172	39.1	23.5	14.2
20	0.004976	927,995	4,618	925,686	38.3	23.3	14.1
21	0.005278	923,377	4,873	920,941	37.5	23.0	14.1
22	0.005472	918,504	5,026	915,991	36.7	22.7	14.0
23	0.005542	913,478	5,063	910,947	35.9	22.4	13.9
24	0.005522	908,415	5,016	905,907	35.1	22.2	13.9
25	0.005470	903,399	4,942	900,928	34.2	21.9	13.8
26	0.005436	898,458	4,884	896,016	33.4	21.6	13.7
27	0.005425	893,573	4,847	891,150	32.6	21.2	13.6
28	0.005461	888,726	4,853	886,300	31.8	20.9	13.5
29	0.005547	883,873	4,903	881,422	31.0	20.6	13.4
30	0.005668	878,970	4,982	876,479	30.1	20.2	13.3
31	0.005830	873,988	5,095	871,440	29.3	19.9	13.2
32	0.006061	868,893	5,266	866,260	28.5	19.5	13.1
33	0.006380	863,626	5,510	860,872	27.6	19.2	12.9
34	0.006792	858,117	5,828	855,203	26.8	18.8	12.8
35	0.007269	852,289	6,195	849,191	26.0	18.4	12.7
36	0.007827	846,094	6,622	842,783	25.2	18.0	12.5
37	0.008510	839,472	7,144	835,900	24.4	17.6	12.3
38	0.009312	832,328	7,750	828,452	23.6	17.2	12.2
39	0.010191	824,577	8,403	820,376	22.8	16.8	12.0
40	0.011084	816,174	9,047	811,651	22.0	16.4	11.8
41	0.012008	807,128	9,692	802,282	21.3	16.0	11.7
42	0.013035	797,436	10,395	792,238	20.5	15.6	11.5
43	0.014215	787,041	11,187	781,447	19.8	15.2	11.3
44	0.015546	775,854	12,061	769,823	19.1	14.8	11.1
45	0.016996	763,792	12,981	757,301	18.4	14.4	10.9
46	0.018503	750,811	13,892	743,865	17.7	14.0	10.7

Table 8B-5. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with Severe COPD (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.020061	736,919	14,784	729,527	17.0	13.6	10.4
48	0.021652	722,135	15,636	714,317	16.3	13.1	10.2
49	0.023303	706,500	16,464	698,268	15.7	12.7	10.0
50	0.025103	690,036	17,322	681,375	15.0	12.3	9.8
51	0.027075	672,714	18,214	663,607	14.4	11.9	9.5
52	0.029144	654,500	19,075	644,963	13.8	11.5	9.3
53	0.031280	635,425	19,876	625,487	13.2	11.1	9.0
54	0.033512	615,549	20,628	605,235	12.6	10.7	8.8
55	0.035880	594,921	21,346	584,248	12.0	10.3	8.5
56	0.038497	573,575	22,081	562,535	11.5	9.9	8.2
57	0.041497	551,494	22,885	540,052	10.9	9.5	8.0
58	0.045046	528,609	23,812	516,703	10.3	9.0	7.7
59	0.049211	504,797	24,842	492,376	9.8	8.6	7.4
60	0.054108	479,956	25,969	466,971	9.3	8.2	7.1
61	0.059560	453,986	27,040	440,467	8.8	7.9	6.9
62	0.065249	426,947	27,858	413,018	8.3	7.5	6.6
63	0.070839	399,089	28,271	384,953	7.9	7.1	6.3
64	0.076425	370,818	28,340	356,648	7.4	6.8	6.0
65	0.082495	342,478	28,253	328,352	7.0	6.4	5.8
66	0.089507	314,225	28,125	300,163	6.6	6.1	5.5
67	0.097361	286,100	27,855	272,173	6.2	5.7	5.2
68	0.106149	258,245	27,413	244,539	5.8	5.4	5.0
69	0.115833	230,833	26,738	217,463	5.4	5.1	4.7
70	0.125993	204,094	25,714	191,237	5.1	4.8	4.4
71	0.136933	178,380	24,426	166,167	4.7	4.5	4.2
72	0.149433	153,954	23,006	142,451	4.4	4.2	3.9
73	0.163847	130,948	21,455	120,220	4.1	3.9	3.7
74	0.179896	109,493	19,697	99,644	3.8	3.6	3.5
75	0.196231	89,795	17,621	80,985	3.5	3.4	3.2
76	0.213062	72,175	15,378	64,486	3.2	3.1	3.0
77	0.232309	56,797	13,194	50,200	3.0	2.9	2.8
78	0.255152	43,603	11,125	38,040	2.7	2.7	2.6
79	0.281552	32,477	9,144	27,905	2.5	2.4	2.4
80	0.310486	23,333	7,245	19,711	2.3	2.2	2.2
81	0.340699	16,089	5,481	13,348	2.1	2.0	2.0
82	0.372994	10,607	3,956	8,629	1.9	1.9	1.8
83	0.408108	6,651	2,714	5,294	1.7	1.7	1.7
84	0.447543	3,937	1,762	3,056	1.5	1.5	1.5
85	0.489619	2,175	1,065	1,642	1.4	1.4	1.4
86	0.535199	1,110	594	813	1.3	1.3	1.2
87	0.584489	516	302	365	1.1	1.1	1.1
88	0.637689	214	137	146	1.0	1.0	1.0
89	0.694992	78	54	51	0.9	0.9	0.9
90	0.756579	24	18	15	0.8	0.8	0.8
91	0.822612	6	5	3	0.6	0.6	0.6
92	0.893232	1	0	0	0.0	0.0	0.0

*Mortality probabilities derived from mortality probabilities for the general population by multiplying by the hazard ratio (5.7) for GOLD 3 or 4, from Mannino et al. (2006).

Table 8B-6. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with COPD of Average Severity

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.012960	1,000,000	12,960	993,520	69.6	29.9	15.1
1	0.000920	987,040	908	986,586	69.5	29.9	15.1
2	0.000566	986,132	558	985,853	68.6	29.8	15.1
3	0.000427	985,574	421	985,363	67.6	29.7	15.1
4	0.000359	985,153	354	984,976	66.7	29.5	15.1
5	0.000327	984,799	322	984,638	65.7	29.4	15.1
6	0.000306	984,477	301	984,326	64.7	29.3	15.1
7	0.000287	984,176	283	984,034	63.7	29.1	15.1
8	0.000260	983,893	256	983,765	62.7	29.0	15.1
9	0.000226	983,638	223	983,526	61.8	28.8	15.1
10	0.000203	983,415	199	983,315	60.8	28.6	15.0
11	0.000213	983,216	209	983,111	59.8	28.5	15.0
12	0.000284	983,006	279	982,867	58.8	28.3	15.0
13	0.000433	982,727	426	982,514	57.8	28.1	15.0
14	0.000642	982,302	630	981,986	56.8	27.9	15.0
15	0.000878	981,671	862	981,241	55.9	27.8	14.9
16	0.001104	980,810	1,083	980,268	54.9	27.6	14.9
17	0.001304	979,727	1,278	979,088	54.0	27.4	14.9
18	0.001455	978,449	1,424	977,737	53.1	27.2	14.9
19	0.001562	977,025	1,526	976,262	52.1	27.0	14.8
20	0.001664	975,499	1,623	974,688	51.2	26.8	14.8
21	0.001765	973,876	1,719	973,017	50.3	26.6	14.8
22	0.001830	972,157	1,779	971,268	49.4	26.4	14.7
23	0.001853	970,378	1,798	969,479	48.5	26.1	14.7
24	0.001846	968,580	1,788	967,686	47.6	25.9	14.7
25	0.001829	966,792	1,769	965,907	46.7	25.7	14.6
26	0.001818	965,023	1,754	964,146	45.7	25.5	14.6
27	0.001814	963,269	1,747	962,395	44.8	25.2	14.5
28	0.001826	961,521	1,756	960,643	43.9	25.0	14.5
29	0.001855	959,766	1,780	958,875	43.0	24.7	14.5
30	0.001896	957,985	1,816	957,077	42.1	24.4	14.4
31	0.001949	956,169	1,864	955,237	41.1	24.2	14.3
32	0.002027	954,305	1,934	953,338	40.2	23.9	14.3
33	0.002133	952,371	2,032	951,355	39.3	23.6	14.2
34	0.002271	950,339	2,158	949,260	38.4	23.3	14.1
35	0.002431	948,181	2,305	947,028	37.5	23.0	14.1
36	0.002617	945,876	2,476	944,638	36.6	22.7	14.0
37	0.002846	943,400	2,685	942,058	35.7	22.4	13.9
38	0.003114	940,716	2,929	939,251	34.8	22.0	13.8
39	0.003408	937,786	3,196	936,189	33.9	21.7	13.7
40	0.003707	934,591	3,464	932,859	33.0	21.4	13.6
41	0.004016	931,127	3,739	929,257	32.1	21.0	13.5
42	0.004359	927,388	4,042	925,366	31.2	20.7	13.4
43	0.004753	923,345	4,389	921,151	30.4	20.3	13.3
44	0.005199	918,956	4,777	916,567	29.5	20.0	13.2
45	0.005683	914,179	5,196	911,581	28.7	19.6	13.1
46	0.006187	908,983	5,624	906,171	27.8	19.2	13.0

Table 8B-6. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with COPD of Average Severity (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.006709	903,359	6,060	900,329	27.0	18.9	12.8
48	0.007241	897,298	6,497	894,050	26.2	18.5	12.7
49	0.007793	890,801	6,942	887,331	25.3	18.1	12.5
50	0.008395	883,860	7,420	880,150	24.5	17.7	12.4
51	0.009054	876,440	7,935	872,472	23.7	17.3	12.2
52	0.009746	868,505	8,464	864,273	23.0	16.9	12.1
53	0.010460	860,040	8,996	855,542	22.2	16.5	11.9
54	0.011207	851,044	9,537	846,276	21.4	16.1	11.7
55	0.011999	841,507	10,097	836,458	20.6	15.7	11.5
56	0.012874	831,410	10,703	826,058	19.9	15.3	11.3
57	0.013877	820,707	11,389	815,012	19.1	14.8	11.1
58	0.015064	809,318	12,191	803,222	18.4	14.4	10.9
59	0.016456	797,127	13,118	790,568	17.7	14.0	10.7
60	0.018094	784,009	14,186	776,916	17.0	13.5	10.4
61	0.019917	769,823	15,333	762,157	16.3	13.1	10.2
62	0.021820	754,490	16,463	746,259	15.6	12.7	10.0
63	0.023689	738,028	17,483	729,286	14.9	12.3	9.7
64	0.025557	720,545	18,415	711,337	14.3	11.8	9.5
65	0.027587	702,130	19,370	692,445	13.6	11.4	9.2
66	0.029932	682,760	20,436	672,542	13.0	11.0	8.9
67	0.032558	662,324	21,564	651,542	12.4	10.5	8.7
68	0.035497	640,760	22,745	629,388	11.8	10.1	8.4
69	0.038735	618,015	23,939	606,046	11.2	9.7	8.1
70	0.042133	594,076	25,030	581,561	10.6	9.3	7.8
71	0.045791	569,046	26,057	556,017	10.1	8.9	7.6
72	0.049971	542,989	27,134	529,422	9.6	8.4	7.3
73	0.054791	515,855	28,264	501,723	9.0	8.0	7.0
74	0.060158	487,591	29,333	472,924	8.5	7.6	6.7
75	0.065621	458,258	30,071	443,223	8.0	7.3	6.4
76	0.071249	428,187	30,508	412,933	7.6	6.9	6.1
77	0.077685	397,679	30,894	382,232	7.1	6.5	5.8
78	0.085324	366,785	31,296	351,137	6.7	6.1	5.6
79	0.094152	335,489	31,587	319,696	6.2	5.8	5.3
80	0.103828	303,902	31,554	288,125	5.8	5.4	5.0
81	0.113932	272,349	31,029	256,834	5.5	5.1	4.7
82	0.124731	241,319	30,100	226,269	5.1	4.8	4.5
83	0.136473	211,219	28,826	196,806	4.8	4.5	4.2
84	0.149661	182,394	27,297	168,745	4.4	4.2	4.0
85	0.163731	155,096	25,394	142,399	4.1	3.9	3.7
86	0.178974	129,702	23,213	118,096	3.8	3.7	3.5
87	0.195456	106,489	20,814	96,082	3.5	3.4	3.3
88	0.213247	85,675	18,270	76,540	3.3	3.2	3.1
89	0.232409	67,405	15,666	59,572	3.0	3.0	2.8
90	0.253004	51,740	13,090	45,194	2.8	2.7	2.7
91	0.275086	38,649	10,632	33,333	2.6	2.5	2.5
92	0.298702	28,017	8,369	23,833	2.4	2.4	2.3
93	0.323890	19,649	6,364	16,467	2.2	2.2	2.1
94	0.350677	13,285	4,659	10,955	2.0	2.0	2.0
95	0.379078	8,626	3,270	6,991	1.9	1.8	1.8
96	0.409089	5,356	2,191	4,261	1.7	1.7	1.6
97	0.440695	3,165	1,395	2,468	1.5	1.5	1.5
98	0.473858	1,770	839	1,351	1.3	1.3	1.3
99	0.508523	931	474	695	1.0	1.0	1.0
100	1.000000	458	458	229	0.5	0.5	0.5

*Mortality probabilities derived from mortality probabilities for the general population (see Table 2) by multiplying by the weighted average of hazard ratios for the GOLD severity categories (1.906) from Mannino et al. (2006).

Table 8B-7. Estimated O_3-Related Life Years Saved in 2020 and in 2030 Under the Final SSI & RME Rule, Using a 3 Percent Discount Rate

Estimated O_3-Related Life Years Saved (95% CI)*				
	2020		2030	
Mortality Study:	Bell et al (2004)	Levy et al. (2005)	Bell et al (2004)	Levy et al. (2005)
Assuming Life Expectancies of the General Population	500 (150 - 800)	2,200 (1,500 - 2,900)	700 (250 - 1,200)	3,500 (2,400 - 4,600)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity	360 (120 - 600)	1,700 (1,200 - 2,200)	560 (180 - 900)	2,700 (1,800 - 3,500)
Assuming Life Expectancies of the Sub-Population with Severe COPD	190 (60 - 320)	1,000 (700 - 1,300)	290 (100 - 490)	1,500 (1,000 - 1,900)

*95 percent confidence or credible intervals are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

Table 8B-8. Estimated O_3-Related Life Years Saved in 2020 and in 2030 Under the Final SSI & RME Rule, Using a 7 Percent Discount Rate

Estimated O_3-Related Life Years Saved (95% CI)*				
	2020		2030	
Mortality Study:	Bell et al (2004)	Levy et al. (2005)	Bell et al (2004)	Levy et al. (2005)
Assuming Life Expectancies of the General Population	360 (120 - 600)	1,700 (1,200 - 2,200)	590 (190 - 1,000)	2,700 (1,900 - 3,500)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity	290 (90 - 500)	1,400 (900 - 1,800)	460 (150 - 800)	2,100 (1,500 - 2,800)
Assuming Life Expectancies of the Sub-Population with Severe COPD	170 (50 - 280)	800 (600 - 1,100)	250 (80 - 430)	1,200 (800 - 1,600)

*95 percent confidence or credible intervals are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

8B.4.3 Reductions in $PM_{2.5}$-Related Premature Deaths

To generate $PM_{2.5}$-related health outcomes, we used the same framework as for the benefit-cost analysis described in Chapter 8 and briefly summarized above in the introductory portion of Section 8B.4.

As in several recent air pollution health impact assessments (e.g., Kunzli et al., 2000; EPA, 2004), we focused on the prospective cohort long-term exposure studies in deriving the health impact function for the estimate of premature mortality. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli et al., 2001; NRC, 2002). We selected an effect estimate from the extended analysis of the ACS cohort (Pope et al., 2002) as well as from the Harvard Six City Study (Laden et al., 2006). Given the focus in this analysis on developing a broader expression of uncertainties in the benefits estimates, and the weight that was placed on both the ACS and Harvard Six-city studies by experts participating in the $PM_{2.5}$ mortality expert elicitation, we elected to provide estimates derived from both Pope et al. (2002) and Laden et al. (2006).

This latest re-analysis of the ACS cohort data (Pope et al, 2002) provides additional refinements to the analysis of PM-related mortality by (a) extending the follow-up period for the ACS study subjects to 16 years, which triples the size of the mortality data set; (b) substantially increasing exposure data, including consideration for cohort exposure to $PM_{2.5}$ following implementation of $PM_{2.5}$ standard in 1999; (c) controlling for a variety of personal risk factors including occupational exposure and diet; and (d) using advanced statistical methods to evaluate specific issues that can adversely affect risk estimates, including the possibility of spatial autocorrelation of survival times in communities located near each other. The effect estimate from Pope et al. (2002) quantifies the relationship between annual mean $PM_{2.5}$ levels and all-cause mortality in adults 30 and older. We selected the effect estimate estimated using the measure of PM representing average exposure over the follow-up period, calculated as the average of 1979–1984 and 1999–2000 $PM_{2.5}$ levels. The effect estimate from this study is 0.0058, which is equivalent to a relative risk of 1.06 for a 10 µg change in $PM_{2.5}$.

A recent follow up to the Harvard 6-city study (Laden et al., 2006) both confirmed the effect size from the first study and provided additional confirmation that reductions in $PM_{2.5}$ directly result in 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 $PM_{2.5}$. The effect estimate obtained from Laden et al. (2006) is 0.0148, which is equivalent to a relative risk of 1.16 for a 10 $\mu g/m^3$ change in $PM_{2.5}$.

Age, cause, and county-specific mortality rates were obtained from CDC for the years 1996 through 1998. CDC maintains an online data repository of health statistics, CDC Wonder, accessible at http://wonder.cdc.gov/. The mortality rates provided are derived from U.S. death records and U.S. Census Bureau postcensal population estimates. Mortality rates were averaged across 3 years (1996 through 1998) to provide more stable estimates. When estimating rates for age groups that differed from the CDC Wonder groupings, we assumed that rates were uniform across all ages in the reported age group. For example, to estimate mortality rates for individuals ages 30 and up, we scaled the 25- to 34-year old death count and population by one-half and then generated a population-weighted mortality rate using data for the older age groups.

The reductions in incidence of $PM_{2.5}$-related premature mortality within each age group associated with the Final SSI & RME Rule in 2020 and 2030 are summarized in Table 8B-9.

Table 8B-9: Estimated Reduction in Incidence of $PM_{2.5}$-Related All-Cause Premature Mortality Under the Final SSI & RME Rule in 2020 and 2030

	Reduction in $PM_{2.5}$-Related Premature Mortality (90% CI)*			
Age Interval	2020		2030	
	Pope et al. (2002)	Laden et al. (2006)	Pope et al. (2002)	Laden et al. (2006)
25 - 29	---	3 (2 - 5)	---	4 (2 - 5)
30 - 34	1 (0 - 2)	3 (2 - 4)	2 (1 - 3)	4 (2 - 5)
35 - 44	3 (1 - 5)	7 (4 - 10)	5 (2 - 8)	11 (6 - 17)
45 - 54	5 (2 - 9)	12 (7 - 18)	9 (3 - 14)	20 (11 - 29)
55 - 64	13 (5 - 21)	29 (16 - 43)	22 (9 - 35)	50 (27 - 72)
65 - 74	19 (7 - 30)	42 (23 - 61)	51 (20 - 81)	110 (62 - 170)
75 - 84	31 (12 - 49)	69 (38 - 100)	69 (27 - 110)	160 (85 - 230)
85+	47 (18 - 75)	110 (57 - 150)	68 (27 - 110)	150 (84 - 220)
Total:	120 (47 - 190)	270 (150 - 390)	230 (88 - 360)	510 (280 - 750)

*90 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

8B.4.4 Life Years Saved as a Result of Reductions in $PM_{2.5}$-Related Mortality Risk

To calculate life years saved associated with a given change in air pollution, we used a life table approach coupled with age-specific estimates of reductions in premature mortality. We began with the complete unabridged life table for the United States in 2000, obtained from CDC (CDC, 2002). For each 1-year age interval (e.g., zero to one, one to two) the life table provides estimates of the baseline probability of dying during the interval, person years lived in the interval, and remaining life expectancy. From this unabridged life table, we constructed an abridged life table to match the age intervals for which we have predictions of changes in incidence of premature mortality. We used the abridgement method described in CDC (2002). Table 8B-10 presents the abridged life table for 10-year age intervals for adults over 30 (to match the Pope et al. [2002] study population). Note that the abridgement actually includes one 5-year interval, covering adults 30 to 34, with the remaining age intervals covering 10 years each. This is to provide conformity with the age intervals available for mortality rates.

From the abridged life table (Table 8B-10), we obtained the remaining life expectancy for each age cohort, conditional on surviving to that age. This is then the number of life years lost for an individual in the general population dying during that age interval. This information can then be combined with the estimated number of premature deaths in each age interval calculated with

BenMAP (see previous subsection). Total life years gained will then be the sum of life years gained in each age interval:

$$TotalLife\ Years = \sum_{i=1}^{N} LE_i \times M_i ,$$

where LE_i is the remaining life expectancy for age interval i, M_i is the change in incidence of mortality in age interval i, and N is the number of age intervals.

As noted above, for the purposes of determining cost-effectiveness, it is also necessary to consider the time-dependent nature of the gains in life years. Standard economic theory suggests that benefits occurring in future years should be discounted relative to benefits occurring in the present. OMB and EPA guidance suggest discount rates of three and seven percent. Selection of a 3 percent discount rate is also consistent with recommendations from the U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine (Gold et al., 1996).

Table 8B-10. Abridged Life Table for the Total Population, United States, 2000

Age Interval		*Probability of Dying Between Ages x to x+1*	*Number Surviving to Age x*	*Number Dying Between Ages x to x+1*	*Person Years Lived Between Ages x to x+1*	*Total Number of Person Years Lived Above Age x*	*Expectation of Life at Age x*
Start Age	End Age	q_x	l_x	d_x	L_x	T_x	e_x
30	35	0.00577	97,696	564	487,130	4,723,539	48.3
35	45	0.01979	97,132	1,922	962,882	4,236,409	43.6
45	55	0.04303	95,210	4,097	934,026	3,273,527	34.4
55	65	0.09858	91,113	8,982	872,003	2,339,501	25.7
65	75	0.21779	82,131	17,887	740,927	1,467,498	17.9
75	85	0.45584	64,244	29,285	505,278	726,571	11.3
85	95	0.79256	34,959	27,707	196,269	221,293	6.3
95	100	0.75441	7,252	5,471	20,388	25,024	3.5
100+		1.00000	1,781	1,781	4,636	4,636	2.6

Unlike O_3-related premature deaths, $PM_{2.5}$-related premature deaths are associated with long-term exposures. We therefore did not assume that these deaths all occur in 2020 or 2030. The $PM_{2.5}$-related premature deaths avoided and associated life years saved are thus further discounted to account for the lag between the reduction in ambient $PM_{2.5}$ and the corresponding reduction in mortality risk. We used the same 20-year segmented lag structure that is used in the benefit-cost analysis (see Chapter 8).

The most complete estimate of the impacts of $PM_{2.5}$ on life years is calculated using the Pope et al. (2002) C-R function relating all-cause mortality in adults 30 and over with ambient $PM_{2.5}$ concentrations averaged over the periods 1979–1983 and 1999–2000. Use of all-cause mortality is appropriate if there are no differences in the life expectancy of individuals dying from air pollution-related causes and those dying from other causes. The argument that long-term exposure to $PM_{2.5}$ may affect mainly individuals with serious preexisting illnesses is not supported by current empirical studies. For example, the Krewski et al. (2000) ACS reanalysis suggests that the mortality risk is no greater for those with preexisting illness at time of enrollment in the study. Life expectancy for the general population in fact includes individuals with serious chronic illness. Mortality rates for the general population then reflect prevalence of chronic disease, and as populations age the prevalence of chronic disease increases.

The only reason one might use a lower life expectancy is if the population at risk from air pollution was limited solely to those with preexisting disease. Also, note that the OMB Circular A-4 notes that "if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimate number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts." As such, use of a general population life expectancy is preferred over disability-specific life expectancies. Our primary life years calculations are thus consistent with the concept of not penalizing individuals with disabling chronic health conditions by assessing them reduced benefits of mortality risk reductions. $PM_{2.5}$-Related life years saved under the Final SSI & RME Rule in 2020 and 2030 are given in Table 8B-11.

Table 8B-11. Estimated $PM_{2.5}$-Related Life Years Saved Under the Final SSI & RME Rule in 2020 and 2030

Estimated $PM_{2.5}$-Related Life Years Saved (95% CI)*				
	2020		2030	
	Pope et al (2002)	Laden et al. (2006)	Pope et al (2002)	Laden et al. (2006)
Discounted back to 2020 or 2030, using a 3 percent discount rate:	1,100 (400 - 1,800)	2,600 (1,400 - 4,000)	2,200 (900 - 3,500)	5,000 (2,700 - 7,000)
Discounted back to 2020 or 2030, using a 7 percent discount rate:	800 (300 - 1,200)	1,800 (1,000 - 2,500)	1,500 (600 - 2,400)	3,500 (1,900 - 5,100)

*95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

For this analysis, direct impacts on life expectancy are measured only through the estimated change in mortality risk based on the Pope et al. (2002) C-R function. The SAB-HES has advised against including additional gains in life expectancy due to reductions in incidence of chronic disease or nonfatal heart attacks (EPA-SAB-COUNCIL-ADV-04-002). Although reductions in these endpoints are likely to result in increased life expectancy, the HES has suggested that the cohort design and relatively long follow-up period in the Pope et al. study should capture any life-prolonging impacts associated with those endpoints. Impacts of CB and nonfatal heart attacks on quality of life will be captured separately in the QALY calculation as years lived with improved quality of life. The methods for calculating this benefit are discussed below.

8B.4.5 Calculating Changes in the Quality of Life Years ($PM_{2.5}$-Related Chronic Morbidity)

In addition to directly measuring the quantity of life gained, measured by life years, it may also be informative to measure gains in the quality of life. The indirect reductions in levels of $PM_{2.5}$ also lead to reductions in serious illnesses that affect quality of life. These include chronic bronchitis (CB) and cardiovascular disease, for which we are able to quantify changes in the incidence of nonfatal heart attacks. To capture these important benefits in the measure of effectiveness, they must first be converted into a life-year equivalent so that they can be combined with the direct gains in life expectancy.

For the cost effectiveness analyses for the PM and O_3 NAAQS RIAs, we developed estimates of the QALYs gained from reductions in the incidence of CB and nonfatal heart attacks associated with reductions in ambient $PM_{2.5}$. In general, QALY calculations require four elements:

1. the estimated change in incidence of the health condition,
2. the duration of the health condition,
3. the quality-of-life weight with the health condition, and
4. the quality-of-life weight without the health condition (i.e., the baseline health state).

The first element is derived using the health impact function approach. The second element is based on the medical literature for each health condition. The third and fourth elements are derived from the medical cost-effectiveness and cost-utility literature. In the following two subsections, we discuss the choices of elements for CB and nonfatal heart attacks.

The preferred source of quality-of-life weights are those based on community preferences, rather than patient or clinician ratings (Gold et al., 1996). Several methods are used to estimate quality-of-life weights. These include rating scale, standard gamble, time trade-off, and person trade-off approaches (Gold, Stevenson, and Fryback, 2002). Only the standard gamble approach is completely consistent with utility theory. However, the time trade-off method has also been widely applied in eliciting community preferences (Gold, Stevenson, and Fryback, 2002).

Quality-of-life weights can be directly elicited for individual specific health states or for a more general set of activity restrictions and health states that can then be used to construct QALY weights for specific conditions (Horsman et al., 2003; Kind, 1996). For this analysis, we used weights based on community-based preferences, using time trade-off or standard gamble when available. In some cases, we used patient or clinician ratings when no community preference-based weights were available. Sources for weights are discussed in more detail below. Table 8B-12 summarizes the key inputs for calculating QALYs associated with chronic health endpoints.

Table 8B-12. Summary of Key Parameters Used in QALY Calculations for Chronic Disease Endpoints

Parameter	*Value(s)*	*Source(s)*
Discount rate	0.03 (0.07 sensitivity analysis)	Gold et al. (1996), U.S. EPA (2000), U.S. OMB (2003)
Quality of life preference score for chronic bronchitis	0.5 – 0.7	Triangular distribution centered at 0.7 with upper bound at 0.9 (Vos, 1999a) (slightly better than a mild/moderate case) and a lower bound at 0.5 (average weight for a severe case based on Vos [1999a] and Smith and Peske [1994])
Duration of acute phase of acute myocardial infarction (AMI)	5.5 days – 22 days	Uniform distribution with lower bound based on average length of stay for an AMI (AHRQ, 2000) and upper bound based on Vos (1999b).
Probability of CHF post AMI	0.2	Vos, 1999a (WHO Burden of Disease Study, based on Cowie et al., 1997)
Probability of angina post AMI	0.51	American Heart Association, 2003 (Calculated as the population with angina divided by the total population with heart disease)
Quality-of-life preference score for post-AMI with CHF (no angina)	0.80 – 0.89	Uniform distribution with lower bound at 0.80 (Stinnett et al., 1996) and upper bound at 0.89 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with CHF and angina	0.76 – 0.85	Uniform distribution with lower bound at 0.76 (Stinnett et al., 1996, adjusted for severity) and upper bound at 0.85 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with angina (no CHF)	0.7 – 0.89	Uniform distribution with lower bound at 0.7, based on the standard gamble elicitation method (Pliskin, Stason, and Weinstein, 1981) and upper bound at 0.89, based on the time trade-off method (Kuntz et al., 1996).
Quality-of-life preference score for post-AMI (no angina, no CHF)	0.93	Only one value available from the literature. Thus, no distribution is specified. Source of value is Kuntz et al. (1996).

8B.4.5.1 Calculating QALYs Associated with Reductions in the Incidence of Chronic Bronchitis

CB is characterized by mucus in the lungs and a persistent wet cough for at least 3 months a year for several years in a row. CB affects an estimated 5 percent of the U.S. population (American Lung Association, 1999). For gains in quality of life resulting from reduced incidences of PM-induced CB, discounted QALYs are calculated as

$$DISCOUNTED\ QALY GAINED = \sum_i \Delta CB_i \times D_i^* \times \left(w_i - w_i^{CB}\right)$$

where ΔCB_i is the number of incidences of CB avoided in age interval i, w_i is the average QALY weight for the ith age interval, w_i^{CB} is the QALY weight associated with CB in the ith age interval, and D_i^* is the discounted duration of life with CB for individuals with onset of disease in the ith age interval, equal to $\int_0^{D_i} e^{-rt}dt$, where D_i is the duration of life with CB for individuals with onset of disease the ith age interval.

A limited number of studies have estimated the impact of air pollution on new incidences of CB. Schwartz (1993) and Abbey et al. (1995) provide evidence that long-term PM exposure gives rise to the development of CB in the United States. Only the Abbey et al. (1995) study was used, because it is the only study focusing on the relationship between $PM_{2.5}$ and new incidences of CB. The number of cases of CB in each age interval was derived by applying the impact function from Abbey et al. (1995) to the population in each age interval with the appropriate baseline incidence rate.[9] The effect estimate from the Abbey et al. (1995) study is 0.0137, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.15 for a 10 μg change in $PM_{2.5}$. Table 8B-13 presents the estimated reduction in new incidences of CB associated with the Final SSI & RME Rule in 2020 and 2030.

CB is assumed to persist for the remainder of an affected individual's lifespan. Duration of CB will thus equal life expectancy conditioned on having CB. CDC has estimated that COPD (of which CB is one element) results in an average loss of life years equal to 4.26 per COPD death, relative to a reference life expectancy of 75 years (CDC, 2003). Thus, we subtracted 4.26 from the remaining life expectancy for each age group, up to age 75. For age groups over 75, we applied the ratio of 4.26 to the life expectancy for the 65 to 74 year group (0.237) to the life expectancy for the 75 to 84 and 85 and up age groups to estimate potential life years lost and then subtracted that value from the base life expectancy.

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[9] Prevalence rates for CB were obtained from the 1999 National Health Interview Survey (American Lung Association, 2002). Prevalence rates were available for three age groups: 18–44, 45–64, and 65 and older. Prevalence rates per person for these groups were 0.0367 for 18–44, 0.0505 for 45–64, and 0.0587 for 65 and older. The incidence rate for new cases of CB (0.00378 per person) was taken directly from Abbey et al. (1995).

Table 8B-13. Estimated Reduction in Incidence of Chronic Bronchitis Under the Final SSI & RME Rule in 2020 and 2030

	Reduction in $PM_{2.5}$-Related Chronic Bronchitis (90% CI)*	
Age Interval	2020	2030
27 - 34	18 (3 - 33)	22 (4 - 40)
35 - 44	15 (3 - 28)	26 (5 - 48)
45 - 54	14 (3 - 26)	22 (4 - 40)
55 - 64	16 (3 - 28)	22 (4 - 40)
65 - 74	11 (2 - 19)	21 (4 - 38)
75 - 84	6 (1 - 11)	12 (2 - 22)
85+	3 (1 - 5)	4 (1 - 8)
Total:	84 (16 - 150)	130 (24 - 240)

*90 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

Quality of life with chronic lung diseases has been examined in several studies. In an analysis of the impacts of environmental exposures to contaminants, de Hollander et al. (1999) assigned a weight of 0.69 to years lived with CB. This weight was based on physicians' evaluations of health states similar to CB. Salomon and Murray (2003) estimated a pooled weight of 0.77 based on visual analogue scale, time trade-off, standard gamble, and person trade-off techniques applied to a convenience sample of health professionals. The Harvard Center for Risk Analysis catalog of preference scores reports a weight of 0.40 for severe COPD, with a range from 0.2 to 0.8, based on the judgments of the study's authors (Bell et al., 2001). The Victoria Burden of Disease (BoD) study used a weight of 0.47 for severe COPD and 0.83 for mild to moderate COPD, based on an analysis by Stouthard et al. (1997) of chronic diseases in Dutch populations (Vos, 1999a). Based on the recommendations of Gold et al. (1996), quality-of-life weights based on community preferences are preferred for CEA of interventions affecting broad populations. Use of weights based on health professionals is not recommended. It is not clear from the Victoria BoD study whether the weights used for COPD are based on community preferences or judgments of health professionals. The Harvard catalog score is clearly identified as based on author judgment. Given the lack of a clear preferred weight, we selected a triangular distribution centered at 0.7 with an upper bound at 0.9 (slightly better than a mild/moderate case defined by the Victoria BoD study) and a lower bound at 0.5 based on the Victoria BoD study. We will need additional empirical data on quality of life with chronic respiratory diseases based on community preferences to improve our estimates.

Selection of a reference weight for the general population without CB is somewhat uncertain. It is clear that the general population is not in perfect health; however, there is some uncertainty as to whether individuals' ratings of health states are in reference to a perfect health state or to a generally achievable "normal" health state given age and general health status. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that "since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY" (Gold et al., 1996). Following Carrothers, Evans, and Graham (2002), we assumed that the reference weight for the general population without CB is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0. Note that the reference weight for the general population is used solely to determine the incremental quality-of-life improvement applied to the duration of life that would have been lived with the chronic disease. For example, if CB has a quality-of-life weight of 0.7 relative to a reference quality-of-life weight of 0.9, then the incremental quality-of-life improvement in 0.2. If the reference quality-of-life weight is 0.95, then the incremental quality-of-life improvement is 0.25. As noted above, the population is assumed to have a reference weight of 1.0 for all life years gained due to mortality risk reductions.

We present discounted QALYs over the duration of the lifespan with CB using a 3 percent discount rate. Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of CB for each age interval.[10] Based on the assumptions defined above, the mean 3 percent discounted QALY gained per incidence of CB for each age interval along with the 95 percent confidence interval resulting from the Monte Carlo simulation is presented in Table 8B-14. Table 8B-14 presents both the undiscounted and discounted QALYs gained per incidence, using a 3 percent discount rate.

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[10] Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables. For more details, see Gentile (1998).

Table 8B-14. QALYs Gained per Avoided Incidence of CB

Age Interval		*QALYs Gained per Incidence*[a]	
Start Age	End Age	Undiscounted	Discounted (3%)
25	34	12.15 (4.40-19.95)	6.52 (2.36-10.71)
35	44	9.91 (3.54-16.10)	5.94 (2.12-9.66)
45	54	7.49 (2.71-12.34)	5.03 (1.82-8.29)
55	64	5.36 (1.95-8.80)	4.03 (1.47-6.61)
65	74	3.40 (1.22-5.64)	2.84 (1.02-4.71)
75	84	2.15 (0.77-3.49)	1.92 (0.69-3.13)
85+		0.79 (0.27-1.29)	0.77 (0.26-1.25)

[a] Mean of Monte Carlo generated distribution; 95% confidence interval presented in parentheses.

8B.4.5.2 Calculating QALYs Associated with Reductions in the Incidence of Nonfatal Myocardial Infarctions

Nonfatal heart attacks, or acute myocardial infarctions, require more complicated calculations to derive estimates of QALY impacts. The actual heart attack, which results when an area of the heart muscle dies or is permanently damaged because of oxygen deprivation, and subsequent emergency care are of relatively short duration. Many heart attacks result in sudden death. However, for survivors, the long-term impacts of advanced coronary heart disease (CHD) are potentially of long duration and can result in significant losses in quality of life and life expectancy.

In this phase of the analysis, we did not independently estimate the gains in life expectancy associated with reductions in nonfatal heart attacks. Based on recommendations from the SAB-HES, we assumed that all gains in life expectancy are captured in the estimates of reduced mortality risk provided by the Pope et al. (2002) analysis. We estimated only the change in quality of life over the period of life affected by the occurrence of a heart attack. This may understate the QALY impacts of nonfatal heart attacks but ensures that the overall QALY impact estimates across endpoints do not double-count potential life-year gains.

Our approach adapts a CHD model developed for the Victoria Burden of Disease study (Vos, 1999b). This model accounts for the lost quality of life during the heart attack and the possible health states following the heart attack. Figure 8B-1 shows the heart attack QALY model in diagrammatic form.

The total gain in QALYs is calculated as:

$$DISCOUNTED\ AMI\ QALY\ GAINED =$$

$$\sum_i \Delta AMI_i \times D_i^{*AMI} \times \left(w_i - w_i^{AMI}\right) + \sum_i \sum_{j=1}^{4} \Delta AMI_i \times p_j D_{ij}^{*PostAMI} \times \left(w_i - w_{ij}^{postAMI}\right)$$

where ΔAMI_i is the number of nonfatal acute myocardial infarctions avoided in age interval *i*, w_i^{AMI} is the QALY weight associated with the acute phase of the AMI, p_j is the probability of being in the *j*th post-AMI status, $w_{ij}^{postAMI}$ is the QALY weight associated with post-AMI health status *j*, w_i is the average QALY weight for age interval i, $D_i^{*AMI} = \int_{t=1}^{D_i^{AMI}} e^{-rt}dt$, the discounted value of D_i^{AMI}, the duration of the acute phase of the AMI, and $D_i^{*postAMI} = \int_{t=1}^{D_i^{postAMI}} e^{-rt}dt$, is the discounted value of $D_{ij}^{PostAMI}$, the duration of post-AMI health status *j*.

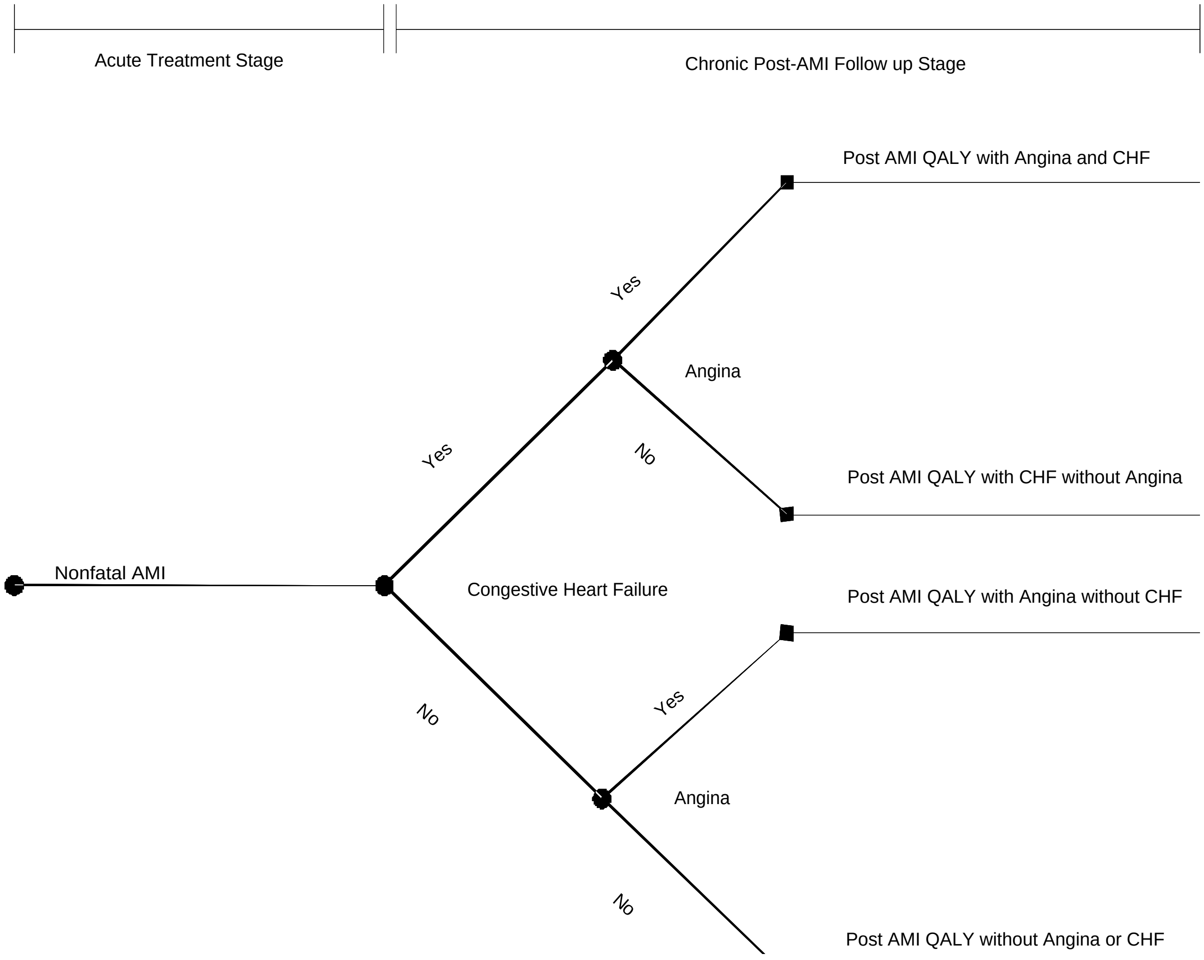

Figure 8B-1. Decision Tree Used in Modeling Gains in QALYs from Reduced Incidence of Nonfatal Acute Myocardial Infarctions

Nonfatal heart attacks have been linked with short-term exposures to $PM_{2.5}$ in the United States (Peters et al., 2001) and other countries (Poloniecki et al., 1997). We used a recent study by Peters et al. (2001) as the basis for the impact function estimating the relationship between $PM_{2.5}$ and nonfatal heart attacks. Peters et al. is the only available U.S. study to provide a specific estimate for heart attacks. Other studies, such as Samet et al. (2000) and Moolgavkar (2000), show a consistent relationship between all cardiovascular hospital admissions, including for nonfatal heart attacks, and PM. Given the lasting impact of a heart attack on longer-term health costs and earnings, we chose to provide a separate estimate for nonfatal heart attacks based on the single available U.S. effect estimate. The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the United States. These studies provide a weight of evidence for this type of effect. Several epidemiologic studies (Liao et al., 1999; Gold et al., 2000; Magari et al., 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other CHDs (Carthenon et al., 2002; Dekker et al., 2000; Liao et al., 1997, Tsuji et al., 1996). As such, significant impacts of PM on heart rate variability are consistent with an increased risk of heart attacks.

The number of avoided nonfatal AMI in each age interval was derived by applying the impact function from Peters et al. (2001) to the population in each age interval with the appropriate baseline incidence rate.[11] The effect estimate from the Peters et al. (2001) study is 0.0241, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.27 for a 10 µg change in $PM_{2.5}$. Table 8B-15 presents the estimated reduction in nonfatal AMI associated with the Final SSI & RME Rule in 2020 and 2030.

Table 8B-15. Estimated Reduction in Nonfatal Acute Myocardial Infarctions Under the Final SSI & RME Rule in 2020 and 2030

	Reduction in $PM_{2.5}$-Related Acute Myocardial Infarction (90% CI)*	
Age Interval	2020	2030
18 - 24	0 (0 - 0)	0 (0 - 0)
25 - 29	1 (1 - 2)	2 (1 - 3)
35 - 44	10 (5 - 14)	16 (9 - 23)
45 - 54	29 (16 - 42)	43 (23 - 63)
55 - 64	68 (37 - 98)	99 (53 - 140)
65 - 74	94 (51 - 140)	160 (84 - 230)
75 - 84	48 (26 - 69)	140 (76 - 210)
85+	42 (23 - 62)	67 (36 - 98)
Total:	290 (160 - 420)	530 (280 - 770)

*90 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

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[11] Daily nonfatal myocardial infarction incidence rates per person were obtained from the 1999 National Hospital Discharge Survey (assuming all diagnosed nonfatal AMI visit the hospital). Age-specific rates for four regions are used in the analysis. Regional averages for populations 18 and older are 0.0000159 for the Northeast, 0.0000135 for the Midwest, 0.0000111 for the South, and 0.0000100 for the West.

Acute myocardial infarction results in significant loss of quality of life for a relatively short duration. The WHO Global Burden of Disease study, as reported in Vos (1999b), assumes that the acute phase of an acute myocardial infarction lasts for 0.06 years, or around 22 days. An alternative assumption is the acute phase is characterized by the average length of hospital stay for an AMI in the United States, which is 5.5 days, based on data from the Agency for Healthcare Research and Quality's Healthcare Cost and Utilization Project (HCUP).[12] We assumed a distribution of acute phase duration characterized by a uniform distribution between 5.5 and 22 days, noting that due to earlier discharges and in-home therapy available in the United States, duration of reduced quality of life may continue after discharge from the hospital. In the period during and directly following an AMI (the acute phase), we assigned a quality of life weight equal to 0.605, consistent with the weight for the period in treatment during and immediately after an attack (Vos, 1999b).

During the post-AMI period, a number of different health states can determine the loss in quality of life. We chose to classify post-AMI health status into four states defined by the presence or absence of angina and congestive heart failure (CHF). This makes a very explicit assumption that without the occurrence of an AMI, individuals would not experience either angina or CHF. If in fact individuals already have CHF or angina, then the quality of life gained will be overstated. We do not have information about the percentage of the population have been diagnosed with angina or CHF with no occurrence of an AMI. Nor do we have information on what proportion of the heart attacks occurring due to PM exposure are first heart attacks versus repeat attacks. Probabilities for the four post-AMI health states sum to one.

Given the occurrence of a nonfatal AMI, the probability of congestive heart failure is set at 0.2, following the heart disease model developed by Vos (1999b). The probability is based on a study by Cowie et al. (1997), which estimated that 20 percent of those surviving AMI develop heart failure, based on an analysis of the results of the Framingham Heart Study.

The probability of angina is based on the prevalence rate of angina in the U.S. population. Using data from the American Heart Association, we calculated the prevalence rate for angina by dividing the estimated number of people with angina (6.6 million) by the estimated number of people with CHD of all types (12.9 million). We then assumed that the prevalence of angina in the population surviving an AMI is similar to the prevalence of angina in the total population with CHD. The estimated prevalence rate is 51 percent, so the probability of angina is 0.51.

Combining these factors leads to the probabilities for each of the four health states as follows:

I. Post AMI with CHF and angina = 0.102
II. Post AMI with CHF without angina = 0.098
III. Post AMI with angina without CHF = 0.408
IV. Post AMI without angina or CHF = 0.392

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[12] Average length of stay estimated from the HCUP data includes all discharges, including those due to death. As such, the 5.5-day average length of stay is likely an underestimate of the average length of stay for AMI admissions where the patient is discharged alive.

Duration of post-AMI health states varies, based in part on assumptions regarding life expectancy with post-AMI complicating health conditions. Based on the model used for established market economies (EME) in the WHO Global Burden of Disease study, as reported in Vos (1999b), we assumed that individuals with CHF have a relatively short remaining life expectancy and thus a relatively short period with reduced quality of life (recall that gains in life expectancy are assumed to be captured by the cohort estimates of reduced mortality risk). Table 8B-16 provides the duration (both discounted and undiscounted) of CHF assumed for post-AMI cases by age interval.

Table 8B-16. Assumed Duration of Congestive Heart Failure

Age Interval		*Duration of Heart Failure (years)*	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	7.11	6.51
25	34	6.98	6.40
35	44	6.49	6.00
45	54	5.31	4.99
55	64	1.96	1.93
65	74	1.71	1.69
75	84	1.52	1.50
85+		1.52	1.50

Duration of health states without CHF is assumed to be equal to the life expectancy of individuals conditional on surviving an AMI. Ganz et al. (2000) note that “Because patients with a history of myocardial infarction have a higher chance of dying of CHD that is unrelated to recurrent myocardial infarction (for example, arrhythmia), this cohort has a higher risk for death from causes other than myocardial infarction or stroke than does an unselected population.” They go on to specify a mortality risk ratio of 1.52 for mortality from other causes for the cohort of individuals with a previous (nonfatal) AMI. The risk ratio is relative to all-cause mortality for an age-matched unselected population (i.e., general population). We adopted the same ratios and applied them to each age-specific all-cause mortality rate to derive life expectancies (both discounted and undiscounted) for each age group after an AMI, presented in Table 8B-17. These life expectancies were then used to represent the duration of non-CHF post-AMI health states (III and IV).

Table 8B-17. Assumed Duration of Non-CHF Post-AMI Health States

Age Interval		Post-AMI Years of Life Expectancy (non-CHF)	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	55.5	27.68
25	34	46.1	25.54
35	44	36.8	22.76
45	54	27.9	19.28
55	64	19.8	15.21
65	74	12.8	10.82
75	84	7.4	6.75
85+		3.6	3.47

For the four post-AMI health states, we used QALY weights based on preferences for the combined conditions characterizing each health state. A number of estimates of QALY weights are available for post-AMI health conditions.

The first two health states are characterized by the presence of CHF, with or without angina. The Harvard Center for Risk Analysis catalog of preference scores provides several specific weights for CHF with and without mild or severe angina and one set specific to post-AMI CHF. Following the Victoria Burden of Disease model, we assumed that most cases of angina will be treated and thus kept at a mild to moderate state. We thus focused our selection on QALY weights for mild to moderate angina. The Harvard database includes two sets of community preference-based scores for CHF (Stinnett et al., 1996; Kuntz et al., 1996). The scores for CHF with angina range from 0.736 to 0.85. The lower of the two scores is based on angina in general with no delineation by severity. Based on the range of the scores for mild to severe cases of angina in the second study, one can infer that an average case of angina has a score around 0.96 of the score for a mild case. Applying this adjustment raises the lower end of the range of preference scores for a mild case of angina to 0.76. We selected a uniform distribution over the range 0.76 to 0.85 for CHF with mild angina, with a midpoint of 0.81. The same two studies in the Harvard catalog also provide weights for CHF without angina. These scores range from 0.801 to 0.89. We selected a uniform distribution over this range, with a midpoint of 0.85.

The third health state is characterized by angina, without the presence of CHF. The Harvard catalog includes five sets of community preference-based scores for angina, one that specifies scores for both mild and severe angina (Kuntz et al., 1996), one that specifies mild angina only (Pliskin, Stason, and Weinstein, 1981), one that specifies severe angina only (Cohen, Breall, and Ho, 1994), and two that specify angina with no severity classification (Salkeld, Phongsavan, and Oldenburg, 1997; Stinnett et al., 1996). With the exception of the Pliskin, Stason, and Weinstein score, all of the angina scores are based on the time trade-off method of elicitation. The Pliskin, Stason, and Weinstein score is based on the standard gamble elicitation method. The scores for the nonspecific severity angina fall within the range of the two scores for mild angina specifically. Thus, we used the range of mild angina scores as the endpoints of a uniform distribution. The range of mild angina scores is from 0.7 to 0.89, with a midpoint of 0.80.

For the fourth health state, characterized by the absence of CHF and/or angina, there is only one relevant community preference score available from the Harvard catalog. This score is 0.93, derived from a time trade-off elicitation (Kuntz et al., 1996). Insufficient information is available to provide a distribution for this weight; therefore, it is treated as a fixed value.

Similar to CB, we assumed that the reference weight for the general population without AMI is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0.

Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of nonfatal AMI for each age interval. For the Monte Carlo simulation, all distributions were assumed to be independent. The mean QALYs gained per incidence of nonfatal AMI for each age interval is presented in Table 8B-18, along with the 95 percent confidence interval resulting from the Monte Carlo simulation. Table 8B-18 presents both the undiscounted and discounted QALYs gained per incidence.

Table 8B-18. QALYs Gained per Avoided Nonfatal Myocardial Infarction

Age Interval		QALYs Gained per Incidence[a]	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	4.18 (1.24-7.09)	2.17 (0.70-3.62)
25	34	3.48 (1.09-5.87)	2.00 (0.68-3.33)
35	44	2.81 (0.88-4.74)	1.79 (0.60-2.99)
45	54	2.14 (0.67-3.61)	1.52 (0.51-2.53)
55	64	1.49 (0.42-2.52)	1.16 (0.34-1.95)
65	74	0.97 (0.30-1.64)	0.83 (0.26-1.39)
75	84	0.59 (0.20-0.97)	0.54 (0.19-0.89)
85+		0.32 (0.13-0.50)	0.31 (0.13-0.49)

[a] Mean of Monte Carlo generated distribution; 95% confidence interval presented in parentheses.

8B.4.6 *Aggregating Life Expectancy and Quality-of-Life Gains*

Given the estimates of changes in life expectancy and quality of life, the next step is to aggregate life expectancy and quality-of-life gains to form an effectiveness measure that can be compared to costs to develop cost-effectiveness ratios. This section discusses the proper characterization of the combined effectiveness measure for the denominator of the cost-effectiveness ratio.

To develop an integrated measure of changes in health, we simply sum together the gains in life years from reduced mortality risk in each age interval with the gains in QALYs from reductions in incidence of chronic morbidity endpoints (CB and acute myocardial infarctions). The resulting measure of effectiveness then forms the denominator in the cost-effectiveness ratio. This combined measure of effectiveness is not a QALY measure in a strict sense, because we have not adjusted life-expectancy gains for preexisting health status (quality of life). It is however, an effectiveness measure that adds a scaled morbidity equivalent to the standard life years calculation. Thus, we term the aggregate measure morbidity inclusive life years, or MILYs. Alternatively, the combined measure could be considered as QALYs with an assumption that the community preference weight for all life-expectancy gains is 1.0. If one considers that this weight might be considered to be a “fair” treatment of those with preexisting disabilities, the effectiveness measure might be termed “fair QALY” gained. However, this implies that all aspects of fairness have been addressed, and there are clearly other issues with the fairness of QALYs (or other effectiveness measures) that are not addressed in this simple adjustment. The MILY measure violates some of the properties used in deriving QALY weights, such as linear substitution between quality of life and quantity of life. However, in aggregating life expectancy and quality-of-life gains, it merely represents an alternative social weighting that is consistent with the spirit of the recent OMB guidance on CEA. The guidance notes that “fairness is important in the choice and execution of effectiveness measures” (OMB, 2003). The resulting aggregate measure of effectiveness will not be consistent with a strict utility interpretation of QALYs; however, it may still be a useful index of effectiveness.

Applying the life expectancies and distributions of QALYs per incidence for CB and AMI to estimated distributions of incidences yields distributions of life expectancy and QALYs gained under the Final SSI & RME Rule. These distributions reflect both the quantified uncertainty in estimates of avoided incidence and the quantified uncertainty in QALYs gained per incidence avoided.

Tables 8B-19 and 8B-20 present the discounted life years, QALYs, and MILYs gained, based on each combination of O_3-mortality study, $PM_{2.5}$-mortality study, and life expectancy assumption for O_3-related life years saved used for the analysis, using a 3 percent discount rate, for 2020 and 2030, respectively. Tables 8B-21 and 8B-22 present the corresponding results using a 7 percent discount rate.

Table 8B-19. Estimated Gains in Discounted MILYs Under the Final SSI & RME Rule in 2020, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	500 (200 - 800)	1,100 (400 - 1,800)	390 (50 - 900)	250 (70 - 510)	5,500 (2,600 - 8,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	400 (100 - 600)				5,400 (2,500 - 8,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	200 (100 - 300)				5,200 (2,400 - 8,000)
Levy et al. (2005)	Pope et al. (2002)	General Population	2,200 (1,500 - 2,900)				7,000 (4,300 - 10,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	1,700 (1,200 - 2,200)				7,000 (3,800 - 10,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	1,000 (700 - 1,300)				6,000 (3,100 - 9,000)
Bell et al. (2004)	Laden et al. (2006)	General Population	500 (200 - 800)	2,600 (1,400 - 4,000)			11,000 (6,300 - 16,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	400 (100 - 600)				11,000 (6,100 - 16,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	200 (100 - 300)				11,000 (6,000 - 15,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	2,200 (1,500 - 2,900)				13,000 (7,900 - 17,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	1,700 (1,200 - 2,200)				12,000 (7,000 - 17,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	1,000 (700 - 1,300)				11,000 (6,800 - 16,000)

*Life years, QALYs, and MILYs are discounted back to 2020. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

Table 8B-20. Estimated Gains in Discounted MILYs Under the Final SSI & RME Rule in 2030, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	700 (200 - 1,200)	2,200 (900 - 3,500)	590 (80 - 1,400)	430 (110 - 880)	6,100 (3,100 - 9,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	600 (200 - 900)				6,000 (3,000 - 9,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	300 (100 - 500)				5,700 (2,700 - 9,000)
Levy et al. (2005)	Pope et al. (2002)	General Population	3,500 (2,400 - 4,600)				9,000 (5,800 - 12,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	2,700 (1,800 - 3,500)				8,000 (5,000 - 11,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	1,500 (1,000 - 1,900)				6,800 (3,900 - 10,000)
Bell et al. (2004)	Laden et al. (2006)	General Population	700 (200 - 1,200)	5,000 (2,700 - 7,000)			11,600 (6,800 - 16,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	600 (200 - 900)				11,000 (6,600 - 16,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	300 (100 - 500)				11,000 (6,400 - 16,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	3,500 (2,400 - 4,600)				14,000 (9,400 - 19,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	2,700 (1,800 - 3,500)				14,000 (9,000 - 18,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	1,500 (1,000 - 1,900)				12,000 (7,500 - 17,000)

*Life years, QALYs, and MILYs are discounted back to 2030. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

Table 8B-21. Estimated Gains in Discounted MILYs Under the Final SSI & RME Rule in 2020, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	360 (120 - 600)	800 (300 - 1,200)	300 (30 - 600)	200 (50 - 400)	3,800 (1,800 - 5,700)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	290 (90 - 500)				3,700 (1,800 - 5,700)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	170 (50 - 280)				3,600 (1,600 - 5,500)
Levy et al. (2005)	Pope et al. (2002)	General Population	1,700 (1,200 - 2,200)				5,100 (3,100 - 7,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	1,400 (900 - 1,800)				4,800 (2,700 - 7,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	800 (600 - 1,100)				4,200 (2,300 - 6,200)
Bell et al. (2004)	Laden et al. (2006)	General Population	360 (120 - 600)	1,800 (1,000 - 2,500)			7,500 (4,300 - 11,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	290 (90 - 500)				7,500 (4,200 - 11,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	170 (50 - 280)				7,300 (4,100 - 11,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	1,700 (1,200 - 2,200)				9,000 (5,600 - 12,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	1,400 (900 - 1,800)				9,000 (5,300 - 12,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	800 (600 - 1,100)				8,000 (4,800 - 11,000)

*Life years, QALYs, and MILYs are discounted back to 2020. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

Table 8B-22. Estimated Gains in Discounted MILYs Under the Final SSI & RME Rule in 2030, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	590 (190 - 1,000)	800 (300 - 1,200)	400 (50 - 900)	340 (90 - 700)	4,300 (2,200 - 6,300)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	460 (150 - 800)				4,100 (2,100 - 6,200)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	250 (80 - 430)				3,900 (1,900 - 5,900)
Levy et al. (2005)	Pope et al. (2002)	General Population	2,700 (1,900 - 3,500)				6,400 (4,200 - 9,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	2,100 (1,500 - 2,800)				5,800 (3,700 - 8,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	1,200 (800 - 1,600)				4,900 (2,900 - 7,000)
Bell et al. (2004)	Laden et al. (2006)	General Population	590 (190 - 1,000)	1,800 (1,000 - 2,500)			8,100 (4,800 - 11,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	460 (150 - 800)				8,000 (4,600 - 11,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	250 (80 - 430)				7,800 (4,500 - 11,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	2,700 (1,900 - 3,500)				10,000 (6,800 - 14,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	2,100 (1,500 - 2,800)				10,000 (6,300 - 13,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	1,200 (800 - 1,600)				9,000 (5,400 - 12,000)

*Life years, QALYs, and MILYs are discounted back to 2030. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

8B.4.7 Estimating the Avoided Costs of Chronic Illness

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. As noted above (see Section 8B.3.1), our estimate of costs in the numerator is net of the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). Among the morbidity costs subtracted from the direct costs of controls in the numerator are the avoided costs of illness (COI) associated with $PM_{2.5}$-related CB and nonfatal AMI.

Avoided costs for CB and nonfatal AMI are based on estimates of lost earnings and medical costs.[13] Using age-specific annual lost earnings and medical costs estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a lifetime present discounted value (in 2005$) due to CB of $179,305 for someone between the ages of 27 and 44; $116,892 for someone between the ages of 45 and 64; and $13,741 for someone over 65. The corresponding age-specific estimates of lifetime present discounted value (in 2005$) using a 7 percent discount rate are $102,300, $86,359, and $11,190, respectively. These estimates assumed that 1) lost earnings continue only until age 65, 2) medical expenditures are incurred until death, and 3) life expectancy is unchanged by CB.

Because the costs associated with a myocardial infarction extend beyond the initial event itself, we consider costs incurred over several years. Using age-specific annual lost earnings estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a present discounted value in lost earnings (in 2005$) over 5 years due to a myocardial infarction of $10,389 for someone between the ages of 25 and 44, $15,313 for someone between the ages of 45 and 54, and $88,508 for someone between the ages of 55 and 65. The corresponding age-specific estimates of lost earnings (in 2005$) using a 7 percent discount rate are $9,301, $13,709, and $79,241, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for populations under 25 or over 65. Thus, we do not include lost earnings in the cost estimates for these age groups.

Two estimates of the direct medical costs of myocardial infarction are used. The first estimate is from Wittels, Hay, and Gotto (1990), which estimated expected total medical costs of MI over 5 years to be $51,211 (in 1986$) for people who were admitted to the hospital and survived hospitalization (there does not appear to be any discounting used). Using the CPI-U for medical care, the Wittels estimate is $135,667 in year 2005$. This estimated cost is based on a medical cost model, which incorporated therapeutic options, projected outcomes, and prices (using "knowledgeable cardiologists" as consultants). The model used medical data and medical

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[13] Gold et al. (1996) recommend not including lost earnings in the cost-of-illness estimates, suggesting that in some cases, they may be already be counted in the effectiveness measures. However, this requires that individuals fully incorporate the value of lost earnings and reduced labor force participation opportunities into their responses to time-tradeoff or standard-gamble questions. For the purposes of this analysis and for consistency with the way costs-of-illness are calculated for the benefit-cost analysis, we have assumed that individuals do not incorporate lost earnings in responses to these questions. This assumption can be relaxed in future analyses with improved understanding of how lost earnings are treated in preference elicitations.

decision algorithms to estimate the probabilities of certain events and/or medical procedures being used. The second estimate is from Russell et al. (1998), which estimated first-year direct medical costs of treating nonfatal myocardial infarction of $15,540 (in 1995$), and $1,051 annually thereafter. Converting to year 2005$, that would be $27,674 for a 5-year period (using a 3 percent discount rate).

The two estimates from these studies are substantially different, and we have not adequately resolved the sources of differences in the estimates. Because the wage-related opportunity cost estimates from Cropper and Krupnick (1990) cover a 5-year period, we used estimates for medical costs that similarly cover a 5-year period. We used a simple average of the two 5-year estimates, or $81,671, and add it to the 5-year opportunity cost estimate. The resulting estimates are given in Table 8B-23.

Table 8B-23. Estimated Costs Over a 5-Year Period (in 2005$) of a Nonfatal Myocardial Infarction

Age of Onset	Opportunity Cost[1]	Medical Cost[2]	Total Cost*
0 - 24	$0	$81,671	$81,671
25 - 44	$10,389	$81,671	$92,060
45 - 54	$15,313	$81,671	$96,984
55 - 65	$88,508	$81,671	$170,179
> 65	$0	$81,671	$81,671

[1] Positive opportunity costs are based on Cropper and Krupnick (1990), using a 3 percent discount rate.

[2] An average of the 5-year costs estimated by Wittels, Hay, and Gotto (1990) and Russell et al. (1998).

The total avoided COI by age group associated with the reductions in CB and nonfatal acute myocardial infarctions (using a 3 percent discount rate) is provided in Table 8B-24. The total avoided COI associated with the Final SSI & RME Rule (using a 3 percent discount rate) is about $42 million in 2020 and about $71 million in 2030. Note that these estimates do not include any direct avoided medical costs associated with premature mortality. Nor do they include any medical costs that occur more than 5 years from the onset of a nonfatal AMI. Therefore, they are likely underestimates of the true avoided COI associated with the Final SSI & RME Rule in 2020 and 2030.

Table 8B-24. Avoided Costs of Illness Associated with Reductions in Chronic Bronchitis and Nonfatal Acute Myocardial Infarctions Under the Final SSI & RME Rule in 2020 and 2030

	Avoided Cost of Illness (in millions of 2005$)*			
Age Interval	2020		2030	
	Chronic Bronchitis	Nonfatal Acute Myocardial Infarction	Chronic Bronchitis	Nonfatal Acute Myocardial Infarction
18 - 24	---	$0.0	---	$0.0
25 - 29	$4.1	$0.1	$4.9	$0.2
35 - 44	$3.4	$0.9	$6.0	$1.5
45 - 54	$2.1	$2.8	$3.2	$4.2
55 - 64	$2.2	$11.5	$3.3	$16.8
65 - 74	$0.2	$7.7	$0.4	$12.8
75 - 84	$0.1	$3.9	$0.2	$11.6
85+	$0.1	$3.5	$0.1	$5.5
Total:	$12.1	$30.4	$18.1	$52.5

*Discounted using a 3 percent discount rate.

8B.4.8 Cost-Effectiveness Ratios

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. As noted above (see Section 8B.3.1), the estimate of costs in the numerator should include both the direct costs of the controls necessary to achieve the reduction in ambient $PM_{2.5}$ and O_3 and the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). In general, because reductions in air pollution do not require direct actions by the affected populations, there are no specific costs to affected individuals (aside from the overall increases in prices that might be expected to occur as control costs are passed on by affected industries). Likewise, because individuals do not engage in any specific actions to realize the health benefit of the pollution reduction, there are no decreases in utility (as might occur from a medical intervention) that need to be adjusted for in the denominator. Thus, the elements of the numerator are direct costs of controls minus the avoided COI associated with CB and nonfatal AMI. In addition, to account for the value of reductions in O_3- and $PM_{2.5}$-related acute health impacts and non-health benefits, we netted out the monetized value of these benefits from the numerator to yield a "net cost" estimate. For the MILY aggregate effectiveness measure, the denominator is simply the sum of (O_3- and $PM_{2.5}$-related) life years gained from increased life expectancy and QALYs gained from the ($PM_{2.5}$-related) reductions in CB and nonfatal AMI. The separate O_3- and $PM_{2.5}$-related inputs to the denominators of the cost-effectiveness ratios are summarized above in Tables 8B-19 through 8B-22. The cost-effectiveness ratios and 95 percent confidence (credible) intervals resulting from all of the sources of uncertainty considered, using Monte Carlo procedures as implemented in the Crystal Ball™ software program and incorporating both the O_3- and $PM_{2.5}$-related benefits are shown in the tables below. Tables 8B-25 and 8B-26 show cost per life saved, using a 3 percent and 7 percent discount rate, respectively. Tables 8B-27 and 8B-28 show cost per life year saved at the two discount rates; and Tables 8B-29 and 8B-30 show cost per MILY gained.

Table 8B-25. Estimated Net Cost (2005$) per O_3- and $PM_{2.5}$-Related Life Saved Under the Final SSI & RME Rule in 2020 and 2030, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Cost Effectiveness Ratio: Net Cost (in Thousand $) per Life Saved* (95% CI)**	
		2020	2030
Bell et al. (2004)	Pope et al. (2002)	$260 ($110 - $580)	$74 ($-99 - $280)
Bell et al. (2004)	Laden et al. (2006)	$110 ($54 - $220)	$34 ($-44 - $120)
Levy et al. (2005)	Pope et al. (2002)	$180 ($85 - $320)	$44 ($-58 - $140)
Levy et al. (2005)	Laden et al. (2006)	$96 ($48 - $170)	$26 ($-34 - $83)

*The cost of the regulation is estimated to be $207.4 million in 2020 and $185.5 million in 2030. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 8B-26. Estimated Net Cost (2005$) per O_3- and $PM_{2.5}$-Related Life Saved Under the Final SSI & RME Rule in 2020 and 2030, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Cost Effectiveness Ratio: Net Cost (in Thousand $) per Life Saved* (95% CI)**	
		2020	2030
Bell et al. (2004)	Pope et al. (2002)	$300 ($130 - $660)	$99 ($-87 - $330)
Bell et al. (2004)	Laden et al. (2006)	$130 ($67 - $250)	$47 ($-39 - $140)
Levy et al. (2005)	Pope et al. (2002)	$200 ($100 - $350)	$57 ($-49 - $160)
Levy et al. (2005)	Laden et al. (2006)	$110 ($58 - $190)	$35 ($-30 - $95)

*The cost of the regulation is estimated to be $207.4 million in 2020 and $185.5 million in 2030. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals incorporate uncertainty surrounding the O3 and PM2.5 coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 8B-27. Estimated Net Cost (2005\$) per O_3- and $PM_{2.5}$-Related Life Year Saved Under the Final SSI & RME Rule in 2020 and 2030, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Thousand \$) per Life Year Saved* (95% CI)**	
			2020	2030
Bell et al. (2004)	Pope et al. (2002)	General Population	\$23 (\$9.9 - \$54)	\$6.8 (\$-9 - \$26)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	\$24 (\$10 - \$56)	\$7.1 (\$-9.5 - \$27)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	\$25 (\$10 - \$61)	\$7.6 (\$-10 - \$30)
Levy et al. (2005)	Pope et al. (2002)	General Population	\$16 (\$7.8 - \$30)	\$4.1 (\$-5.5 - \$13)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	\$18 (\$8.3 - \$34)	\$4.7 (\$-6.2 - \$15)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	\$21 (\$9.2 - \$44)	\$5.8 (\$-7.6 - \$20)
Bell et al. (2004)	Laden et al. (2006)	General Population	\$10 (\$5 - \$20)	\$3.1 (\$-4.2 - \$11)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	\$11 (\$5 - \$21)	\$3.2 (\$-4.2 - \$11)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	\$11 (\$5.1 - \$21)	\$3.3 (\$-4.4 - \$11)
Levy et al. (2005)	Laden et al. (2006)	General Population	\$8.8 (\$4.4 - \$16)	\$2.4 (\$-3.2 - \$7.7)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	\$9.2 (\$4.5 - \$17)	\$2.6 (\$-3.4 - \$8.3)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	\$9.9 (\$4.8 - \$19)	\$2.9 (\$-3.9 - \$9.5)

*The cost of the regulation is estimated to be \$207.4 million in 2020 and \$185.5 million in 2030. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 8B-28. Estimated Net Cost (2005$) per O_3- and $PM_{2.5}$-Related Life Year Saved Under the Final SSI & RME Rule in 2020 and 2030, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Thousand $) per Life Year Saved* (95% CI)**	
			2020	2030
Bell et al. (2004)	Pope et al. (2002)	General Population	$36 ($16 - $81)	$12 ($-11 - $42)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$37 ($16 - $85)	$13 ($-11 - $44)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$39 ($17 - $93)	$14 ($-12 - $50)
Levy et al. (2005)	Pope et al. (2002)	General Population	$24 ($12 - $44)	$7 ($-6 - $20)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$26 ($13 - $49)	$8.0 ($-6.7 - $23)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$31 ($15 - $62)	$10 ($-8.3 - $31)
Bell et al. (2004)	Laden et al. (2006)	General Population	$16 ($7.8 - $30)	$5.6 ($-4.7 - $17)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$16 ($7.9 - $31)	$5.7 ($-4.8 - $17)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$17 ($8 - $32)	$5.9 ($-5 - $18)
Levy et al. (2005)	Laden et al. (2006)	General Population	$13 ($6.8 - $23)	$4.3 ($-3.5 - $12)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$14 ($7.1 - $24)	$4.6 ($-3.9 - $13)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$15 ($7.5 - $28)	$5.1 ($-4.4 - $15)

*The cost of the regulation is estimated to be $207.4 million in 2020 and $185.5 million in 2030. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 8B-29. Estimated Net Cost (2005$) per O_3- and $PM_{2.5}$-Related MILY Gained Under the Final SSI & RME Rule in 2020 and 2030, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Thousand $) per MILY Gained* (95% CI)**	
			2020	2030
Bell et al. (2004)	Pope et al. (2002)	General Population	$20 ($9 - $42)	$5.5 ($-7.4 - $19)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$21 ($9.3 - $44)	$5.6 ($-7.6 - $20)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$21 ($9.4 - $46)	$6.0 ($-8.1 - $21)
Levy et al. (2005)	Pope et al. (2002)	General Population	$15 ($7.2 - $26)	$3.6 ($-4.9 - $11)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$16 ($7.6 - $29)	$4.0 ($-5.4 - $13)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$18 ($8.4 - $36)	$4.8 ($-6.4 - $16)
Bell et al. (2004)	Laden et al. (2006)	General Population	$9.8 ($4.7 - $18)	$2.8 ($-3.8 - $9.4)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$9.9 ($4.8 - $19)	$2.9 ($-3.8 - $9.6)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$10 ($4.8 - $19)	$3.0 ($-3.9 - $10)
Levy et al. (2005)	Laden et al. (2006)	General Population	$8.3 ($4.2 - $14)	$2.2 ($-2.9 - $7)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$8.7 ($4.3 - $16)	$2.4 ($-3.2 - $7.5)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$9.3 ($4.5 - $17)	$2.7 ($-3.5 - $8.6)

*The cost of the regulation is estimated to be $207.4 million in 2020 and $185.5 million in 2030. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 8B-30. Estimated Net Cost (2005$) per O_3- and $PM_{2.5}$-Related MILY Gained Under the Final SSI & RME Rule in 2020 and 2030, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Thousand $) per MILY Gained* (95% CI)**	
			2020	2030
Bell et al. (2004)	Pope et al. (2002)	General Population	$110 ($58 - $190)	$31 ($15 - $64)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$33 ($15 - $70)	$31 ($15 - $66)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$31 ($15 - $64)	$33 ($15 - $70)
Levy et al. (2005)	Pope et al. (2002)	General Population	$31 ($15 - $66)	$22 ($12 - $38)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$27 ($13 - $51)	$24 ($12 - $42)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$22 ($12 - $38)	$27 ($13 - $51)
Bell et al. (2004)	Laden et al. (2006)	General Population	$23 ($12 - $42)	$15 ($7.4 - $27)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$15 ($7.6 - $29)	$15 ($7.5 - $28)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$15 ($7.4 - $27)	$15 ($7.6 - $29)
Levy et al. (2005)	Laden et al. (2006)	General Population	$15 ($7.5 - $28)	$13 ($6.5 - $21)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$14 ($7.1 - $25)	$13 ($6.8 - $22)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$13 ($6.5 - $21)	$14 ($7.1 - $25)

*The cost of the regulation is estimated to be $207.4 million in 2020 and $185.5 million in 2030. $PM_{2.5}$-related avoided deaths are discounted back to 2020 or 2030. O_3-related deaths are assumed to occur in 2020 or 2030.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

8B.5 Conclusions

We estimated the cost effectiveness of attaining the Final Small SI and Recreational Marine Engine Rule in 2020 and in 2030, based on reductions in premature deaths and incidence of chronic disease. We measured effectiveness using several different metrics, including lives saved, life years saved, and QALYs gained (for improvements in quality of life due to reductions in incidence of chronic disease). We suggested a new metric for aggregating life years saved and improvements in quality of life, morbidity inclusive life years (MILY) which assumes that society assigns a weight of one to years of life extended regardless of preexisting disabilities or chronic health conditions.

CEA of environmental regulations that have substantial public health impacts may be informative in identifying programs that have achieved cost-effective reductions in health impacts and can suggest areas where additional controls may be justified. However, the overall efficiency of a regulatory action can only be judged through a complete benefit-cost analysis that takes into account all benefits and costs, including both health and non-health effects. The benefit-cost analysis for the Final Small SI and Recreational Marine Engine Rule, provided in Chapter 8, shows that the rule has potentially large net benefits, indicating that implementation of the Final Small SI and Recreational Marine Engine Rule will likely result in improvements in overall public welfare.

8B.6 References

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CHAPTER 9: Economic Impact Analysis

We prepared an Economic Impact Analysis (EIA) to estimate the economic impacts of the final 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 final program to be about $186 million in 2030.[1] 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 $459 million in 2030. Consumers of Small SI and Marine products are expected to bear about 86 percent of these costs. Engine and equipment manufacturers are expected to bear 3.3 percent and 10.3 percent, respectively. We estimate fuel savings of about $273 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 7.4 percent ($12 per unit). The average price increase for Marine SI engines is expected to be about 1.9 percent ($213 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 2.4 percent ($204 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 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 final emission control program can be expected to

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[1] All estimates presented in this section are in 2005$. The fuel savings in this net social cost is calculated by 2005 gasoline price. *2005 Petroleum Marketing Annual* (Table 31). U.S. Department of Energy, Energy Information Administration (DoE 2005).

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 final 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 final 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 supply or 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 supply or 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 and were 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 9 engine categories, depending on engine class and useful life (Class I: UL125, UL250, and UL500; Class I -snowblower: UL 125, UL250, and UL 500; 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 final 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 final 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 final 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).

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	Competitive	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 & other LG: 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 either the fixed cost or the variable cost. For the market analysis, this leads to a small increase in estimated price impacts for the years 2008 through 2014, the period during which the costs change over time reflecting the phase-in of either the different costs (variable and fixed costs) or the different standards. The increase is small because, for many elements of the program, annual per unit compliance costs are relatively smaller than engine or equipment per unit price . 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 final 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 2014, 2018, and 2030. These years were chosen because 2014 is the year of highest compliance cost; the market impacts reflect the compliance costs for all the programs as well as growth in equipment population; 2018 is the year in which the learning curve is expected to be applied to the variable cost; 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.[2] 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 2014, the high cost year, is estimated to be about 2.4 percent, or $266. By 2018, this average price increase is expected to decline to about 1.9 percent, or $213, 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 2014 is about 2.7 percent, or 10,883 engines. This decreases to about 2.2 percent in 2018, or about 9,055 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 2014 is expected to be about 1.6 percent, or

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[2] 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.

$285. By 2018, this average price increase is expected to decline to about 1.3 percent, or $231. These price increases are expected to vary across vessel categories. The category with the largest price increase in 2014 is expected to be personal watercraft , with an estimated price increase of about 3.0 percent in 2014; this is expected to decrease to 2.4 percent in 2018. The smallest expected change in 2014 is expected to be for sterndrive/inboards vessels, which are expected to see price increases of about 0.9 percent. The market impact analysis predicts that with these increases in vessel prices the expected average decrease in quantity produced in 2014 is about 3.2 percent, or 12,230 vessels. This is expected to decrease to about 2.6 percent in 2018, or about 10,145 vessels. The personal watercraft category is expected to experience the largest decline in 2014, about 6.0 percent (4,800 vessels). The smallest percentage decrease in production is expected for sterndrive/inboards at 1.7 percent (1,580 vessels); the smallest absolute decrease in quantity is expected for outboard recreational vessels, at 144 vessels (2.0 percent).

9.1.4.1.2 Small SI Market Analysis

The average price increase for Small SI engines in 2014, the high cost year, is estimated to be about 8.3 percent, or $14. By 2018, this average price increase is expected to decline to about 7.4 percent, or $12, 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 2014 is expected to be about 1.9 percent, or 304,000 engines. This is expected to decrease to about 1.7 percent in 2018, or about 285,000 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 2014 is expected to be about 2.6 percent, or $10. By 2018, this average price increase is expected to decline to about 2.3 percent, or $8. The average price increase and quantity decrease differs by category of equipment. As shown in Table 9.1-2, the price increase for Class I equipment is estimated to be about 6.2 percent ($17) in 2014, decreasing to 5.6 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 2014 is about 2.1 percent, or 209,000 units. This is expected to decrease to about 1.9 percent in 2018, or about 200,000 units. For Class II equipment, a higher price increase is expected, about 2.6 percent ($24) in 2014, decreasing to 2.2 percent ($20) in 2018. The expected average decrease in the quantity of Class II equipment produced in 2014 is about 2.8 percent, or 101,000 units, decreasing to 2.4 percent, or about 92,000 units, in 2018.

For the handheld equipment market, prices are expected to increase about 0.2 percent for all years, and quantities are expected to decrease about 0.3 percent.

Table 9.1-2: Summary of Estimated Market Impacts for 2014, 2018, 2030 (2005$)

	Change in Price		Change in Quantity	
Market	Absolute	Percent	Absolute	Percent
2014				
Marine				
Engines	$266	2.4%	-10,883	-2.7%
Equipment	$285	1.6%	-12,229	-3.2%
SD/I	$299	0.9%	-1,578	-1.7%
OB Recreational	$870	1.0%	-144	-2.0%
OB Luxury	$271	1.4%	-5,666	-2.8%
PWC	$253	3.0%	-4,841	-6.0%
Small SI				
Engines	$14	8.3%	-303,992	-1.9%
Equipment	$10	2.6%	-360,310	-1.4%
Class I	$17	6.2%	-209,284	-2.1%
Class II	$24	2.6%	-101,104	-2.8%
HH	$0.3	0.2%	-49,922	-0.3%
2018				
Marine				
Engines	$213	1.9%	-9,055	-2.2%
Equipment	$231	1.3%	-10,145	-2.6%
SD/I	$244	0.7%	-1,318	-1.4%
OB Recreational	$702	0.8%	-119	-1.6%
OB Luxury	$218	1.1%	-4,697	-2.3%
PWC	$204	2.4%	-4,010	-4.8%
Small SI				
Engines	$12	7.4%	-284,995	-1.7%
Equipment	$8	2.3%	-347,189	-1.2%
Class I	$15	5.6%	-200,155	-1.9%
Class II	$20	2.2%	-91,871	-2.4%
HH	$0.3	0.2%	-55,164	-0.3%
2030				
Marine				
Engines	$213	1.9%	-9,802	-2.2%
Equipment	$231	1.3%	-10,981	-2.6%
SD/I	$244	0.7%	-1,426	-1.4%
OB Recreational	$702	0.8%	-129	-1.6%
OB Luxury	$218	1.1%	-5,085	-2.3%
PWC	$204	2.4%	-4,341	-4.8%
Small SI				
Engines	$12	7.4%	-338,346	-1.7%
Equipment	$8	2.3%	-412,103	-1.2%
Class I	$15	5.6%	-237,485	-1.9%
Class II	$20	2.2%	-109,120	-2.4%
HH	$0.3	0.2%	-65,498	-0.3%

9.1.4.2 Economic Welfare Results

In the economic welfare analysis we look at the costs to society of the final 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 2037 (2005$, $million)

Year	Total Engineering Costs	Total Social Costs	Fuel Savings	Net Engineering Costs (including fuel savings)	Net Social Costs (including fuel savings)
2008	$53.8	$53.8	$3.2	$50.7	$50.6
2009	$126.8	$126.2	$8.1	$118.7	$118.1
2010	$271.0	$267.4	$19.6	$251.5	$247.8
2011	$328.7	$324.1	$43.9	$284.8	$280.2
2012	$441.6	$435.5	$70.8	$370.8	$364.7
2013	$445.4	$439.3	$95.7	$349.7	$343.6
2014	$450.0	$443.8	$115.9	$334.1	$327.9
2015	$411.6	$406.8	$134.3	$277.3	$272.5
2016	$408.8	$404.2	$150.9	$258.0	$253.3
2017	$398.3	$393.8	$165.3	$233.0	$228.6
2018	$403.3	$398.8	$178.3	$225.0	$220.5
2019	$408.3	$403.8	$190.4	$217.9	$213.4
2020	$413.4	$408.8	$201.4	$212.0	$207.4
2021	$418.4	$413.7	$211.1	$207.2	$202.6
2022	$423.4	$418.6	$220.5	$202.9	$198.2
2023	$428.4	$423.6	$229.3	$199.0	$194.3
2024	$433.4	$428.6	$237.1	$196.3	$191.5
2025	$438.4	$433.6	$244.2	$194.2	$189.3
2026	$443.5	$438.6	$250.8	$192.7	$187.8
2027	$448.5	$443.6	$256.9	$191.6	$186.6
2028	$453.6	$448.6	$262.7	$190.8	$185.8
2029	$458.6	$453.5	$268.1	$190.5	$185.4
2030	$463.7	$458.6	$273.0	$190.6	$185.5
2031	$468.7	$463.6	$277.6	$191.1	$185.9
2032	$473.8	$468.6	$281.9	$191.9	$186.7
2033	$478.8	$473.6	$285.8	$193.0	$187.7
2034	$483.9	$478.5	$289.6	$194.2	$188.9
2035	$488.9	$483.6	$293.3	$195.6	$190.3
2036	$494.0	$488.6	$296.8	$197.2	$191.8
2037	$499.0	$493.6	$300.1	$198.9	$193.5
NPV at 3%[a]	$7,705.3	$7,616.6	$3,374.6	$4,330.7	$4,242.0
NPV at 7%[a]	$4,559.3	$4,506.2	$1,774.7	$2,784.6	$2,731.4

[a] 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

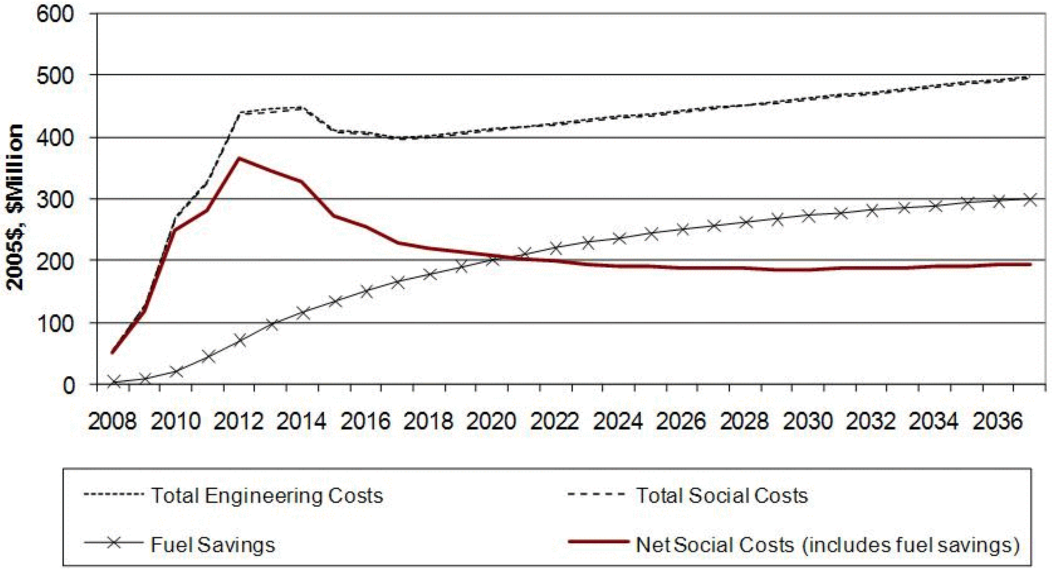

Table 9.1-4 shows how total social costs are expected to be shared across stakeholders, for selected years. According to these results, consumers in the Marine SI market are expected to bear approximately 76 percent of the cost of the Marine SI program. This is expected to be offset by the fuel savings. Vessel manufacturers are expected to bear about 17 percent of that program, and engine manufacturers the remaining 6 percent. In the Small SI market, consumers are expected to bear 91 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 7 percent of that program, and engine manufacturers the remaining 2 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 2014, 2018, 2030 (2005$, $million)

Market	Absolute Change in Surplus	Percent Change in Surplus	Fuel Savings	Total Change in Surplus
2014				
Marine SI				
Engine Manufacturers	-$10.5	6%		-$10.5
Equipment Manufacturers	-$29.7	17%		-$29.7
End User (Households)	-$130.0	76%	$45.4	-$84.6
Subtotal	-$170.2			-$124.8
Small SI				
Engine Manufacturers	-$5.4	2%		-$5.4
Equipment Manufacturers	-$18.1	7%		-$18.1
End User (Households)	-$250.2	91%	$70.4	-$179.7
Subtotal	-$273.6			-$203.2
TOTAL	**-$443.8**		**$115.9**	**-$327.9**
2018				
Marine SI				
Engine Manufacturers	-$8.7	6%	-	-$8.7
Equipment Manufacturers	-$25.0	18%		-$25.0
End User (Households)	-$108.2	76%	$82.7	-$25.6
Subtotal	-$142.0			-$59.3
Small SI				
Engine Manufacturers	-$5.0	2%		-$5.0
Equipment Manufacturers	-$16.9	7%		-$16.9
End User (Households)	-$235.0	91%	$95.6	-$139.4
Subtotal	-$256.8			-$161.2
TOTAL	**-$398.8**		**$178.3**	**-$220.5**
2030				
Marine SI				
Engine Manufacturers	-$9.4	6%		-$9.4
Equipment Manufacturers	-$27.1	18%		-$27.1
End User (Households)	-$117.2	76%	$152.9	$35.8
Subtotal	-$153.7			-$0.8
Small SI				
Engine Manufacturers	-$5.9	2%		-$5.9
Equipment Manufacturers	-$20.0	7%		-$20.0
End User (Households)	-$278.9	91%	$120.1	-$158.8
Subtotal	-$304.9			-$184.8
TOTAL	**-$458.6**		**$273.0**	**-$185.5**

Table 9.1-5 contains more detailed information on the sources of the social costs for 2014. This table shows that engines and equipment manufacturers are expected to bear more of the burden of the program than end users. The loss of producer surplus for the small SI equipment and 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. In comparing with small SI equipment manufactures, marine SI vessel manufacturers would be able to pass along a relatively smaller share of compliance costs to end consumers due to the elastic price elasticity of demand for consumers of these vessels. As indicated in Table 9.3-22, the price elasticity of small SI equipment demand is inelastic while the price elasticity of vessel demand is very elastic.

Table 9.1-5: Estimated Surplus Changes by Market and Stakeholder for 2014 (2005$, $million)

Scenario	Engineering Compliance Costs	Producer Surplus	Consumer Surplus	Total Surplus	Fuel Savings	Net Surplus
Marine SI						
Engine Manufacturers	*$118.7*	*-$10.5*		*-$10.5*		*-$10.5*
Equipment Manufacturers	*$55.1*	*-$29.7*		*-$29.7*		*-$29.7*
Engine Price Changes		*-$13.2*				
Equipment Cost Changes		-$16.5				
End User (Households)			*-$130.0*	*-$130.0*	*$45.4*	*-$84.6*
Engine Price Changes			-$93.6			
Equipment Price Changes			-$36.4			
Subtotal	**$173.8**	**-$40.2**	**-$130.0**	**-$170.2**	**$45.4**	**-$124.8**
Small SI						
Engine Manufacturers	*$227.2*	*-$5.4*		*-$5.4*		*-$5.4*
Equipment Manufacturers	*$49.0*	*-$18.1*		*-$18.1*		*-$18.1*
Engine Price Changes		-$13.0				
Equipment Cost Changes		-$5.1				
End User (Households)			*-$250.1*	*-$250.1*	*$70.4*	*-$179.6*
Engine Price Changes			-$206.6			
Equipment Cost Changes			-$43.5			
Subtotal	**$276.2**	**-$23.6**	**-$250.1**	**-$273.6**	**$70.4**	**-$203.2**
TOTAL	**$450.0**	**-$63.7**	**-$380.1**	**-$443.8**	**$115.9**	**-$327.9**

The present value of net social costs of the final standards through 2037 at a 3 percent discount rate, shown in Table 9.1-6, is estimated to be $4.2 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 2037 is estimated to be $2.7 billion, including the fuel savings.

Table 9.1-6. Estimated Net Social Costs Through 2037 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	-$167.0	6%		-$167.0
Equipment Manufacturers	-$474.5	17%		-$474.5
End User (Households)	-$2,079.0	76%	$1,730.8	-$348.1
Subtotal	-$2,720.5		$1,730.8	-$989.6
Small SI				
Engine Manufacturers	-$94.1	2%		-$94.1
Equipment Manufacturers	-$329.9	7%		-$329.9
End User (Households)	-$4,472.1	91%	$1,643.8	-$2,828.3
Subtotal	-$4,896.1		$1,643.8	-$3,252.3
TOTAL	**-$7,616.6**		**$3,374.6**	**-$4,242.0**
		Net Present Value 7%		
Marine SI				
Engine Manufacturers	-$100.8	6%		-$100.8
Equipment Manufacturers	-$285.2	17%		-$285.2
End User (Households)	-$1,257.1	77%	$881.0	-$376.1
Subtotal	-$1,643.2		$881.0	-$762.2
Small SI				
Engine Manufacturers	-$54.8	2%		-$54.8
Equipment Manufacturers	-$195.4	7%		-$195.4
End User (Households)	-$2,612.8	91%	$893.8	-$1,719.1
Subtotal	-$2,863.0		$893.8	-$1,969.2
TOTAL	**-$4,506.2**		**$1,774.7**	**-$2,731.4**

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 illustrates 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 final 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 final controls in the agricultural and construction sectors. This is appropriate because the vast majority of engines and equipment that would be subject to the final 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 final 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 Competitive Market Structure Model

In a market oriented economic analysis, the analyst must determine the market structure according to most appropriate characteristics of the market under study. This market structure will form the basis of the economic impact model and determine the economic relationship to be reflected in the model. There are several types of market structures in economics: perfect competition, oligopoly, monopolistic competition, and monopoly. The typical economic impact analysis assumes a competitive market structure, although circumstance may require relaxing this assumption.[3]

The assumption of a competitive market is not about the number of firms in a market. It is about wether producers in the market are price takers or wether they have sufficient market power to influence the market price. In a competitive market, producers are price takers. Indicators of a competitive market include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[4] In addition, 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 imperfectly competitive markets, producers 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 final 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).

This EIA is based on a competitive market structure. This is appropriate because the markets under analysis 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.

As described in the industry profiles for this final 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 a competitive market structure is justified. Among the mitigating factors are the presence of substantial import competition, relative ease of entry, existing excess

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[3] U.S. EPA. 2000. Guidelines for Preparing Economics Analyses, EPA-240-R-00-003, page 126; 1999. OAQPS Economic Analysis Resource Document, page 5-8.

[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.

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 competitive market structure 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 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).

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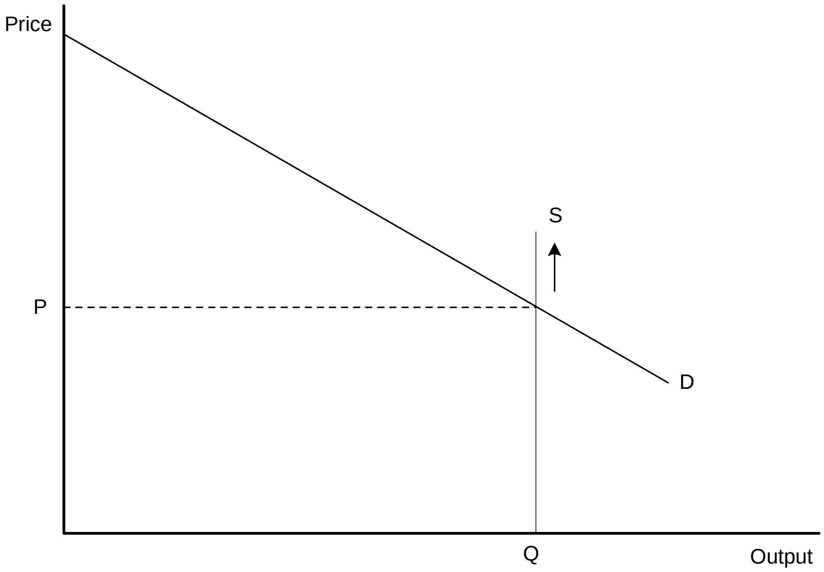
[5] RTI (2006). Historical Market Data and Trends, Industry Profile for Small SI Engines and Equipment, Section 2.5. Draft Report

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.

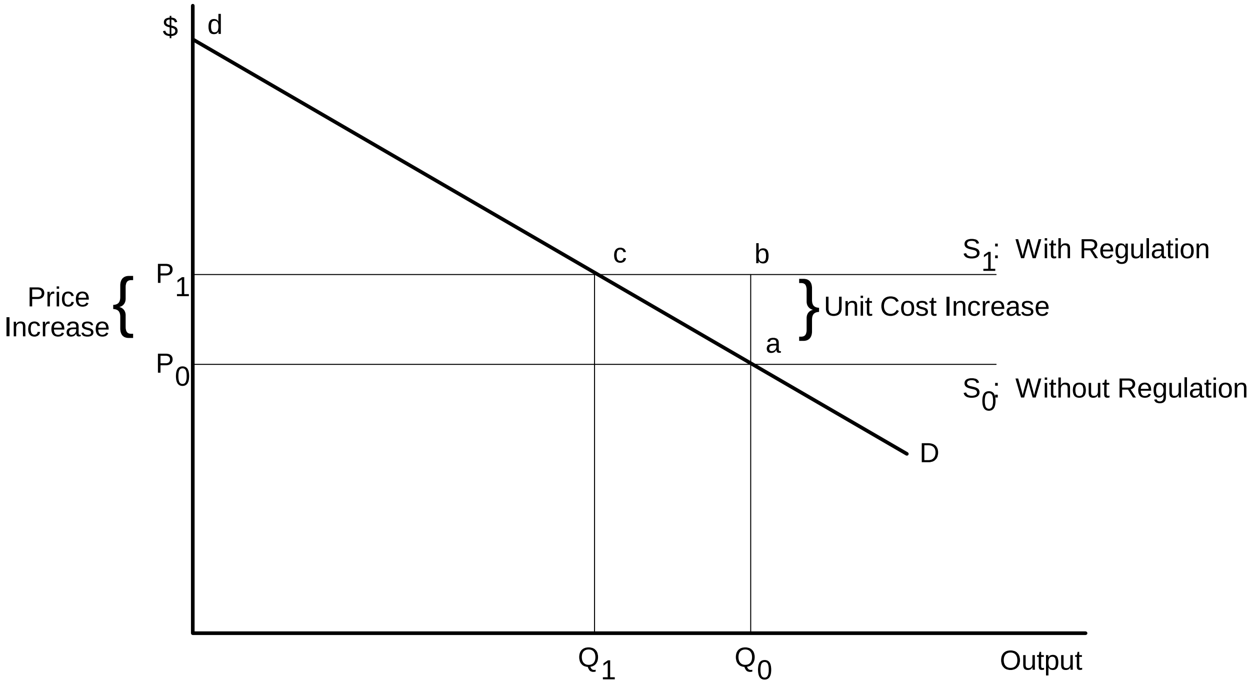
Figure 9.2-1: Short Run: All Costs Born by Producers



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 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.

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.

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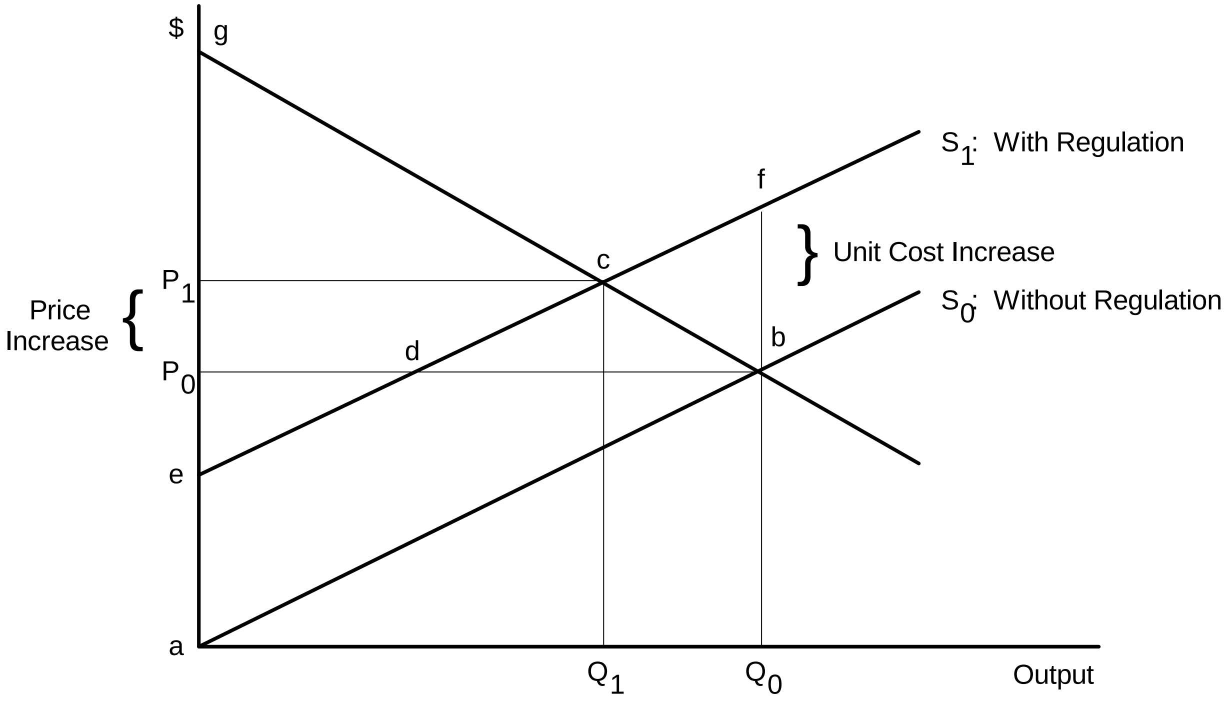
[6] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

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.

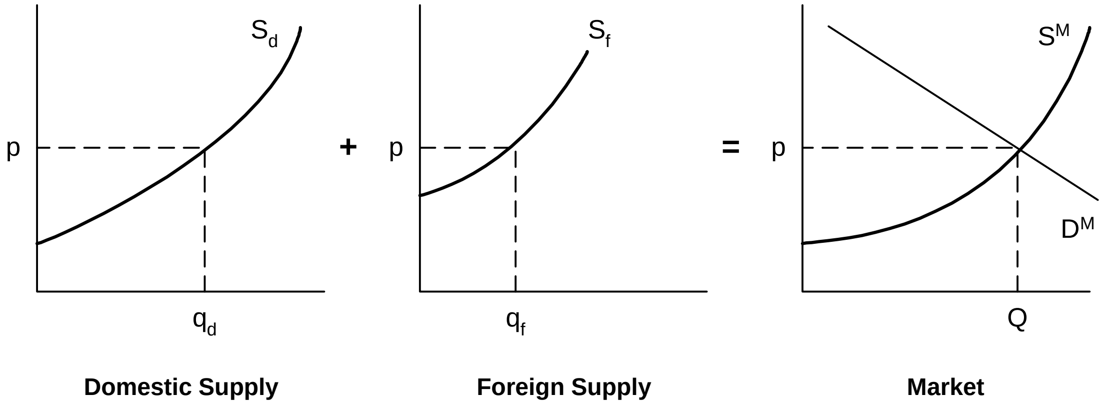
Consistent with other economic impact analyses performed by EPA, this EIM uses an intermediate run approach. This approach allows us to examine the market and social welfare impacts of the program as producers adjust their output and consumers adjust their consumption of affected products in response 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?

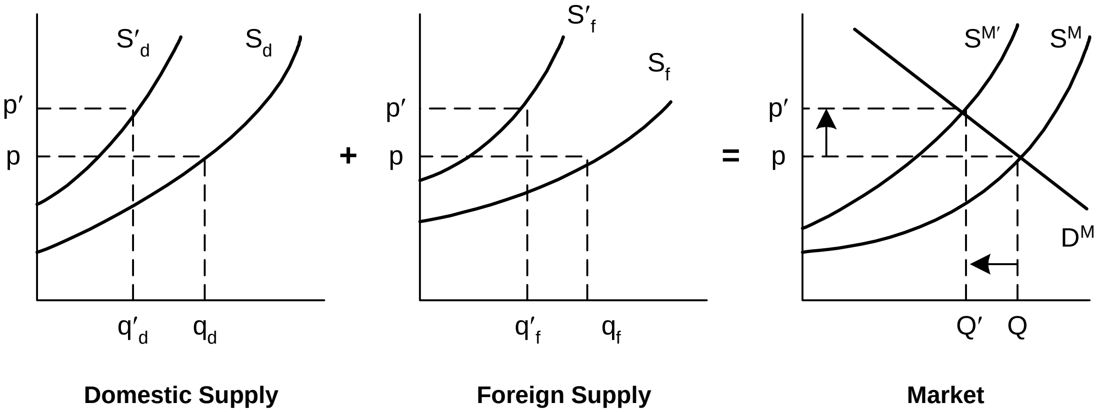
9.2.3.1 Estimation of Market Impacts (Single Market)

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 final 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 final 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 final 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 final 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.

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

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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.

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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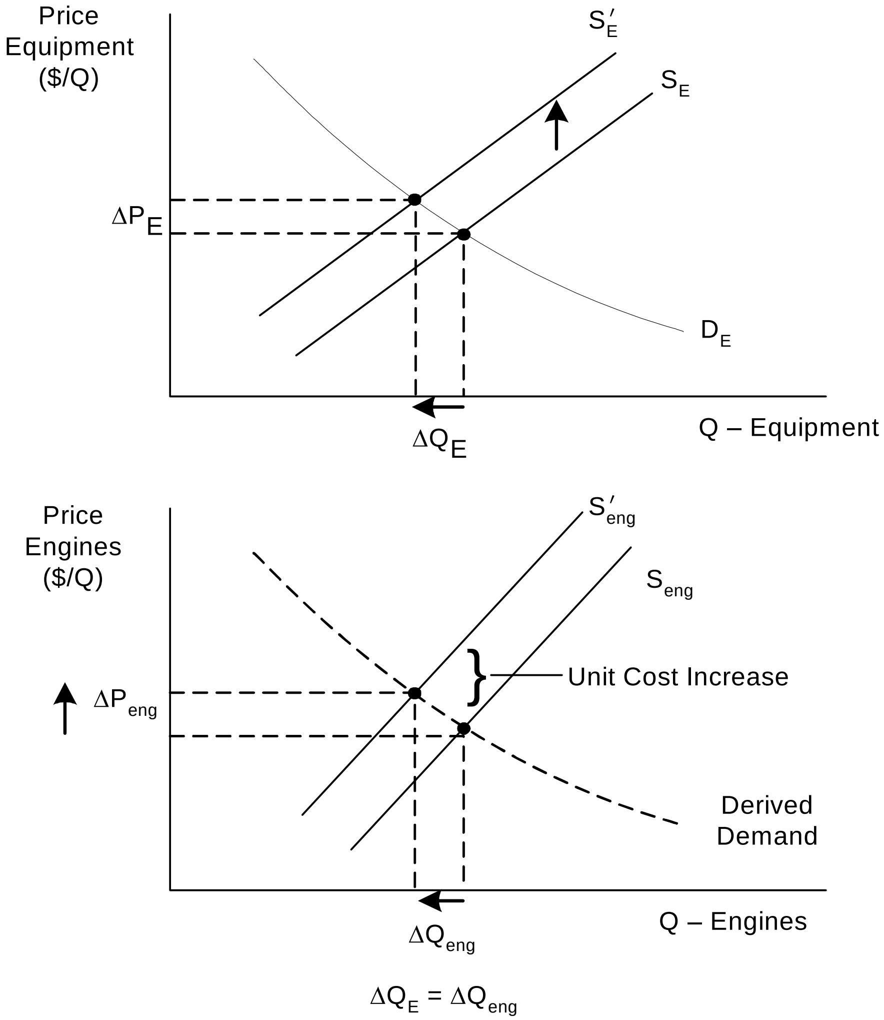
[9] In marine applications, one or two engines are used per boat, depending on its intrinsic design, and this configuration is insensitive to small changes in engine used. In the case of Small SI equipment, the one-to-one correspondence is exact. Furthermore, there is no potential for technical substitution, 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.

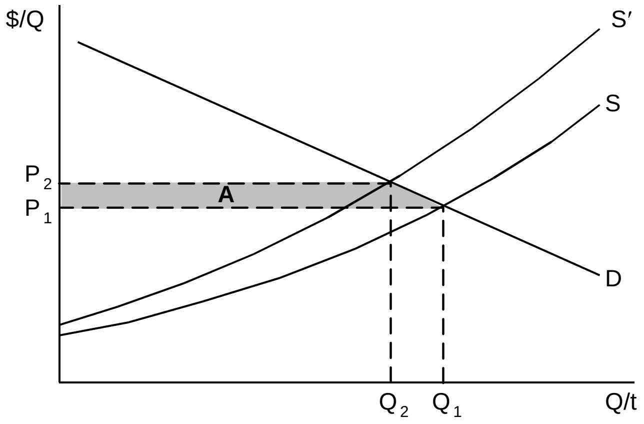
The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 9.2-6).

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.

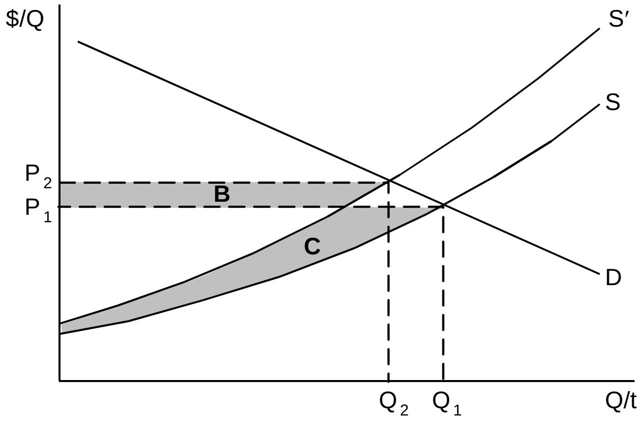
In Figure 9.2-6, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_1 with quantity Q_1. The increased cost of production with the regulation will cause the market supply curve to shift upward to S'. The new equilibrium price of the product is P_2. 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.

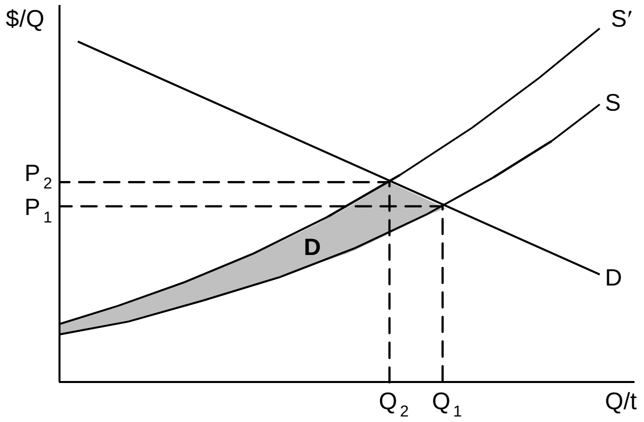
Figure 9.2-6: Market Surplus Changes with Regulations
Consumer and Producer Surplus



(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?

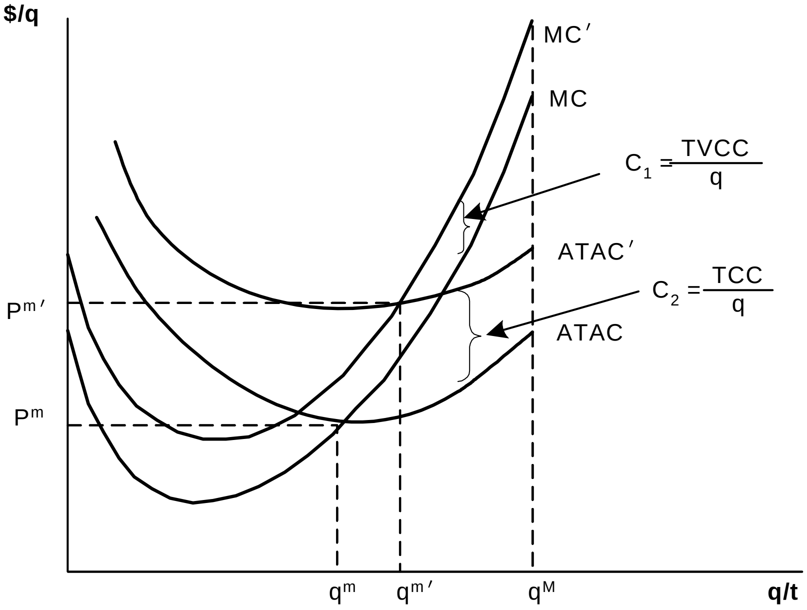
In addition to the general model features described in Section 9.2.2, there are several specific characteristics of the Small SI and Marine SI markets that need to be addressed in the EIM. These are the treatment of fixed and variable costs, fuel savings, programmatic flexibilities, and substitution, 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 (c_1= TVCC/q), while the average total cost (ATAC) curve will shift up by the per-unit total compliance costs (c_2 = 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., $P^{m'}$). 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 compliance cost and variable compliance cost. 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 final 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 in attempting to recover both fixed and variable 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. As stated in the section 9.3.3, this analysis applied fixed costs in the year in which they occur prior to the rule taking effect, and variable costs during the years that the rule is implemented. To reflect these conditions, the supply shift in this EIM is based on either fixed costs prior to the rule or variable costs after the rule starts, even though the model assumes a competitive market structure.

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 final 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 final 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 or 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 final 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 final 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 extra 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 average costs or 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 cost increase if it is the only entity affected by that cost increase. In such a case, retailers would clearly have an incentive to purchase comparable engines or equipment that were not affected by the cost increase, placing the affected firm at a competitive disadvantage and reducing its market share. However, in this case all engine manufacturers will face increased average costs or 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 final 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 final standards for HH consist only of evaporative emission controls and the 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 final program. The final 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 combinations 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 final 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 final standards, so the final 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 final 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 21,700 out of a total of 356,300 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 13 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
SD/I Recreation				XXX	XXX	XXX
SD/I Luxury					XXX	XXX
OB Recreational	XXX	XXX	XXX	XXX	XXX	
OB Luxury				XXX	XXX	
OB Loose	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	37,757	42,828	350,908
Lawn Mowers	5,895,706	631,254	434,846	NA	NA	NA	6,961,805
Tractors	NA	NA	NA	1,701,351	369,516	419,141	2,490,008
Lawn and Garden Other	647,256	NA	NA	127,915	27,782	31,513	834,465
Gensets/ Welders	271,391	29,058	20,017	605,169	131,437	149,088	1,206,160
Pumps/ Compressors/ Pressure Washers	579,775	62,077	42,762	253,971	55,160	62,568	1,056,313
Snowblowers	551,509	59,050	40,677	475,353	103,242	117,107	1,346,938
Total	8,099,022	797,861	549,615	3,408,985	740,396	839,829	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
$210

Table 9.3-10a: Small SI Nonhandheld Engine Prices (2005$)

Class I			Class II		
UL 125	UL 250	UL 500	UL 250	UL 500	UL 1000
$125	$217	$218	$208	$409	$757

Table 9.3-10b: Small SI Nonhandheld Equipment Prices (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			19,327	53,137	3,496		75,960
SD/I Recreational				13,985	33,101	24,106	71,192
SD/I Luxury					8,877	12,027	20,904
OB Recreational	35,756	49,055	73,393	42,903	39,609		240,716
OB Luxury				8,393	8,393		16,785
OB loose engines	30,317						30,317
Total	66,073	49,055	92,720	118,417	93,476	36,133	455,875

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			19,327	53,137	3,496		75,960
SD/I Recreational				13,985	32,383	23,799	70,168
SD/I Luxury					7,081	7,927	15,009
OB Recreational	28,605	39,244	56,780	33,191	30,644		188,464
OB Luxury				3,357	3,357		6,714
Total	28,605	39,244	76,107	103,670	76,961	31,727	356,314

9.3.2.2.2 Marine SI Engine and Vessel Initial Equilibrium 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 final 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.

This analysis applies fixed costs in the year in which they occur prior to the rule taking effect. The small SI exhaust standards begin in 2011 for Class II and 2012 for Class I. Fixed costs are applied during 3 years (2008 to 2010) for Class II or 4 years (2008-2011) for Class I. The fixed costs include research and development, tooling, certification, and 1065 compliance. The marine exhaust standards generally begin in 2010; however, there are some exceptions for SD/I engines, where additional lead time was given in specific instances to provide regulatory flexibility. All fixed costs associated with marine exhaust standards are applied in the year of 2008 and 2009. The implementation dates for the small SI evaporative emission standards are staggered beginning in 2008, with regulatory flexibility providing some small delays until as late as 2013. The implementation dates for the marine evaporative emission standards are staggered beginning in 2009, with regulatory flexibility providing some small delays until as late as 2015. Fixed costs due to evaporative emission standard are applied in the two years before the primary effective date for each of the evaporative emission standards (tank permeation, hose permeation, and diurnal emissions). For simplicity, all of the fixed costs associated with certification are applied in 2008 and 2009. Variable costs for either exhaust or evaporative emission standards on small SI and marine SI begin to be incurred only when the programs go into effect.

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 seven sets of engine compliance costs for NHH engines, one for each engine market. These costs begin in 2008 for HH and 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 final 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 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	$0.65	$0.65	$0.65	$0.84	$0.84	$0.71	$0.71	$0.71	$0.71
		Fixed	$0.30	$0.30	$0.27	$0.26	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.30	$0.95	$0.92	$0.91	$0.84	$0.84	$0.71	$0.71	$0.71	$0.71
Nonhandheld												
1	125	Variable	$0.34	$0.34	$0.53	$0.53	$12.71	$12.58	$12.58	$12.58	$12.58	$11.34
		Fixed	$0.51	$0.50	$1.90	$1.87	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.85	$0.84	$2.44	$2.40	$12.71	$12.58	$12.58	$12.58	$12.58	$11.34
1	250	Variable	$0.34	$0.34	$0.53	$0.53	$15.11	$14.98	$14.98	$14.98	$14.98	$13.66
		Fixed	$3.24	$3.19	$8.36	$8.21	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$3.58	$3.52	$8.89	$8.75	$15.11	$14.98	$14.98	$14.98	$14.98	$13.66
1	500	Variable	$0.34	$0.34	$0.53	$0.53	$14.65	$14.52	$14.52	$14.52	$14.52	$13.21
		Fixed	$4.44	$4.36	$12.09	$11.88	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$4.77	$4.70	$12.63	$12.41	$14.65	$14.52	$14.52	$14.52	$14.52	$13.21
1	125/250/500 snow-blower	Variable	$0.34	$0.34	$0.53	$0.53	$2.94	$2.81	$2.81	$2.81	$2.81	$2.33
		Fixed	$0.13	$0.13	$0.18	$0.18	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.47	$0.47	$0.71	$0.71	$2.94	$2.81	$2.81	$2.81	$2.81	$2.33
2	250	Variable	$0.00	$0.00	$0.00	$16.80	$16.80	$16.80	$16.80	$14.24	$14.24	$14.24
		Fixed	$1.40	$3.55	$3.49	$0.12	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.40	$3.55	$3.49	$16.92	$16.80	$16.80	$16.80	$14.24	$14.24	$14.24
2	500	Variable	$0.00	$0.00	$0.00	$12.05	$12.05	$12.05	$12.05	$9.98	$9.98	$9.98
		Fixed	$5.82	$13.16	$12.93	$0.83	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$5.82	$13.16	$12.93	$12.88	$12.05	$12.05	$12.05	$9.98	$9.98	$9.98
2	1,000	Variable	$0.00	$0.00	$0.00	$30.56	$30.56	$30.56	$30.56	$25.71	$25.71	$25.71
		Fixed	$11.41	$31.34	$30.80	$0.59	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$11.41	$31.34	$30.80	$31.15	$30.56	$30.56	$30.56	$25.71	$25.71	$25.71

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 manufacturers									
		Fixed										
		Total										
Nonhandheld												
1	125-500	Variable	No equipment costs for NHH Class I, all costs are allocated to engine manufacturers									
		Fixed										
		Total										
2	250	Variable	$1.29	$1.29	$1.29	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16
	ag/const	Fixed	$0.26	$4.47	$4.13	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.55	$5.76	$5.42	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16
2	250	Variable	$1.21	$1.21	$1.21	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
	tractor res	Fixed	$0.26	$4.84	$4.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.47	$6.05	$5.71	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
2	250	Variable	$0.60	$0.60	$0.60	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
	L&G other	Fixed	$0.26	$3.68	$3.36	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.86	$4.28	$3.96	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
2	250	Variable	$0.96	$0.96	$0.96	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
	pumps	Fixed	$0.26	$4.32	$3.99	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.22	$5.28	$4.95	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
2	250	Variable	$1.00	$1.00	$1.00	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
	utility	Fixed	$0.26	$4.14	$3.81	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.26	$5.14	$4.81	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
2	250	Variable	$1.34	$1.34	$1.34	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
	weld/press	Fixed	$0.26	$4.58	$4.25	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.60	$5.93	$5.59	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
2	500	Variable	$1.29	$1.29	$1.29	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16
	ag/const	Fixed	$0.26	$22.36	$21.72	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.55	$23.65	$23.01	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16
2	500	Variable	$1.21	$1.21	$1.21	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
	tractor com	Fixed	$0.26	$22.73	$22.08	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.47	$23.94	$23.29	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
2	500	Variable	$0.60	$0.60	$0.60	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
	L&G other	Fixed	$0.26	$21.58	$20.95	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.86	$22.18	$21.55	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
2	500	Variable	$0.96	$0.96	$0.96	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
	pumps	Fixed	$0.26	$22.21	$21.57	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.22	$23.17	$22.53	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
2	500	Variable	$1.00	$1.00	$1.00	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
	utility	Fixed	$0.26	$22.04	$21.39	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.26	$23.04	$22.40	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
2	500	Variable	$1.34	$1.34	$1.34	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
	weld/press	Fixed	$0.26	$22.48	$21.83	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.60	$23.82	$23.17	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
2	1,000	Variable	$1.29	$1.29	$1.29	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16
	ag/const	Fixed	$0.26	$16.22	$15.68	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.55	$17.51	$16.97	$9.60	$9.60	$9.47	$9.47	$9.47	$8.16	$8.16

Class	Useful life	Cost type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017+
2	1,000	Variable	$1.21	$1.21	$1.21	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
	tractor com	Fixed	$0.26	$16.59	$16.04	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.47	$17.80	$17.25	$7.07	$7.07	$6.94	$6.94	$6.94	$6.08	$6.08
2	1,000	Variable	$0.60	$0.60	$0.60	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
	L&G other	Fixed	$0.26	$15.44	$14.91	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$0.86	$16.04	$15.51	$5.44	$5.44	$5.32	$5.32	$5.32	$4.63	$4.63
2	1,000	Variable	$0.96	$0.96	$0.96	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
	pumps	Fixed	$0.26	$16.07	$15.53	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.22	$17.03	$16.49	$8.53	$8.53	$8.41	$8.41	$8.41	$7.23	$7.23
2	1,000	Variable	$1.00	$1.00	$1.00	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
	utility	Fixed	$0.26	$15.89	$15.36	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.26	$16.89	$16.36	$7.96	$7.96	$7.83	$7.83	$7.83	$6.76	$6.76
2	1,000	Variable	$1.34	$1.34	$1.34	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
	weld/press	Fixed	$0.26	$16.33	$15.79	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		Total	$1.60	$17.68	$17.14	$10.09	$10.09	$9.96	$9.96	$9.96	$8.58	$8.58
2	250/500/1000	Variable	$0.51	$0.51	$0.51	$3.98	$3.98	$3.85	$3.85	$3.85	$3.27	$3.27
	snow-	Fixed	$0.26	$0.47	$0.20	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	blower	Total	$0.77	$0.97	$0.71	$3.98	$3.98	$3.85	$3.85	$3.85	$3.27	$3.27

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 2008 and increase in 2010 when the variable costs for exhaust emission standards begin to be incurred. 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 2015 and later years. The equipment costs are more complicated due to the phase in of the different standards. They begin in 2009, increase in 2011 or 2012 , and then decrease in 2015. Equipment compliance costs remain the same for 2015 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	$0	$0	$870	$870	$870	$870	$870	$696	$696	$696	$696	$696
		Fixed	$73	$73	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$73	$73	$870	$870	$870	$870	$870	$696	$696	$696	$696	$696
PWC	100-175	Variable	$0	$0	$85	$85	$85	$85	$85	$68	$68	$68	$68	$68
		Fixed	$34	$34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$34	$34	$85	$85	$85	$85	$85	$68	$68	$68	$68	$68
PWC	175-300	Variable	$0	$0	$1,290	$1,290	$1,290	$1,290	$1,290	$1,032	$1,032	$1,032	$1,032	$1,032
		Fixed	$113	$113	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$113	$113	$1,290	$1,290	$1,290	$1,290	$1,290	$1,032	$1,032	$1,032	$1,032	$1,032
SD/I recreational	100-175	Variable	$0	$0	$465	$465	$465	$465	$465	$372	$372	$372	$372	$372
		Fixed	$45	$45	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$45	$45	$465	$465	$465	$465	$465	$372	$372	$372	$372	$372
SD/I recreational	175-300	Variable	$0	$0	$320	$320	$320	$320	$320	$256	$256	$256	$256	$256
		Fixed	$50	$50	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$50	$50	$320	$320	$320	$320	$320	$256	$256	$256	$256	$256
SD/I recreational	300+	Variable	$0	$0	$297	$297	$297	$297	$297	$238	$238	$238	$238	$238
		Fixed	$57	$57	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$57	$57	$297	$297	$297	$297	$297	$238	$238	$238	$238	$238
SD/I luxury	175-300	Variable	$0	$0	$320	$320	$320	$320	$320	$256	$256	$256	$256	$256
		Fixed	$50	$50	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$50	$50	$320	$320	$320	$320	$320	$256	$256	$256	$256	$256
SD/I luxury	300+	Variable	$0	$0	$297	$297	$297	$297	$297	$238	$238	$238	$238	$238
		Fixed	$57	$57	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$57	$57	$297	$297	$297	$297	$297	$238	$238	$238	$238	$238

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
OB recreational	<25	Variable	$0	$0	$69	$69	$69	$69	$69	$55	$55	$55	$55	$55
		Fixed	$12	$12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$12	$12	$69	$69	$69	$69	$69	$55	$55	$55	$55	$55
OB recreational	25-50	Variable	$0	$0	$216	$216	$216	$216	$216	$173	$173	$173	$173	$173
		Fixed	$14	$14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$14	$14	$216	$216	$216	$216	$216	$173	$173	$173	$173	$173
OB recreational	50-100	Variable	$0	$0	$203	$203	$203	$203	$203	$162	$162	$162	$162	$162
		Fixed	$20	$20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$20	$20	$203	$203	$203	$203	$203	$162	$162	$162	$162	$162
OB recreational	100-175	Variable	$0	$0	$338	$338	$338	$338	$338	$270	$270	$270	$270	$270
		Fixed	$37	$37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$37	$37	$338	$338	$338	$338	$338	$270	$270	$270	$270	$270
OB recreational	175-300	Variable	$0	$0	$690	$690	$690	$690	$690	$552	$552	$552	$552	$552
		Fixed	$67	$67	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$67	$67	$690	$690	$690	$690	$690	$552	$552	$552	$552	$552
OB luxury	100-175	Variable	$0	$0	$338	$338	$338	$338	$338	$270	$270	$270	$270	$270
		Fixed	$37	$37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$37	$37	$338	$338	$338	$338	$338	$270	$270	$270	$270	$270
OB luxury	175-300	Variable	$0	$0	$690	$690	$690	$690	$690	$552	$552	$552	$552	$552
		Fixed	$67	$67	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$67	$67	$690	$690	$690	$690	$690	$552	$552	$552	$552	$552
OB loose engines	<25	Variable	$0	$0	$69	$69	$69	$69	$69	$55	$55	$55	$55	$55
		Fixed	$12	$12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		Total	$12	$12	$69	$69	$69	$69	$69	$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	$0.0	$1.6	$1.6	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7
		Fixed	$0.9	$15.5	$14.7	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$0.9	$17.1	$16.2	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7	$9.7
PWC	100-175	Variable	$0.0	$1.9	$1.9	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2
		Fixed	$0.9	$17.0	$16.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$0.9	$18.9	$18.1	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2
PWC	175-300	Variable	$0.0	$1.9	$1.9	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2
		Fixed	$0.9	$17.0	$16.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$0.9	$18.9	$18.1	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2	$11.2
SD/I recreational	100-175	Variable	$0.0	$3.8	$3.8	$31.4	$67.2	$67.2	$67.2	$67.2	$61.7	$56.3	$56.3	$56.3
		Fixed	$1.5	$1.5	$0.3	$0.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.5	$5.3	$4.1	$31.7	$67.2	$67.2	$67.2	$67.2	$61.7	$56.3	$56.3	$56.3
SD/I recreational	175-300	Variable	$0.0	$4.6	$4.6	$43.7	$94.4	$94.4	$94.4	$94.4	$86.6	$80.7	$80.7	$80.7
		Fixed	$1.5	$1.5	$0.3	$0.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.5	$6.2	$4.9	$44.0	$94.4	$94.4	$94.4	$94.4	$86.6	$80.7	$80.7	$80.7
SD/I recreational	300+	Variable	$0.0	$5.2	$5.2	$71.6	$157.6	$157.6	$157.6	$157.6	$144.3	$137.4	$137.4	$137.4
		Fixed	$1.5	$1.5	$0.3	$0.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.5	$6.8	$5.5	$71.9	$157.6	$157.6	$157.6	$157.6	$144.3	$137.4	$137.4	$137.4
SD/I luxury	175-300	Variable	$0.0	$5.7	$5.7	$53.6	$115.7	$115.7	$115.7	$115.7	$106.1	$98.9	$98.9	$98.9
		Fixed	$1.9	$1.9	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.9	$7.5	$6.0	$54.0	$115.7	$115.7	$115.7	$115.7	$106.1	$98.9	$98.9	$98.9

Application Category	HP Category	Cost Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-23	2024+
SD/I luxury	300+	Variable	$0.0	$7.8	$7.8	$107.2	$236.1	$236.1	$236.1	$236.1	$216.2	$205.8	$205.8	$205.8
		Fixed	$2.3	$2.3	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$2.3	$10.1	$8.3	$107.7	$236.1	$236.1	$236.1	$236.1	$216.2	$205.8	$205.8	$205.8
OB recreational	<25	Variable	$0.0	$3.9	$5.5	$10.8	$10.8	$10.8	$10.8	$10.4	$10.4	$10.4	$10.4	$10.4
		Fixed	$0.7	$10.8	$10.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$0.7	$14.6	$15.5	$10.8	$10.8	$10.8	$10.8	$10.4	$10.4	$10.4	$10.4	$10.4
OB recreational	25-50	Variable	$0.0	$5.5	$5.5	$21.6	$38.6	$38.6	$38.6	$38.6	$35.4	$29.5	$29.5	$29.5
		Fixed	$1.6	$1.6	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.6	$7.2	$5.9	$22.0	$38.6	$38.6	$38.6	$38.6	$35.4	$29.5	$29.5	$29.5
OB recreational	50-100	Variable	$0.0	$8.3	$8.3	$34.6	$61.6	$61.6	$61.6	$61.6	$56.4	$49.9	$49.9	$49.9
		Fixed	$1.7	$1.7	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.7	$10.0	$8.7	$34.9	$61.6	$61.6	$61.6	$61.6	$56.4	$49.9	$49.9	$49.9
OB recreational	100-175	Variable	$0.0	$10.0	$10.0	$52.4	$95.4	$95.4	$95.4	$95.4	$86.9	$79.8	$79.8	$79.8
		Fixed	$1.7	$1.7	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.7	$11.7	$10.4	$52.8	$95.4	$95.4	$95.4	$95.4	$86.9	$79.8	$79.8	$79.8
OB recreational	175-300	Variable	$0.0	$11.7	$11.7	$74.9	$138.3	$138.3	$138.3	$138.3	$125.6	$117.6	$117.6	$117.6
		Fixed	$1.7	$1.7	$0.4	$0.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$1.7	$13.3	$12.0	$75.2	$138.3	$138.3	$138.3	$138.3	$125.6	$117.6	$117.6	$117.6
OB luxury	100-175	Variable	$0.0	$19.4	$19.4	$101.4	$184.5	$184.5	$184.5	$184.5	$168.1	$154.3	$154.3	$154.3
		Fixed	$3.2	$3.2	$0.7	$0.7	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$3.2	$22.6	$20.1	$102.1	$184.5	$184.5	$184.5	$184.5	$168.1	$154.3	$154.3	$154.3
OB luxury	175-300	Variable	$0.0	$22.6	$22.6	$144.8	$267.4	$267.4	$267.4	$267.4	$243.0	$227.5	$227.5	$227.5
		Fixed	$3.2	$3.2	$0.7	$0.7	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$3.2	$25.8	$23.3	$145.5	$267.4	$267.4	$267.4	$267.4	$243.0	$227.5	$227.5	$227.5
OB loose engine	<25	Variable	$0.0	$3.1	$4.4	$8.6	$8.6	$8.6	$8.6	$8.3	$8.3	$8.3	$8.3	$8.3
		Fixed	$0.6	$8.6	$8.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
		Total	$0.6	$11.7	$12.4	$8.6	$8.6	$8.6	$8.6	$8.3	$8.3	$8.3	$8.3	$8.3

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 final emission control program, reflecting the reduction in evaporative emissions and the use of more fuel-efficient engine technology to meet the final 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 2008 until 2020 the estimated consumer savings associated with reduced gasoline consumption from the small SI and marine SI programs gas can controls increases sharply, from $3.2 million to $201 million. After 2020 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 $0.7 million in 2008 to $43 million in 2020.

Table 9.3-20: 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 (Million$)
2008	1,748,394	0	1,748,394	$3.9	$0.7	$3.2
2009	4,060,953	398,339	4,459,291	$9.8	$1.7	$8.1
2010	6,304,081	4,488,257	10,792,339	$23.8	$4.2	$19.6
2011	14,982,484	9,200,101	24,182,584	$53.3	$9.4	$43.9
2012	24,473,425	14,543,630	39,017,055	$86.0	$15.2	$70.8
2013	32,954,248	19,806,738	52,760,987	$116.3	$20.6	$95.7
2014	38,823,924	25,044,187	63,868,112	$140.8	$24.9	$115.9
2015	43,779,918	30,265,803	74,045,720	$163.2	$28.9	$134.3
2016	47,746,869	35,426,120	83,172,989	$183.3	$32.4	$150.9
2017	50,580,035	40,529,842	91,109,877	$200.8	$35.5	$165.3
2018	52,702,739	45,571,856	98,274,595	$216.6	$38.3	$178.3
2019	54,429,770	50,527,419	104,957,189	$231.3	$40.9	$190.4
2020	55,917,371	55,085,140	111,002,511	$244.6	$43.3	$201.4
2021	57,171,954	59,222,320	116,394,274	$256.5	$45.4	$211.1
2022	58,309,088	63,220,853	121,529,941	$267.9	$47.4	$220.5
2023	59,361,292	67,056,116	126,417,408	$278.6	$49.3	$229.3
2024	60,376,870	70,326,971	130,703,841	$288.1	$51.0	$237.1
2025	61,369,887	73,270,886	134,640,773	$296.7	$52.5	$244.2
2026	62,353,284	75,906,088	138,259,372	$304.7	$53.9	$250.8
2027	63,326,668	78,313,723	141,640,391	$312.2	$55.2	$256.9
2028	64,292,904	80,527,973	144,820,877	$319.2	$56.5	$262.7
2029	65,253,036	82,543,743	147,796,779	$325.7	$57.6	$268.1
2030	66,207,356	84,310,121	150,517,478	$331.7	$58.7	$273.0
2031	67,157,496	85,894,203	153,051,700	$337.3	$59.7	$277.6
2032	68,105,401	87,275,207	155,380,608	$342.5	$60.6	$281.9
2033	69,050,694	88,524,271	157,574,965	$347.3	$61.5	$285.8
2034	69,993,828	89,672,904	159,666,732	$351.9	$62.3	$289.6
2035	70,935,570	90,731,710	161,667,280	$356.3	$63.1	$293.3
2036	71,874,840	91,713,009	163,587,849	$360.5	$63.8	$296.7
2037	72,811,766	92,624,481	165,436,247	$364.6	$64.5	$300.1

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 elasticities are expected to be more elastic. It should also be noted that the aggregate data (6 digits NAICS code or 4 digit SIC code industry 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.

The estimated supply and demand elasticities were based on best data we could find. For supply elasticities, we used the establishment-level or plant-level data from Census of Manufactures, conducted by the U. S. Census Bureau to estimate the production function for affected industries by this rule. The estimated coefficients of the production function were then used to calculate the supply elasticity for the industry. Establishments-level data were selected from 6 digit NAICS code industry for five Census years between 1972 and 1997. The supply elasticities estimated from plant-level data are more elastic than industry-level data, as we previously used for the EIA chapter in the NPRM

For demand elasitcities, we used the industry-level data published by the National Bureau of Economic Research (NBER)-Center for Economic Studies (Bartlesman, Becker, and Gray, 2000). In addition to NBER data, we also 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]

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[13] In estimating demand elasticity, all values are expressed in 1987$.

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 final rule.

The estimated supply elasticities for all of the equipment and engine markets are elastic, ranging from 3.8 for all recreational marine except PWC, to 8.8 for generators, 5.2 for PWCs and, 10 for all Small SI applications except generators, and 9.5 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 8.8 percent change in quantity of generator producers are willing to supply).

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.

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.

As discussed in 9.2.3.2, the EIM model uses a derived demand approach for the engine market to incorporate the interaction between the equipment and engine markets. The demand curve for the engine market is solely derived from the equipment market. The derived demand is not affected by the product attributes that could shift the demand curve. In other words, as explained in 9.2.3.1, the demand curves for either the equipment or engine markets do not shift in response to any change in consumer preferences that may occur due to the compliance strategies of the producers in the analysis. We explore the impacts of relaxing this assumption in a sensitivity analysis (see 9.H.4). The engine and equipment changes needed to meet emission standards may affect the demand because of the potential changes to fuel consumption and engine performance. Section 9H.1 contains a sensitivity analysis that evaluates the effect of increased or decreased demand elasticities on the estimates of social cost of the rule. How this demand change affects the total social welfare of the rule is outside the scope of the analysis presented in Chapter 9 because the corresponding market failure (e.g., the health effects of air pollution) is not explicitly modeled; for example the economic impact of this regulation through reducing selected air pollutants is discussed separately in Chapter 8.

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	9.5	EPA econometric estimate	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 333618
Marine Equipment Markets				
PWC	5.2	EPA econometric estimate	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 336999
All other vessel types	3.8	EPA econometric estimate	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 336612
Small SI Equipment Markets				
Gensets/welders	8.8	EPA econometric estimate	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 335312
All other Small SI equipment (handheld and nonhandheld)	10.0	EPA econometric estimate	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 333618

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); Manufacturing Industry Data from US Census Bureau: 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:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s}\right)^z \qquad (10.1)$$

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 final 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 final 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 previous 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 has investigated 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 used the cross-sectional data model at the firm-level or plant level from the U.S. Census Bureau to estimate these elasticities. We used the results of this research for the analysis.

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 final 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 either fixed or variable compliance 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 final standards would require manufacturers to devote new funds and resources to product redesign.	Results may overstate distribution of social costs to some producers, understate market impacts; magnitude of impact is uncertain
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
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), 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	2014	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 3.6 percent of burden of compliance costs from producers to consumers in Marine SI market; shift of about 2.5 percent of burden of compliance costs from producers to consumers in Small SI market)
	2014	Less Elastic (lower bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 0.2 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 6 percent of burden of compliance costs from consumers to producers in Marine SI market; shift of about 6 percent of burden of compliance costs from consumers to producers in Small SI market)
Price Elasticity of Demand	2014	More Elastic (upper bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 0.5 percent additional increase in price increase compared to primary analysis; less than 1.5 percent 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 5 percent of burden of compliance costs from consumers to producers in Small SI market)

	2014	Less Elastic (lower bound of 95 percent confidence interval for each elasticity estimate)	Negligible impact on expected price increase and quantity decrease (less than 1 percent additional increase in price increase compared to primary analysis; less than 3 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 22 percent of burden of compliance costs from producers to consumers in Marine SI market; shift of about 6 percent of burden of compliance costs from producers to consumers in Small SI market)
Alternative Baseline Equilibrium Price - Lawnmowers and Tractors	2014	Lower baseline equilibrium price	Larger percent increase in price and percent decrease in quantity, although absolute changes are smaller (less than 2 percent additional price change for both sectors compared to primary analysis; about 0.3 percent additional quantity decrease for lawn mowers and about 1 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 2037 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, 2008). 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
- Handheld equipment
- 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 = $140)[a,b]

	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	$1	$1	0.8%	–0.1%	$11.4	–$0.1
2009	$1	$1	0.8%	–0.1%	$11.5	–$0.2
2010	$3	$3	2.3%	–0.4%	$32.3	–$0.6
2011	$3	$3	2.2%	–0.4%	$32.4	–$0.5
2012	$12	$12	8.9%	–1.9%	$131.3	–$2.8
2013	$12	$12	8.8%	–1.9%	$132.2	–$2.7
2014	$12	$12	8.8%	–1.9%	$134.4	–$2.8
2015	$12	$12	8.8%	–1.9%	$136.6	–$2.8
2016	$12	$12	8.8%	–1.9%	$138.8	–$2.9
2017	$11	$11	7.9%	–1.7%	$127.1	–$2.6
2018	$11	$11	7.9%	–1.7%	$129.1	–$2.6
2019	$11	$11	7.9%	–1.7%	$131.1	–$2.7
2020	$11	$11	7.9%	–1.7%	$133.1	–$2.7
2021	$11	$11	7.9%	–1.7%	$135.1	–$2.8
2022	$11	$11	7.9%	–1.7%	$137.1	–$2.8
2023	$11	$11	7.9%	–1.7%	$139.1	–$2.8
2024	$11	$11	7.9%	–1.7%	$141.1	–$2.9
2025	$11	$11	7.9%	–1.7%	$143.1	–$2.9
2026	$11	$11	7.9%	–1.7%	$145.1	–$3.0
2027	$11	$11	7.9%	–1.7%	$147.1	–$3.0
2028	$11	$11	7.9%	–1.7%	$149.1	–$3.0
2029	$11	$11	7.9%	–1.7%	$151.2	–$3.1
2030	$11	$11	7.9%	–1.7%	$153.2	–$3.1
2031	$11	$11	7.9%	–1.7%	$155.2	–$3.2
2032	$11	$11	7.9%	–1.7%	$157.2	–$3.2
2033	$11	$11	7.9%	–1.7%	$159.2	–$3.2
2034	$11	$11	7.9%	–1.7%	$161.3	–$3.3
2035	$11	$11	7.9%	–1.7%	$163.3	–$3.3
2036	$11	$11	7.9%	–1.7%	$165.3	–$3.4
2037	$11	$11	7.9%	–1.7%	$167.3	–$3.4
NPV (3%)					$2,340.8	–$47.5
NPV (7%)					$1,331.1	–$27.0

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engines by UL.

Table 9A-2. Impact on Small SI Engine Market Class II (Average Price per Engine = $310)[a,b]

	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	$3	$3	1.1%	–0.3%	$15.4	–$0.4
2009	$9	$8	2.7%	–0.9%	$40.6	–$1.5
2010	$9	$8	2.7%	–0.9%	$40.6	–$1.5
2011	$19	$18	5.8%	–1.9%	$89.4	–$2.5
2012	$18	$18	5.7%	–1.9%	$89.7	–$2.5
2013	$18	$18	5.7%	–1.9%	$91.2	–$2.6
2014	$18	$18	5.7%	–1.9%	$92.8	–$2.6
2015	$16	$15	4.8%	–1.7%	$79.7	–$2.3
2016	$16	$15	4.8%	–1.6%	$80.9	–$2.3
2017	$16	$15	4.8%	–1.6%	$82.2	–$2.3
2018	$16	$15	4.8%	–1.6%	$83.5	–$2.4
2019	$16	$15	4.8%	–1.6%	$84.9	–$2.4
2020	$16	$15	4.8%	–1.6%	$86.2	–$2.4
2021	$16	$15	4.8%	–1.6%	$87.5	–$2.5
2022	$16	$15	4.8%	–1.6%	$88.8	–$2.5
2023	$16	$15	4.8%	–1.6%	$90.1	–$2.5
2024	$16	$15	4.8%	–1.6%	$91.4	–$2.6
2025	$16	$15	4.8%	–1.6%	$92.7	–$2.6
2026	$16	$15	4.8%	–1.6%	$94.0	–$2.7
2027	$16	$15	4.8%	–1.6%	$95.3	–$2.7
2028	$16	$15	4.8%	–1.6%	$96.6	–$2.7
2029	$16	$15	4.8%	–1.6%	$97.9	–$2.8
2030	$16	$15	4.8%	–1.6%	$99.2	–$2.8
2031	$16	$15	4.8%	–1.6%	$100.6	–$2.8
2032	$16	$15	4.8%	–1.6%	$101.9	–$2.9
2033	$16	$15	4.8%	–1.6%	$103.2	–$2.9
2034	$16	$15	4.8%	–1.6%	$104.5	–$2.9
2035	$16	$15	4.8%	–1.6%	$105.8	–$3.0
2036	$16	$15	4.8%	–1.6%	$107.1	–$3.0
2037	$16	$15	4.8%	–1.6%	$108.4	–$3.1
NPV (3%)					$1,633.5	–$46.6
NPV (7%)					$967.4	–$27.8

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engines by UL.

Table 9A-3: Impact on Small SI Equipment Market
Handheld (Average Price per Equipment = $210)[a]

	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	0.1%	–0.2%	$2.6	–$0.4
2009	$1	$1	0.4%	–0.7%	$8.3	–$1.3
2010	$1	$1	0.4%	–0.7%	$8.2	–$1.3
2011	$1	$1	0.4%	–0.7%	$8.3	–$1.3
2012	$1	$1	0.3%	–0.6%	$7.8	–$1.2
2013	$1	$1	0.3%	–0.6%	$7.9	–$1.3
2014	$1	$1	0.3%	–0.5%	$6.8	–$1.1
2015	$1	$1	0.3%	–0.5%	$6.9	–$1.1
2016	$1	$1	0.3%	–0.5%	$7.0	–$1.1
2017	$1	$1	0.3%	–0.5%	$7.1	–$1.1
2018	$1	$1	0.3%	–0.5%	$7.3	–$1.2
2019	$1	$1	0.3%	–0.5%	$7.4	–$1.2
2020	$1	$1	0.3%	–0.5%	$7.5	–$1.2
2021	$1	$1	0.3%	–0.5%	$7.6	–$1.2
2022	$1	$1	0.3%	–0.5%	$7.7	–$1.2
2023	$1	$1	0.3%	–0.5%	$7.8	–$1.3
2024	$1	$1	0.3%	–0.5%	$7.9	–$1.3
2025	$1	$1	0.3%	–0.5%	$8.0	–$1.3
2026	$1	$1	0.3%	–0.5%	$8.2	–$1.3
2027	$1	$1	0.3%	–0.5%	$8.3	–$1.3
2028	$1	$1	0.3%	–0.5%	$8.4	–$1.3
2029	$1	$1	0.3%	–0.5%	$8.5	–$1.4
2030	$1	$1	0.3%	–0.5%	$8.6	–$1.4
2031	$1	$1	0.3%	–0.5%	$8.7	–$1.4
2032	$1	$1	0.3%	–0.5%	$8.8	–$1.4
2033	$1	$1	0.3%	–0.5%	$8.9	–$1.4
2034	$1	$1	0.3%	–0.5%	$9.1	–$1.5
2035	$1	$1	0.3%	–0.5%	$9.2	–$1.5
2036	$1	$1	0.3%	–0.5%	$9.3	–$1.5
2037	$1	$1	0.3%	–0.5%	$9.4	–$1.5
NPV (3%)					$151.3	–$24.2
NPV (7%)					$92.8	–$14.8

[a] Figures are in 2005 dollars.

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]

	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	$1	0.1%	–0.1%	$0.0	$0.0
2009	$0	$1	0.1%	–0.1%	$0.0	$0.0
2010	$0	$2	0.2%	–0.2%	$0.0	$0.0
2011	$0	$2	0.2%	–0.2%	$0.0	$0.0
2012	$0	$11	1.0%	–1.0%	$0.0	–$0.1
2013	$0	$11	1.0%	–1.0%	$0.0	–$0.1
2014	$0	$11	1.0%	–1.0%	$0.0	–$0.1
2015	$0	$11	1.0%	–1.0%	$0.0	–$0.1
2016	$0	$11	1.0%	–1.0%	$0.0	–$0.1
2017	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2018	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2019	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2020	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2021	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2022	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2023	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2024	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2025	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2026	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2027	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2028	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2029	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2030	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2031	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2032	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2033	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2034	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2035	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2036	$0	$10	0.9%	–0.9%	$0.0	–$0.1
2037	$0	$10	0.9%	–0.9%	$0.0	–$0.1
NPV (3%)					$0.0	–$1.7
NPV (7%)					$0.0	–$1.0

[a] Figures are in 2005 dollars.

Table 9A-5: Impact on Small SI Equipment Market: Class I Utility and Recreational Vehicles UL 125 (Average Price per Equipment = $570)[a]

	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	$1	0.1%	–0.1%	$0.0	$0.0
2009	$0	$1	0.1%	–0.1%	$0.0	$0.0
2010	$0	$2	0.4%	–0.4%	$0.0	$0.0
2011	$0	$2	0.4%	–0.4%	$0.0	$0.0
2012	$0	$11	2.0%	–2.0%	$0.0	–$0.1
2013	$0	$11	2.0%	–2.0%	$0.0	–$0.1
2014	$0	$11	2.0%	–2.0%	$0.0	–$0.1
2015	$0	$11	2.0%	–2.0%	$0.0	–$0.1
2016	$0	$11	2.0%	–2.0%	$0.0	–$0.1
2017	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2018	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2019	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2020	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2021	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2022	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2023	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2024	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2025	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2026	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2027	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2028	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2029	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2030	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2031	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2032	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2033	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2034	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2035	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2036	$0	$10	1.8%	–1.8%	$0.0	–$0.1
2037	$0	$10	1.8%	–1.8%	$0.0	–$0.1
NPV (3%)					$0.0	–$1.9
NPV (7%)					$0.0	–$1.1

[a] Figures are in 2005 dollars.

Table 9A-6: Impact on Small SI Equipment Market: Class I Lawn Mowers UL 125
(Average Price per Equipment = $218)[a]

	Small SI Equipment (Class I Lawn Mowers 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	$1	0.4%	–0.1%	$0.0	–$0.1
2009	$0	$1	0.4%	–0.1%	$0.0	–$0.1
2010	$0	$2	1.1%	–0.2%	$0.0	–$0.3
2011	$0	$2	1.1%	–0.2%	$0.0	–$0.3
2012	$0	$12	5.6%	–1.1%	$0.0	–$1.6
2013	$0	$12	5.5%	–1.1%	$0.0	–$1.6
2014	$0	$12	5.5%	–1.1%	$0.0	–$1.7
2015	$0	$12	5.5%	–1.1%	$0.0	–$1.7
2016	$0	$12	5.5%	–1.1%	$0.0	–$1.7
2017	$0	$11	5.0%	–0.9%	$0.0	–$1.6
2018	$0	$11	5.0%	–0.9%	$0.0	–$1.6
2019	$0	$11	5.0%	–0.9%	$0.0	–$1.6
2020	$0	$11	5.0%	–0.9%	$0.0	–$1.6
2021	$0	$11	5.0%	–0.9%	$0.0	–$1.7
2022	$0	$11	5.0%	–0.9%	$0.0	–$1.7
2023	$0	$11	5.0%	–0.9%	$0.0	–$1.7
2024	$0	$11	5.0%	–0.9%	$0.0	–$1.7
2025	$0	$11	5.0%	–0.9%	$0.0	–$1.8
2026	$0	$11	5.0%	–0.9%	$0.0	–$1.8
2027	$0	$11	5.0%	–0.9%	$0.0	–$1.8
2028	$0	$11	5.0%	–0.9%	$0.0	–$1.8
2029	$0	$11	5.0%	–0.9%	$0.0	–$1.9
2030	$0	$11	5.0%	–0.9%	$0.0	–$1.9
2031	$0	$11	5.0%	–0.9%	$0.0	–$1.9
2032	$0	$11	5.0%	–0.9%	$0.0	–$1.9
2033	$0	$11	5.0%	–0.9%	$0.0	–$2.0
2034	$0	$11	5.0%	–0.9%	$0.0	–$2.0
2035	$0	$11	5.0%	–0.9%	$0.0	–$2.0
2036	$0	$11	5.0%	–0.9%	$0.0	–$2.0
2037	$0	$11	5.0%	–0.9%	$0.0	–$2.1
NPV (3%)					$0.0	–$28.6
NPV (7%)					$0.0	–$16.2

[a] Figures are in 2005 dollars.

Table 9A-7: Impact on Small SI Equipment Market: Class I Other Lawn and Garden Equipment UL 125 (Average Price per Equipment = $245)[a]

	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	$1	0.3%	–0.3%	$0.0	–$0.1
2009	$0	$1	0.3%	–0.3%	$0.0	–$0.1
2010	$0	$2	0.9%	–0.8%	$0.0	–$0.1
2011	$0	$2	0.9%	–0.8%	$0.0	–$0.1
2012	$0	$11	4.7%	–4.2%	$0.0	–$0.7
2013	$0	$11	4.6%	–4.1%	$0.0	–$0.8
2014	$0	$11	4.6%	–4.1%	$0.0	–$0.8
2015	$0	$11	4.6%	–4.1%	$0.0	–$0.8
2016	$0	$11	4.6%	–4.1%	$0.0	–$0.8
2017	$0	$10	4.2%	–3.7%	$0.0	–$0.7
2018	$0	$10	4.2%	–3.7%	$0.0	–$0.7
2019	$0	$10	4.2%	–3.7%	$0.0	–$0.7
2020	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2021	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2022	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2023	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2024	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2025	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2026	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2027	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2028	$0	$10	4.2%	–3.7%	$0.0	–$0.8
2029	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2030	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2031	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2032	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2033	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2034	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2035	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2036	$0	$10	4.2%	–3.7%	$0.0	–$0.9
2037	$0	$10	4.2%	–3.7%	$0.0	–$1.0
NPV (3%)					$0.0	–$13.1
NPV (7%)					$0.0	–$7.4

[a] Figures are in 2005 dollars.

Table 9A-8: Impact on Small SI Equipment Market: Class I Gensets/Welders UL 125 (Average Price per Equipment = $999)[a]

	Small SI Equipment (Class I Gensets/Welders 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	$1	0.1%	–0.1%	$0.0	$0.0
2009	$0	$1	0.1%	–0.1%	$0.0	$0.0
2010	$0	$2	0.2%	–0.3%	$0.0	–$0.1
2011	$0	$2	0.2%	–0.3%	$0.0	–$0.1
2012	$0	$11	1.1%	–1.5%	$0.0	–$0.5
2013	$0	$11	1.1%	–1.5%	$0.0	–$0.5
2014	$0	$11	1.1%	–1.5%	$0.0	–$0.5
2015	$0	$11	1.1%	–1.5%	$0.0	–$0.5
2016	$0	$11	1.1%	–1.5%	$0.0	–$0.5
2017	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2018	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2019	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2020	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2021	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2022	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2023	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2024	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2025	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2026	$0	$10	1.0%	–1.4%	$0.0	–$0.5
2027	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2028	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2029	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2030	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2031	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2032	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2033	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2034	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2035	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2036	$0	$10	1.0%	–1.4%	$0.0	–$0.6
2037	$0	$10	1.0%	–1.4%	$0.0	–$0.6
NPV (3%)					$0.0	–$8.7
NPV (7%)					$0.0	–$4.9

[a] Figures are in 2005 dollars.

Table 9A-9: Impact on Small SI Equipment Market: Class I Pumps/Compressors/Pressure Washers UL 125 (Average Price per Equipment = $96)[a]

	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	$1	0.8%	–0.7%	$0.0	$0.0
2009	$0	$1	0.8%	–0.7%	$0.0	–$0.1
2010	$0	$2	2.3%	–2.3%	$0.0	–$0.1
2011	$0	$2	2.2%	–2.2%	$0.0	–$0.1
2012	$0	$11	11.8%	–11.8%	$0.0	–$0.7
2013	$0	$11	11.7%	–11.6%	$0.0	–$0.7
2014	$0	$11	11.7%	–11.6%	$0.0	–$0.8
2015	$0	$11	11.6%	–11.6%	$0.0	–$0.8
2016	$0	$11	11.6%	–11.6%	$0.0	–$0.8
2017	$0	$10	10.5%	–10.4%	$0.0	–$0.7
2018	$0	$10	10.5%	–10.4%	$0.0	–$0.7
2019	$0	$10	10.5%	–10.4%	$0.0	–$0.7
2020	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2021	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2022	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2023	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2024	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2025	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2026	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2027	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2028	$0	$10	10.5%	–10.4%	$0.0	–$0.8
2029	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2030	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2031	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2032	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2033	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2034	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2035	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2036	$0	$10	10.5%	–10.4%	$0.0	–$0.9
2037	$0	$10	10.5%	–10.4%	$0.0	–$0.9
NPV (3%)					$0.0	–$13.0
NPV (7%)					$0.0	–$7.4

[a] Figures are in 2005 dollars.

Table 9A-10: Impact on Small SI Equipment Market: Class I Snowblowers UL 125 (Average Price per Equipment = $324)[a]

	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	$1	0.2%	–0.2%	$0.0	$0.0
2011	$0	$1	0.2%	–0.2%	$0.0	$0.0
2012	$0	$3	0.8%	–0.8%	$0.0	–$0.2
2013	$0	$2	0.8%	–0.8%	$0.0	–$0.2
2014	$0	$2	0.8%	–0.8%	$0.0	–$0.2
2015	$0	$2	0.8%	–0.8%	$0.0	–$0.2
2016	$0	$2	0.8%	–0.8%	$0.0	–$0.2
2017	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2018	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2019	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2020	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2021	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2022	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2023	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2024	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2025	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2026	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2027	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2028	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2029	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2030	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2031	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2032	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2033	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2034	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2035	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2036	$0	$2	0.6%	–0.6%	$0.0	–$0.2
2037	$0	$2	0.6%	–0.6%	$0.0	–$0.2
NPV (3%)					$0.0	–$2.8
NPV (7%)					$0.0	–$1.6

[a] Figures are in 2005 dollars.

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]

	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	$2	$3	0.1%	–0.1%	$0.0	$0.0
2009	$6	$8	0.5%	–0.5%	$0.5	–$0.1
2010	$5	$8	0.4%	–0.4%	$0.5	–$0.1
2011	$10	$24	1.3%	–1.3%	$0.8	–$0.2
2012	$10	$24	1.3%	–1.3%	$0.8	–$0.2
2013	$9	$23	1.3%	–1.3%	$0.8	–$0.2
2014	$9	$23	1.3%	–1.3%	$0.9	–$0.2
2015	$9	$21	1.2%	–1.2%	$0.9	–$0.2
2016	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2017	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2018	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2019	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2020	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2021	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2022	$8	$20	1.1%	–1.1%	$0.8	–$0.2
2023	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2024	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2025	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2026	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2027	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2028	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2029	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2030	$8	$20	1.1%	–1.1%	$0.9	–$0.2
2031	$8	$20	1.1%	–1.1%	$1.0	–$0.2
2032	$8	$20	1.1%	–1.1%	$1.0	–$0.2
2033	$8	$20	1.1%	–1.1%	$1.0	–$0.2
2034	$8	$20	1.1%	–1.1%	$1.0	–$0.2
2035	$8	$20	1.1%	–1.1%	$1.0	–$0.3
2036	$8	$20	1.1%	–1.1%	$1.0	–$0.3
2037	$8	$20	1.1%	–1.1%	$1.0	–$0.3
NPV (3%)					$15.7	–$3.7
NPV (7%)					$9.3	–$2.2

[a] Figures are in 2005 dollars.

Table 9A-12: Impact on Small SI Equipment Market: Class II Utility and Recreational Vehicle UL 250 (Average Price per Equipment = $2,894)[a]

	Small SI Equipment (Class II Utility and Recreational Vehicle 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	$1	$2	0.1%	–0.1%	$0.3	–$0.1
2009	$5	$8	0.3%	–0.3%	$1.0	–$0.2
2010	$5	$7	0.3%	–0.3%	$1.0	–$0.2
2011	$8	$22	0.8%	–0.8%	$1.7	–$0.5
2012	$8	$22	0.8%	–0.8%	$1.7	–$0.5
2013	$8	$22	0.8%	–0.8%	$1.7	–$0.5
2014	$8	$22	0.8%	–0.8%	$1.7	–$0.5
2015	$7	$20	0.7%	–0.7%	$1.8	–$0.5
2016	$7	$19	0.6%	–0.6%	$1.6	–$0.4
2017	$7	$19	0.6%	–0.6%	$1.6	–$0.4
2018	$7	$19	0.6%	–0.6%	$1.6	–$0.4
2019	$7	$19	0.6%	–0.6%	$1.6	–$0.5
2020	$7	$19	0.6%	–0.6%	$1.7	–$0.5
2021	$7	$19	0.6%	–0.6%	$1.7	–$0.5
2022	$7	$19	0.6%	–0.6%	$1.7	–$0.5
2023	$7	$19	0.6%	–0.6%	$1.7	–$0.5
2024	$7	$19	0.6%	–0.6%	$1.8	–$0.5
2025	$7	$19	0.6%	–0.6%	$1.8	–$0.5
2026	$7	$19	0.6%	–0.6%	$1.8	–$0.5
2027	$7	$19	0.6%	–0.6%	$1.8	–$0.5
2028	$7	$19	0.6%	–0.6%	$1.9	–$0.5
2029	$7	$19	0.6%	–0.6%	$1.9	–$0.5
2030	$7	$19	0.6%	–0.6%	$1.9	–$0.5
2031	$7	$19	0.6%	–0.6%	$1.9	–$0.5
2032	$7	$19	0.6%	–0.6%	$2.0	–$0.5
2033	$7	$19	0.6%	–0.6%	$2.0	–$0.6
2034	$7	$19	0.6%	–0.6%	$2.0	–$0.6
2035	$7	$19	0.6%	–0.6%	$2.0	–$0.6
2036	$7	$19	0.6%	–0.6%	$2.1	–$0.6
2037	$7	$19	0.6%	–0.6%	$2.1	–$0.6
NPV (3%)					$31.8	–$8.5
NPV (7%)					$19.0	$5.0

[a] Figures are in 2005 dollars.

Table 9A-13: Impact on Small SI Equipment Market: Class II Tractors UL 250 (Average Price per Equipment = $1,937)[a]

	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	$1	$3	0.1%	–0.1%	$2.9	–$0.5
2009	$6	$9	0.4%	–0.4%	$12.0	–$1.7
2010	$6	$8	0.4%	–0.4%	$11.6	–$1.7
2011	$7	$21	1.1%	–1.1%	$14.6	–$4.4
2012	$7	$21	1.1%	–1.1%	$14.8	–$4.5
2013	$7	$21	1.1%	–1.1%	$14.8	–$4.5
2014	$7	$21	1.1%	–1.1%	$15.1	–$4.6
2015	$7	$19	1.0%	–1.0%	$15.3	–$4.2
2016	$6	$18	0.9%	–0.9%	$13.7	–$4.1
2017	$6	$18	0.9%	–0.9%	$13.9	–$4.1
2018	$6	$18	0.9%	–0.9%	$14.1	–$4.2
2019	$6	$18	0.9%	–0.9%	$14.3	–$4.3
2020	$6	$18	0.9%	–0.9%	$14.5	–$4.3
2021	$6	$18	0.9%	–0.9%	$14.8	–$4.4
2022	$6	$18	0.9%	–0.9%	$15.0	–$4.5
2023	$6	$18	0.9%	–0.9%	$15.2	–$4.5
2024	$6	$18	0.9%	–0.9%	$15.4	–$4.6
2025	$6	$18	0.9%	–0.9%	$15.6	–$4.6
2026	$6	$18	0.9%	–0.9%	$15.9	–$4.7
2027	$6	$18	0.9%	–0.9%	$16.1	–$4.8
2028	$6	$18	0.9%	–0.9%	$16.3	–$4.8
2029	$6	$18	0.9%	–0.9%	$16.5	–$4.9
2030	$6	$18	0.9%	–0.9%	$16.7	–$5.0
2031	$6	$18	0.9%	–0.9%	$17.0	–$5.0
2032	$6	$18	0.9%	–0.9%	$17.2	–$5.1
2033	$6	$18	0.9%	–0.9%	$17.4	–$5.2
2034	$6	$18	0.9%	–0.9%	$17.6	–$5.2
2035	$6	$18	0.9%	–0.9%	$17.9	–$5.3
2036	$6	$18	0.9%	–0.9%	$18.1	–$5.4
2037	$6	$18	0.9%	–0.9%	$18.3	–$5.4
NPV (3%)					$284.9	–$81.0
NPV (7%)					$171.7	–$47.6

[a] Figures are in 2005 dollars.

Table 9A-14: Impact on Small SI Equipment Market: Class II Other Lawn and Garden Equipment UL 250 (Average Price per Equipment = $312)[a]

	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	$1	$2	0.6%	–0.6%	$0.1	$0.0
2009	$4	$7	2.2%	–2.0%	$0.6	–$0.1
2010	$4	$7	2.1%	–1.9%	$0.6	–$0.1
2011	$5	$20	6.4%	–5.8%	$0.8	–$0.3
2012	$5	$20	6.4%	–5.7%	$0.9	–$0.3
2013	$5	$20	6.4%	–5.7%	$0.9	–$0.3
2014	$5	$20	6.4%	–5.7%	$0.9	–$0.3
2015	$5	$18	5.6%	–5.1%	$0.9	–$0.3
2016	$5	$17	5.4%	–5.0%	$0.8	–$0.3
2017	$5	$17	5.4%	–4.9%	$0.8	–$0.3
2018	$5	$17	5.4%	–4.9%	$0.8	–$0.3
2019	$5	$17	5.4%	–4.9%	$0.8	–$0.3
2020	$5	$17	5.4%	–4.9%	$0.8	–$0.3
2021	$5	$17	5.4%	–4.9%	$0.8	–$0.3
2022	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2023	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2024	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2025	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2026	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2027	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2028	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2029	$5	$17	5.4%	–4.9%	$0.9	–$0.3
2030	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2031	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2032	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2033	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2034	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2035	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2036	$5	$17	5.4%	–4.9%	$1.0	–$0.3
2037	$5	$17	5.4%	–4.9%	$1.0	–$0.3
NPV (3%)					$16.2	–$5.0
NPV (7%)					$9.7	–$2.9

[a] Figures are in 2005 dollars.

Table 9A-15: Impact on Small SI Equipment Market: Class II Gensets/Welders UL 250 (Average Price per Equipment = $666)[a]

	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	$2	$3	0.4%	–0.4%	$1.1	–$0.2
2009	$6	$8	1.2%	–1.4%	$4.2	–$0.7
2010	$6	$8	1.2%	–1.3%	$4.0	–$0.7
2011	$10	$24	3.5%	–3.9%	$7.4	–$2.1
2012	$10	$23	3.5%	–3.9%	$7.5	–$2.2
2013	$10	$23	3.5%	–3.9%	$7.6	–$2.2
2014	$10	$23	3.5%	–3.9%	$7.7	–$2.2
2015	$10	$21	3.2%	–3.5%	$7.8	–$2.1
2016	$9	$20	3.0%	–3.3%	$6.8	–$2.0
2017	$9	$20	3.0%	–3.3%	$7.0	–$2.0
2018	$9	$20	3.0%	–3.3%	$7.1	–$2.0
2019	$9	$20	3.0%	–3.3%	$7.2	–$2.1
2020	$9	$20	3.0%	–3.3%	$7.3	–$2.1
2021	$9	$20	3.0%	–3.3%	$7.4	–$2.1
2022	$9	$20	3.0%	–3.3%	$7.5	–$2.1
2023	$9	$20	3.0%	–3.3%	$7.6	–$2.2
2024	$9	$20	3.0%	–3.3%	$7.7	–$2.2
2025	$9	$20	3.0%	–3.3%	$7.8	–$2.2
2026	$9	$20	3.0%	–3.3%	$8.0	–$2.3
2027	$9	$20	3.0%	–3.3%	$8.1	–$2.3
2028	$9	$20	3.0%	–3.3%	$8.2	–$2.3
2029	$9	$20	3.0%	–3.3%	$8.3	–$2.4
2030	$9	$20	3.0%	–3.3%	$8.4	–$2.4
2031	$9	$20	3.0%	–3.3%	$8.5	–$2.4
2032	$9	$20	3.0%	–3.3%	$8.6	–$2.5
2033	$9	$20	3.0%	–3.3%	$8.7	–$2.5
2034	$9	$20	3.0%	–3.3%	$8.8	–$2.5
2035	$9	$20	3.0%	–3.3%	$9.0	–$2.6
2036	$9	$20	3.0%	–3.3%	$9.1	–$2.6
2037	$9	$20	3.0%	–3.3%	$9.2	–$2.6
NPV (3%)					$139.8	–$38.9
NPV (7%)					$83.1	–$22.8

[a] Figures are in 2005 dollars.

Table 9A-16: Impact on Small SI Equipment Market: Class II Pumps/Compressors/ Pressure Washers UL 250 (Average Price per Equipment = $349)[a]

	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	$1	$2	0.7%	–0.7%	$0.4	–$0.1
2009	$5	$8	2.3%	–2.3%	$1.6	–$0.2
2010	$5	$8	2.2%	–2.2%	$1.5	–$0.2
2011	$9	$23	6.5%	–6.6%	$2.6	–$0.7
2012	$9	$23	6.5%	–6.5%	$2.7	–$0.7
2013	$8	$22	6.4%	–6.4%	$2.7	–$0.7
2014	$8	$22	6.4%	–6.4%	$2.7	–$0.7
2015	$8	$20	5.8%	–5.9%	$2.8	–$0.7
2016	$7	$19	5.5%	–5.5%	$2.4	–$0.6
2017	$7	$19	5.5%	–5.5%	$2.5	–$0.6
2018	$7	$19	5.5%	–5.5%	$2.5	–$0.7
2019	$7	$19	5.5%	–5.5%	$2.5	–$0.7
2020	$7	$19	5.5%	–5.5%	$2.6	–$0.7
2021	$7	$19	5.5%	–5.5%	$2.6	–$0.7
2022	$7	$19	5.5%	–5.5%	$2.7	–$0.7
2023	$7	$19	5.5%	–5.5%	$2.7	–$0.7
2024	$7	$19	5.5%	–5.5%	$2.7	–$0.7
2025	$7	$19	5.5%	–5.5%	$2.8	–$0.7
2026	$7	$19	5.5%	–5.5%	$2.8	–$0.7
2027	$7	$19	5.5%	–5.5%	$2.9	–$0.7
2028	$7	$19	5.5%	–5.5%	$2.9	–$0.8
2029	$7	$19	5.5%	–5.5%	$2.9	–$0.8
2030	$7	$19	5.5%	–5.5%	$3.0	–$0.8
2031	$7	$19	5.5%	–5.5%	$3.0	–$0.8
2032	$7	$19	5.5%	–5.5%	$3.1	–$0.8
2033	$7	$19	5.5%	–5.5%	$3.1	–$0.8
2034	$7	$19	5.5%	–5.5%	$3.1	–$0.8
2035	$7	$19	5.5%	–5.5%	$3.2	–$0.8
2036	$7	$19	5.5%	–5.5%	$3.2	–$0.8
2037	$7	$19	5.5%	–5.5%	$3.2	–$0.8
NPV (3%)					$49.6	–$12.5
NPV (7%)					$29.5	–$7.3

[a] Figures are in 2005 dollars.

Table 9A-17: Impact on Small SI Equipment Market: Class II Snowblowers UL 250 (Average Price per Equipment = $665)[a]

	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	$1	$1	0.1%	–0.1%	$0.4	$0.0
2009	$1	$1	0.1%	–0.1%	$0.5	–$0.1
2010	$1	$1	0.1%	–0.1%	$0.4	$0.0
2011	$4	$4	0.5%	–0.5%	$2.3	–$0.2
2012	$4	$4	0.5%	–0.5%	$2.3	–$0.2
2013	$4	$4	0.5%	–0.5%	$2.3	–$0.2
2014	$4	$4	0.5%	–0.5%	$2.3	–$0.2
2015	$4	$4	0.5%	–0.5%	$2.4	–$0.2
2016	$3	$3	0.4%	–0.4%	$2.0	–$0.2
2017	$3	$3	0.4%	–0.4%	$2.1	–$0.2
2018	$3	$3	0.4%	–0.4%	$2.1	–$0.2
2019	$3	$3	0.4%	–0.4%	$2.1	–$0.2
2020	$3	$3	0.4%	–0.4%	$2.2	–$0.2
2021	$3	$3	0.4%	–0.4%	$2.2	–$0.2
2022	$3	$3	0.4%	–0.4%	$2.2	–$0.2
2023	$3	$3	0.4%	–0.4%	$2.3	–$0.2
2024	$3	$3	0.4%	–0.4%	$2.3	–$0.2
2025	$3	$3	0.4%	–0.4%	$2.3	–$0.2
2026	$3	$3	0.4%	–0.4%	$2.4	–$0.2
2027	$3	$3	0.4%	–0.4%	$2.4	–$0.2
2028	$3	$3	0.4%	–0.4%	$2.4	–$0.2
2029	$3	$3	0.4%	–0.4%	$2.5	–$0.2
2030	$3	$3	0.4%	–0.4%	$2.5	–$0.2
2031	$3	$3	0.4%	–0.4%	$2.5	–$0.2
2032	$3	$3	0.4%	–0.4%	$2.6	–$0.2
2033	$3	$3	0.4%	–0.4%	$2.6	–$0.2
2034	$3	$3	0.4%	–0.4%	$2.6	–$0.2
2035	$3	$3	0.4%	–0.4%	$2.6	–$0.2
2036	$3	$3	0.4%	–0.4%	$2.7	–$0.2
2037	$3	$3	0.4%	–0.4%	$2.7	–$0.3
NPV (3%)					$40.4	–$3.7
NPV (7%)					$23.7	–$2.2

[a] Figures are in 2005 dollars.

Appendix 9B: Impacts on Marine SI Markets

This appendix provides the time series of impacts from 2008 through 2037 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, 2008). 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 9B-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,b]

	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	$12	$10	0.4%	–0.8%	$0.8	–$0.2
2009	$12	$8	0.3%	–1.6%	$0.8	–$0.3
2010	$69	$54	2.2%	–5.5%	$4.7	–$1.0
2011	$69	$55	2.2%	–5.2%	$4.8	–$1.0
2012	$69	$55	2.2%	–5.2%	$4.8	–$1.0
2013	$69	$55	2.2%	–5.2%	$4.8	–$1.0
2014	$69	$55	2.2%	–5.2%	$4.9	–$1.0
2015	$55	$44	1.7%	–4.3%	$3.9	–$0.8
2016	$55	$44	1.7%	–4.3%	$3.9	–$0.8
2017	$55	$44	1.7%	–4.3%	$4.0	–$0.8
2018	$55	$44	1.7%	–4.3%	$4.0	–$0.8
2019	$55	$44	1.7%	–4.3%	$4.0	–$0.8
2020	$55	$44	1.7%	–4.3%	$4.1	–$0.8
2021	$55	$44	1.7%	–4.3%	$4.1	–$0.8
2022	$55	$44	1.7%	–4.3%	$4.1	–$0.9
2023	$55	$44	1.7%	–4.3%	$4.1	–$0.9
2024	$55	$44	1.7%	–4.3%	$4.2	–$0.9
2025	$55	$44	1.7%	–4.3%	$4.2	–$0.9
2026	$55	$44	1.7%	–4.3%	$4.2	–$0.9
2027	$55	$44	1.7%	–4.3%	$4.3	–$0.9
2028	$55	$44	1.7%	–4.3%	$4.3	–$0.9
2029	$55	$44	1.7%	–4.3%	$4.3	–$0.9
2030	$55	$44	1.7%	–4.3%	$4.3	–$0.9
2031	$55	$44	1.7%	–4.3%	$4.4	–$0.9
2032	$55	$44	1.7%	–4.3%	$4.4	–$0.9
2033	$55	$44	1.7%	–4.3%	$4.4	–$0.9
2034	$55	$44	1.7%	–4.3%	$4.4	–$0.9
2035	$55	$44	1.7%	–4.3%	$4.5	–$0.9
2036	$55	$44	1.7%	–4.3%	$4.5	–$0.9
2037	$55	$44	1.7%	–4.3%	$4.5	–$0.9
NPV (3%)					$78.2	–$16.1
NPV (7%)					$47.7	–$9.8

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-2: Impact on Marine SI Engine Market: 26–50hp (Average Price per Engine = $5,700)[a,b]

	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	$14	$12	0.2%	–0.2%	$0.7	–$0.1
2009	$14	$12	0.2%	–0.3%	$0.7	–$0.1
2010	$216	$198	3.5%	–3.0%	$11.0	–$0.9
2011	$216	$197	3.5%	–3.2%	$11.1	–$1.0
2012	$216	$196	3.4%	–3.4%	$11.2	–$1.0
2013	$216	$196	3.4%	–3.4%	$11.2	–$1.1
2014	$216	$196	3.4%	–3.4%	$11.3	–$1.1
2015	$173	$156	2.7%	–2.8%	$9.1	–$0.9
2016	$173	$156	2.7%	–2.8%	$9.2	–$0.9
2017	$173	$157	2.7%	–2.7%	$9.2	–$0.9
2018	$173	$157	2.7%	–2.7%	$9.3	–$0.9
2019	$173	$157	2.7%	–2.7%	$9.4	–$0.9
2020	$173	$157	2.7%	–2.7%	$9.4	–$0.9
2021	$173	$157	2.7%	–2.7%	$9.5	–$0.9
2022	$173	$157	2.7%	–2.7%	$9.6	–$0.9
2023	$173	$157	2.7%	–2.7%	$9.6	–$0.9
2024	$173	$157	2.7%	–2.7%	$9.7	–$0.9
2025	$173	$157	2.7%	–2.7%	$9.8	–$0.9
2026	$173	$157	2.7%	–2.7%	$9.8	–$0.9
2027	$173	$157	2.7%	–2.7%	$9.9	–$0.9
2028	$173	$157	2.7%	–2.7%	$9.9	–$0.9
2029	$173	$157	2.7%	–2.7%	$10.0	–$0.9
2030	$173	$157	2.7%	–2.7%	$10.1	–$0.9
2031	$173	$157	2.7%	–2.7%	$10.1	–$0.9
2032	$173	$157	2.7%	–2.7%	$10.2	–$1.0
2033	$173	$157	2.7%	–2.7%	$10.3	–$1.0
2034	$173	$157	2.7%	–2.7%	$10.3	–$1.0
2035	$173	$157	2.7%	–2.7%	$10.4	–$1.0
2036	$173	$157	2.7%	–2.7%	$10.5	–$1.0
2037	$173	$157	2.7%	–2.7%	$10.5	–$1.0
NPV (3%)					$179.6	–$16.6
NPV (7%)					$108.8	–$10.0

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-3: Impact on Marine SI Engine Market: 51–100hp (Average Price per Engine = $9,100)[a,b]

	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	$20	$18	0.2%	–0.2%	$1.5	$1.5
2009	$20	$18	0.2%	–0.2%	$1.5	$1.5
2010	$203	$188	2.1%	–1.5%	$15.5	$15.5
2011	$203	$187	2.1%	–1.7%	$15.6	$15.6
2012	$203	$185	2.0%	–1.8%	$15.7	$15.7
2013	$203	$185	2.0%	–1.8%	$15.8	$15.8
2014	$203	$185	2.0%	–1.8%	$15.9	$15.9
2015	$162	$148	1.6%	–1.5%	$12.8	$12.8
2016	$162	$148	1.6%	–1.5%	$12.9	$12.9
2017	$162	$148	1.6%	–1.5%	$13.0	$13.0
2018	$162	$148	1.6%	–1.5%	$13.1	$13.1
2019	$162	$148	1.6%	–1.5%	$13.2	$13.2
2020	$162	$148	1.6%	–1.5%	$13.3	$13.3
2021	$162	$148	1.6%	–1.5%	$13.4	$13.4
2022	$162	$148	1.6%	–1.5%	$13.4	$13.4
2023	$162	$148	1.6%	–1.5%	$13.5	$13.5
2024	$162	$148	1.6%	–1.5%	$13.6	$13.6
2025	$162	$148	1.6%	–1.5%	$13.7	$13.7
2026	$162	$148	1.6%	–1.5%	$13.8	$13.8
2027	$162	$148	1.6%	–1.5%	$13.9	$13.9
2028	$162	$148	1.6%	–1.5%	$14.0	$14.0
2029	$162	$148	1.6%	–1.5%	$14.1	$14.1
2030	$162	$148	1.6%	–1.5%	$14.2	$14.2
2031	$162	$148	1.6%	–1.5%	$14.3	$14.3
2032	$162	$148	1.6%	–1.5%	$14.3	$14.3
2033	$162	$148	1.6%	–1.5%	$14.4	$14.4
2034	$162	$148	1.6%	–1.5%	$14.5	$14.5
2035	$162	$148	1.6%	–1.5%	$14.6	$14.6
2036	$162	$148	1.6%	–1.5%	$14.7	$14.7
2037	$162	$148	1.6%	–1.5%	$14.8	$14.8
NPV (3%)					$253.5	–$21.6
NPV (7%)					$153.8	–$13.0

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-4: Impact on Marine SI Engine Market: 101–175hp (Average Price per Engine =$12,700)[a,b]

	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	$39	$36	0.3%	–0.2%	$2.6	–$0.2
2009	$39	$36	0.3%	–0.3%	$2.6	–$0.2
2010	$365	$338	2.7%	–2.0%	$24.7	–$1.8
2011	$365	$336	2.6%	–2.2%	$24.9	–$2.0
2012	$365	$333	2.6%	–2.4%	$25.1	–$2.2
2013	$365	$333	2.6%	–2.4%	$25.3	–$2.2
2014	$365	$333	2.6%	–2.4%	$25.5	–$2.2
2015	$292	$266	2.1%	–2.0%	$20.5	–$1.9
2016	$292	$266	2.1%	–2.0%	$20.7	–$1.8
2017	$292	$266	2.1%	–1.9%	$20.8	–$1.8
2018	$292	$266	2.1%	–1.9%	$20.9	–$1.8
2019	$292	$266	2.1%	–1.9%	$21.1	–$1.8
2020	$292	$266	2.1%	–1.9%	$21.2	–$1.9
2021	$292	$266	2.1%	–1.9%	$21.4	–$1.9
2022	$292	$266	2.1%	–1.9%	$21.5	–$1.9
2023	$292	$266	2.1%	–1.9%	$21.7	–$1.9
2024	$292	$266	2.1%	–1.9%	$21.8	–$1.9
2025	$292	$266	2.1%	–1.9%	$21.9	–$1.9
2026	$292	$266	2.1%	–1.9%	$22.1	–$1.9
2027	$292	$266	2.1%	–1.9%	$22.2	–$1.9
2028	$292	$266	2.1%	–1.9%	$22.4	–$1.9
2029	$292	$266	2.1%	–1.9%	$22.5	–$2.0
2030	$292	$266	2.1%	–1.9%	$22.7	–$2.0
2031	$292	$266	2.1%	–1.9%	$22.8	–$2.0
2032	$292	$266	2.1%	–1.9%	$23.0	–$2.0
2033	$292	$266	2.1%	–1.9%	$23.1	–$2.0
2034	$292	$266	2.1%	–1.9%	$23.2	–$2.0
2035	$292	$266	2.1%	–1.9%	$23.4	–$2.0
2036	$292	$266	2.1%	–1.9%	$23.5	–$2.0
2037	$292	$266	2.1%	–1.9%	$23.7	–$2.1
NPV (3%)					$406.1	–$34.9
NPV (7%)					$246.7	–$21.1

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-5: Impact on Marine SI Engine Market:
176–300hp (Average Price per Engine =$17,600)[a,b]

Year	Marine SI Engine (176–300hp) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers Surplus (million $)
2008	$59	$55	0.3%	–0.2%	$5.4	–$0.4
2009	$59	$54	0.3%	–0.2%	$5.5	–$0.4
2010	$517	$480	2.7%	–1.7%	$48.3	–$3.4
2011	$517	$477	2.7%	–1.9%	$48.6	–$3.7
2012	$517	$474	2.7%	–2.0%	$49.0	–$4.0
2013	$517	$474	2.7%	–2.0%	$49.3	–$4.1
2014	$517	$474	2.7%	–2.0%	$49.7	–$4.1
2015	$414	$378	2.1%	–1.7%	$40.0	–$3.4
2016	$414	$379	2.2%	–1.7%	$40.3	–$3.4
2017	$414	$379	2.2%	–1.6%	$40.6	–$3.4
2018	$414	$379	2.2%	–1.6%	$40.9	–$3.4
2019	$414	$379	2.2%	–1.6%	$41.2	–$3.4
2020	$414	$379	2.2%	–1.6%	$41.4	–$3.5
2021	$414	$379	2.2%	–1.6%	$41.7	–$3.5
2022	$414	$379	2.2%	–1.6%	$42.0	–$3.5
2023	$414	$379	2.2%	–1.6%	$42.3	–$3.5
2024	$414	$379	2.2%	–1.6%	$42.6	–$3.5
2025	$414	$379	2.2%	–1.6%	$42.8	–$3.6
2026	$414	$379	2.2%	–1.6%	$43.1	–$3.6
2027	$414	$379	2.2%	–1.6%	$43.4	–$3.6
2028	$414	$379	2.2%	–1.6%	$43.7	–$3.6
2029	$414	$379	2.2%	–1.6%	$44.0	–$3.7
2030	$414	$379	2.2%	–1.6%	$44.2	–$3.7
2031	$414	$379	2.2%	–1.6%	$44.5	–$3.7
2032	$414	$379	2.2%	–1.6%	$44.8	–$3.7
2033	$414	$379	2.2%	–1.6%	$45.1	–$3.8
2034	$414	$379	2.2%	–1.6%	$45.4	–$3.8
2035	$414	$379	2.2%	–1.6%	$45.7	–$3.8
2036	$414	$379	2.2%	–1.6%	$45.9	–$3.8
2037	$414	$379	2.2%	–1.6%	$46.2	–$3.9
NPV (3%)					$793.5	–$65.0
NPV (7%)					$482.1	–$39.2

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-6: Impact on Marine SI Engine Market:
300+ hp (Average Price per Engine = $22,000)[a,b]

	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	$57	$54	0.2%	–0.1%	$2.1	–$0.1
2009	$57	$54	0.2%	–0.1%	$2.1	–$0.1
2010	$297	$283	1.3%	–0.6%	$11.1	–$0.5
2011	$297	$280	1.3%	–0.8%	$11.2	–$0.6
2012	$297	$276	1.3%	–1.0%	$11.3	–$0.8
2013	$297	$276	1.3%	–1.0%	$11.4	–$0.8
2014	$297	$276	1.3%	–1.0%	$11.5	–$0.8
2015	$238	$220	1.0%	–0.8%	$9.2	–$0.7
2016	$238	$220	1.0%	–0.8%	$9.3	–$0.7
2017	$238	$221	1.0%	–0.8%	$9.4	–$0.7
2018	$238	$221	1.0%	–0.8%	$9.4	–$0.7
2019	$238	$221	1.0%	–0.8%	$9.5	–$0.7
2020	$238	$221	1.0%	–0.8%	$9.6	–$0.7
2021	$238	$221	1.0%	–0.8%	$9.6	–$0.7
2022	$238	$221	1.0%	–0.8%	$9.7	–$0.7
2023	$238	$221	1.0%	–0.8%	$9.8	–$0.7
2024	$238	$221	1.0%	–0.8%	$9.8	–$0.7
2025	$238	$221	1.0%	–0.8%	$9.9	–$0.7
2026	$238	$221	1.0%	–0.8%	$10.0	–$0.7
2027	$238	$221	1.0%	–0.8%	$10.0	–$0.7
2028	$238	$221	1.0%	–0.8%	$10.1	–$0.7
2029	$238	$221	1.0%	–0.8%	$10.1	–$0.7
2030	$238	$221	1.0%	–0.8%	$10.2	–$0.7
2031	$238	$221	1.0%	–0.8%	$10.3	–$0.7
2032	$238	$221	1.0%	–0.8%	$10.3	–$0.8
2033	$238	$221	1.0%	–0.8%	$10.4	–$0.8
2034	$238	$221	1.0%	–0.8%	$10.5	–$0.8
2035	$238	$221	1.0%	–0.8%	$10.5	–$0.8
2036	$238	$221	1.0%	–0.8%	$10.6	–$0.8
2037	$238	$221	1.0%	–0.8%	$10.7	–$0.8
NPV (3%)					$184.7	–$12.8
NPV (7%)					$112.8	–$7.7

[a] Figures are in 2005 dollars.

[b] Average price per engine is a weighted average price of engine by equipment type.

Table 9B-7: Impact on Marine Vessels Market:
SD/I Recreational 175–300 hp (Average Price per Equipment = $32,356)[a]

	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	$2	$33	0.1%	–0.2%	$0.1	–$0.6
2009	$6	$35	0.1%	–0.2%	$0.2	–$0.6
2010	$5	$205	0.6%	–1.3%	$0.2	–$3.6
2011	$44	$230	0.7%	–1.4%	$1.5	–$4.1
2012	$94	$261	0.8%	–1.6%	$3.2	–$4.7
2013	$94	$261	0.8%	–1.6%	$3.2	–$4.7
2014	$94	$261	0.8%	–1.6%	$3.3	–$4.8
2015	$94	$220	0.7%	–1.4%	$3.3	–$4.0
2016	$87	$216	0.7%	–1.3%	$3.0	–$4.0
2017	$81	$212	0.7%	–1.3%	$2.8	–$3.9
2018	$81	$212	0.7%	–1.3%	$2.9	–$4.0
2019	$81	$212	0.7%	–1.3%	$2.9	–$4.0
2020	$81	$212	0.7%	–1.3%	$2.9	–$4.0
2021	$81	$212	0.7%	–1.3%	$2.9	–$4.1
2022	$81	$212	0.7%	–1.3%	$2.9	–$4.1
2023	$81	$212	0.7%	–1.3%	$3.0	–$4.1
2024	$81	$212	0.7%	–1.3%	$3.0	–$4.1
2025	$81	$212	0.7%	–1.3%	$3.0	–$4.2
2026	$81	$212	0.7%	–1.3%	$3.0	–$4.2
2027	$81	$212	0.7%	–1.3%	$3.0	–$4.2
2028	$81	$212	0.7%	–1.3%	$3.1	–$4.2
2029	$81	$212	0.7%	–1.3%	$3.1	–$4.3
2030	$81	$212	0.7%	–1.3%	$3.1	–$4.3
2031	$81	$212	0.7%	–1.3%	$3.1	–$4.3
2032	$81	$212	0.7%	–1.3%	$3.1	–$4.4
2033	$81	$212	0.7%	–1.3%	$3.2	–$4.4
2034	$81	$212	0.7%	–1.3%	$3.2	–$4.4
2035	$81	$212	0.7%	–1.3%	$3.2	–$4.4
2036	$81	$212	0.7%	–1.3%	$3.2	–$4.5
2037	$81	$212	0.7%	–1.3%	$3.2	–$4.5
NPV (3%)					$50.5	–$75.6
NPV (7%)					$29.2	–$45.6

[a] Figures are in 2005 dollars.

Table 9B-8: Impact on Marine Vessels Market: SD/I Luxury 300+ hp (Average Price per Equipment = $205,658)[a]

Year	Marine Vessel (SD/I Luxury 300+ hp) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$2	$56	0.0%	–0.1%	$0.0	–$0.2
2009	$10	$61	0.0%	–0.1%	$0.1	–$0.3
2010	$8	$291	0.1%	–0.3%	$0.1	–$1.3
2011	$108	$354	0.2%	–0.3%	$0.9	–$1.6
2012	$236	$435	0.2%	–0.4%	$2.0	–$1.9
2013	$236	$435	0.2%	–0.4%	$2.0	–$1.9
2014	$236	$435	0.2%	–0.4%	$2.0	–$2.0
2015	$236	$378	0.2%	–0.4%	$2.0	–$1.7
2016	$216	$365	0.2%	–0.4%	$1.9	–$1.7
2017	$206	$359	0.2%	–0.3%	$1.8	–$1.6
2018	$206	$359	0.2%	–0.3%	$1.8	–$1.7
2019	$206	$359	0.2%	–0.3%	$1.8	–$1.7
2020	$206	$359	0.2%	–0.3%	$1.8	–$1.7
2021	$206	$359	0.2%	–0.3%	$1.8	–$1.7
2022	$206	$359	0.2%	–0.3%	$1.8	–$1.7
2023	$206	$359	0.2%	–0.3%	$1.9	–$1.7
2024	$206	$359	0.2%	–0.3%	$1.9	–$1.7
2025	$206	$359	0.2%	–0.3%	$1.9	–$1.7
2026	$206	$359	0.2%	–0.3%	$1.9	–$1.7
2027	$206	$359	0.2%	–0.3%	$1.9	–$1.8
2028	$206	$359	0.2%	–0.3%	$1.9	–$1.8
2029	$206	$359	0.2%	–0.3%	$1.9	–$1.8
2030	$206	$359	0.2%	–0.3%	$1.9	–$1.8
2031	$206	$359	0.2%	–0.3%	$2.0	–$1.8
2032	$206	$359	0.2%	–0.3%	$2.0	–$1.8
2033	$206	$359	0.2%	–0.3%	$2.0	–$1.8
2034	$206	$359	0.2%	–0.3%	$2.0	–$1.8
2035	$206	$359	0.2%	–0.3%	$2.0	–$1.9
2036	$206	$359	0.2%	–0.3%	$2.0	–$1.9
2037	$206	$359	0.2%	–0.3%	$2.0	–$1.9
NPV (3%)					$31.3	–$31.1
NPV (7%)					$18.0	–$18.6

[a] Figures are in 2005 dollars.

Table 9B-9: Impact on Marine Vessels Market:
OB Recreational 50–100 hp (Average Price per Equipment = $21,561)[a]

	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	$2	$16	0.1%	–0.2%	$0.1	$0.0
2009	$10	$21	0.1%	–0.2%	$0.6	–$0.2
2010	$9	$165	0.8%	–1.5%	$0.5	–$0.2
2011	$35	$181	0.8%	–1.7%	$2.1	–$0.7
2012	$62	$197	0.9%	–1.8%	$3.7	–$1.3
2013	$62	$197	0.9%	–1.8%	$3.7	–$1.3
2014	$62	$197	0.9%	–1.8%	$3.7	–$1.3
2015	$62	$165	0.8%	–1.5%	$3.8	–$1.3
2016	$56	$162	0.8%	–1.5%	$3.5	–$1.2
2017	$50	$158	0.7%	–1.5%	$3.1	–$1.1
2018	$50	$158	0.7%	–1.5%	$3.1	–$1.1
2019	$50	$158	0.7%	–1.5%	$3.1	–$1.1
2020	$50	$158	0.7%	–1.5%	$3.2	–$1.1
2021	$50	$158	0.7%	–1.5%	$3.2	–$1.1
2022	$50	$158	0.7%	–1.5%	$3.2	–$1.1
2023	$50	$158	0.7%	–1.5%	$3.2	–$1.1
2024	$50	$158	0.7%	–1.5%	$3.2	–$1.1
2025	$50	$158	0.7%	–1.5%	$3.3	–$1.1
2026	$50	$158	0.7%	–1.5%	$3.3	–$1.1
2027	$50	$158	0.7%	–1.5%	$3.3	–$1.1
2028	$50	$158	0.7%	–1.5%	$3.3	–$1.1
2029	$50	$158	0.7%	–1.5%	$3.3	–$1.2
2030	$50	$158	0.7%	–1.5%	$3.4	–$1.2
2031	$50	$158	0.7%	–1.5%	$3.4	–$1.2
2032	$50	$158	0.7%	–1.5%	$3.4	–$1.2
2033	$50	$158	0.7%	–1.5%	$3.4	–$1.2
2034	$50	$158	0.7%	–1.5%	$3.5	–$1.2
2035	$50	$158	0.7%	–1.5%	$3.5	–$1.2
2036	$50	$158	0.7%	–1.5%	$3.5	–$1.2
2037	$50	$158	0.7%	–1.5%	$3.5	–$1.2
NPV (3%)					$56.6	–$19.5
NPV (7%)					$33.3	–$11.4

[a] Figures are in 2005 dollars.

Table 9B-10: Impact on Marine Vessels Market: OB Luxury 175–300 hp (Average Price per Equipment = $104,562)[a]

Year	Marine Vessel (OB Luxury 175–300 hp) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$3	$98	0.1%	–0.2%	$0.0	–$0.2
2009	$26	$111	0.1%	–0.2%	$0.1	–$0.2
2010	$23	$1,009	1.0%	–1.9%	$0.1	–$1.9
2011	$145	$1,079	1.0%	–2.1%	$0.5	–$2.0
2012	$267	$1,150	1.1%	–2.2%	$0.9	–$2.1
2013	$267	$1,150	1.1%	–2.2%	$1.0	–$2.2
2014	$267	$1,150	1.1%	–2.2%	$1.0	–$2.2
2015	$267	$951	0.9%	–1.8%	$1.0	–$1.8
2016	$243	$937	0.9%	–1.8%	$0.9	–$1.8
2017	$227	$928	0.9%	–1.8%	$0.8	–$1.8
2018	$227	$928	0.9%	–1.8%	$0.8	–$1.8
2019	$227	$928	0.9%	–1.8%	$0.8	–$1.8
2020	$227	$928	0.9%	–1.8%	$0.8	–$1.8
2021	$227	$928	0.9%	–1.8%	$0.9	–$1.8
2022	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2023	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2024	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2025	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2026	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2027	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2028	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2029	$227	$928	0.9%	–1.8%	$0.9	–$1.9
2030	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2031	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2032	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2033	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2034	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2035	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2036	$227	$928	0.9%	–1.8%	$0.9	–$2.0
2037	$227	$928	0.9%	–1.8%	$0.9	–$2.0
NPV (3%)					$14.9	–$34.4
NPV (7%)					$8.7	–$20.8

[a] Figures are in 2005 dollars.

Table 9B-11: Impact on Marine Vessels Market:
PWC 100–175 hp (Average Price per Equipment = $9,982)[a]

Year	Marine Vessel (PWC 100–175 hp) Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers Surplus (million $)
2008	$35	$25	0.3%	–0.5%	$1.9	–$0.5
2009	$53	$38	0.4%	–0.8%	$2.9	–$0.8
2010	$103	$74	0.7%	–1.5%	$5.7	–$1.6
2011	$96	$69	0.7%	–1.4%	$5.3	–$1.5
2012	$96	$69	0.7%	–1.4%	$5.4	–$1.5
2013	$96	$69	0.7%	–1.4%	$5.4	–$1.5
2014	$96	$69	0.7%	–1.4%	$5.5	–$1.5
2015	$79	$57	0.6%	–1.1%	$4.5	–$1.3
2016	$79	$57	0.6%	–1.1%	$4.6	–$1.3
2017	$79	$57	0.6%	–1.1%	$4.6	–$1.3
2018	$79	$57	0.6%	–1.1%	$4.6	–$1.3
2019	$79	$57	0.6%	–1.1%	$4.6	–$1.3
2020	$79	$57	0.6%	–1.1%	$4.7	–$1.3
2021	$79	$57	0.6%	–1.1%	$4.7	–$1.3
2022	$79	$57	0.6%	–1.1%	$4.7	–$1.3
2023	$79	$57	0.6%	–1.1%	$4.8	–$1.3
2024	$79	$57	0.6%	–1.1%	$4.8	–$1.3
2025	$79	$57	0.6%	–1.1%	$4.8	–$1.3
2026	$79	$57	0.6%	–1.1%	$4.9	–$1.4
2027	$79	$57	0.6%	–1.1%	$4.9	–$1.4
2028	$79	$57	0.6%	–1.1%	$4.9	–$1.4
2029	$79	$57	0.6%	–1.1%	$5.0	–$1.4
2030	$79	$57	0.6%	–1.1%	$5.0	–$1.4
2031	$79	$57	0.6%	–1.1%	$5.0	–$1.4
2032	$79	$57	0.6%	–1.1%	$5.1	–$1.4
2033	$79	$57	0.6%	–1.1%	$5.1	–$1.4
2034	$79	$57	0.6%	–1.1%	$5.1	–$1.4
2035	$79	$57	0.6%	–1.1%	$5.2	–$1.4
2036	$79	$57	0.6%	–1.1%	$5.2	–$1.4
2037	$79	$57	0.6%	–1.1%	$5.2	–$1.4
NPV (3%)					$92.7	–$25.6
NPV (7%)					$57.4	–$15.8

[a] Figures are in 2005 dollars.

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 2037. 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 the 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	–$46.3	–$109.2	–$224.9	–$272.1	–$372.8	–$376.1	–$380.2	–$349.8	–$348.1	–$338.8	–$343.2
Marine SI											
End users (households)	–$13.2	–$15.8	–$113.2	–$120.0	–$128.2	–$129.1	–$130.0	–$108.5	–$107.9	–$107.5	–$108.2
Small SI											
End users (households)	–$33.1	–$93.4	–$111.7	–$152.1	–$244.6	–$247.0	–$250.2	–$241.4	–$240.2	–$231.3	–$235.0
Producer Surplus Change, Total	–$7.5	–$17.0	–$42.5	–$52.0	–$62.7	–$63.2	–$63.6	–$57.0	–$56.1	–$55.0	–$55.6
Marine SI	–$4.1	–$5.7	–$30.2	–$34.5	–$39.6	–$39.9	–$40.2	–$34.7	–$34.0	–$33.5	–$33.7
Engine manufacturers	–$1.0	–$1.3	–$8.8	–$9.5	–$10.3	–$10.4	–$10.5	–$8.8	–$8.7	–$8.7	–$8.7
Equipment manufacturers	–$3.1	–$4.4	–$21.4	–$25.0	–$29.3	–$29.5	–$29.7	–$25.9	–$25.3	–$24.8	–$25.0
Small SI	–$3.4	–$11.3	–$12.3	–$17.5	–$23.1	–$23.3	–$23.4	–$22.3	–$22.1	–$21.5	–$21.9
Engine manufacturers	–$0.6	–$1.7	–$2.1	–$3.0	–$5.3	–$5.3	–$5.4	–$5.2	–$5.1	–$4.9	–$5.0
Equipment manufacturers	–$2.9	–$9.6	–$10.2	–$14.5	–$17.8	–$18.0	–$18.1	–$17.2	–$16.9	–$16.6	–$16.9
Fuel Savings	$3.2	$8.1	$19.6	$43.9	$70.8	$95.7	$115.9	$134.3	$150.9	$165.3	$178.3
Consumer savings	$3.9	$9.8	$23.8	$53.3	$86.0	$116.3	$140.8	$163.2	$183.3	$200.8	$216.6
Fuel	$3.2	$8.1	$19.6	$43.9	$70.8	$95.7	$115.9	$134.3	$150.9	$165.3	$178.3
Tax	$0.7	$1.7	$4.2	$9.4	$15.2	$20.6	$24.9	$28.9	$32.4	$35.5	$38.3
Government revenue	–$0.7	–$1.7	–$4.2	–$9.4	–$15.2	–$20.6	–$24.9	–$28.9	–$32.4	–$35.5	–$38.3
Total Surplus Change	–$50.6	–$118.1	–$247.8	–$280.2	–$364.7	–$343.6	–$327.9	–$272.5	–$253.3	–$228.5	–$220.5

(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	–$347.6	–$352.0	–$356.4	–$360.8	–$365.2	–$369.6	–$374.0	–$378.4	–$382.8	–$387.2	–$391.7
Marine SI											
End users (households)	–$109.0	–$109.7	–$110.5	–$111.2	–$112.0	–$112.7	–$113.4	–$114.2	–$114.9	–$115.7	–$116.4
Small SI											
End users (households)	–$238.6	–$242.3	–$245.9	–$249.6	–$253.2	–$256.9	–$260.5	–$264.2	–$267.9	–$271.6	–$275.2
Producer Surplus Change, Total	–$56.2	–$56.7	–$57.3	–$57.9	–$58.5	–$59.0	–$59.6	–$60.2	–$60.7	–$61.3	–$61.9
Marine SI	–$34.0	–$34.2	–$34.4	–$34.7	–$34.9	–$35.1	–$35.4	–$35.6	–$35.8	–$36.1	–$36.3
Engine manufacturers	–$8.8	–$8.8	–$8.9	–$9.0	–$9.0	–$9.1	–$9.1	–$9.2	–$9.3	–$9.3	–$9.4
Equipment manufacturers	–$25.2	–$25.4	–$25.5	–$25.7	–$25.9	–$26.0	–$26.2	–$26.4	–$26.6	–$26.7	–$26.9
Small SI	–$22.2	–$22.5	–$22.9	–$23.2	–$23.6	–$23.9	–$24.2	–$24.6	–$24.9	–$25.3	–$25.6
Engine manufacturers	–$5.1	–$5.1	–$5.2	–$5.3	–$5.4	–$5.4	–$5.5	–$5.6	–$5.7	–$5.8	–$5.8
Equipment manufacturers	–$17.1	–$17.4	–$17.7	–$17.9	–$18.2	–$18.5	–$18.7	–$19.0	–$19.2	–$19.5	–$19.8
Fuel Savings	$190.4	$201.4	$211.1	$220.5	$229.3	$237.1	$244.2	$250.8	$256.9	$262.7	$268.1
Consumer savings	$231.3	$244.6	$256.5	$267.9	$278.6	$288.1	$296.7	$304.7	$312.2	$319.2	$325.7
Fuel	$190.4	$201.4	$211.1	$220.5	$229.3	$237.1	$244.2	$250.8	$256.9	$262.7	$268.1
Tax	$40.9	$43.3	$45.4	$47.4	$49.3	$51.0	$52.5	$53.9	$55.2	$56.5	$57.6
Government revenue	–$40.9	–$43.3	–$45.4	–$47.4	–$49.3	–$51.0	–$52.5	–$53.9	–$55.2	–$56.5	–$57.6
Total Surplus Change	–$213.4	–$207.4	–$202.6	–$198.2	–$194.3	–$191.5	–$189.3	–$187.8	–$186.6	–$185.8	–$185.4

(continued)

Table 9C: Time Series Projection of Social Costs (million $) (continued)

	2030	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**NPV (3%)**	**NPV (7%)**
Consumer Surplus Change, Total	–$396.1	–$400.5	–$404.9	–$409.4	–$413.8	–$418.2	–$422.6	–$427.1	–$6,551.1	–$3,869.9
Marine SI										
End users (households)	–$117.2	–$117.9	–$118.7	–$119.4	–$120.2	–$120.9	–$121.7	–$122.4	–$2,079.0	–$1,257.1
Small SI										
End users (households)	–$278.9	–$282.6	–$286.3	–$290.0	–$293.6	–$297.3	–$301.0	–$304.7	–$4,472.1	–$2,612.8
Producer Surplus Change, Total	–$62.5	–$63.0	–$63.6	–$64.2	–$64.8	–$65.3	–$65.9	–$66.5	–$1,065.5	–$636.3
Marine SI	–$36.5	–$36.8	–$37.0	–$37.2	–$37.5	–$37.7	–$37.9	–$38.2	–$641.5	–$386.1
Engine manufacturers	–$9.4	–$9.5	–$9.6	–$9.6	–$9.7	–$9.7	–$9.8	–$9.9	–$167.0	–$100.8
Equipment manufacturers	–$27.1	–$27.3	–$27.4	–$27.6	–$27.8	–$27.9	–$28.1	–$28.3	–$474.5	–$285.2
Small SI	–$26.0	–$26.3	–$26.6	–$27.0	–$27.3	–$27.7	–$28.0	–$28.4	–$424.0	–$250.2
Engine manufacturers	–$5.9	–$6.0	–$6.1	–$6.2	–$6.2	–$6.3	–$6.4	–$6.5	–$94.1	–$54.8
Equipment manufacturers	–$20.0	–$20.3	–$20.6	–$20.8	–$21.1	–$21.4	–$21.6	–$21.9	–$329.9	–$195.4
Fuel Savings	$273.0	$277.6	$281.9	$285.8	$289.6	$293.3	$296.7	$300.1	$3,374.6	$1,774.7
Consumer savings	$331.7	$337.3	$342.5	$347.3	$351.9	$356.3	$360.5	$364.6	$4,100.2	$2,156.3
Fuel	$273.0	$277.6	$281.9	$285.8	$289.6	$293.3	$296.7	$300.1	$3,374.6	$1,774.7
Tax	$58.7	$59.7	$60.6	$61.5	$62.3	$63.1	$63.8	$64.5	$725.5	$381.6
Government revenue	–$58.7	–$59.7	–$60.6	–$61.5	–$62.3	–$63.1	–$63.8	–$64.5	–$725.5	–$381.6
Total Surplus Change	–$185.5	–$185.9	–$186.7	–$187.7	–$188.9	–$190.3	–$191.8	–$193.5	–$4,242.0	–$2,731.4

[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:

$$\varepsilon_s \equiv \frac{dQ_s / Q_s}{dp / p}. \qquad (9D.1)$$

Next, we can use "hat" notation to transform Eq. (C.1) to proportional changes and rearrange terms:

$$\hat{Q}_s = \varepsilon_s \hat{p} \qquad (9D.1a)$$

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 Metcalf (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 competitive market (price equals marginal cost), we can approximate this shift at the initial equilibrium point as follows:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o}. \qquad (9D.2)$$

The with-regulation supply response to price and cost changes can now be written as:

$$\hat{Q}_s = \varepsilon_s (\hat{p} - \hat{MC}) \qquad (9D.3)$$

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:

$$\hat{MC} = \frac{c + \alpha(\Delta p_{engine})}{MC_o} = \frac{c + \alpha(\Delta p_{engine})}{p_o} \qquad (9D.3a)$$

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 α = 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:

$$\hat{Q}_d = \eta_d \hat{p} \qquad (9D.4)$$

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:

$$\hat{Q}_d engines = \hat{Q}_s equipment \qquad (9D.5)$$

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:

$$\hat{Q}_d = \hat{Q}_s \qquad (9D.6)$$

9D.2 Computing With-Regulation Equilibrium Conditions

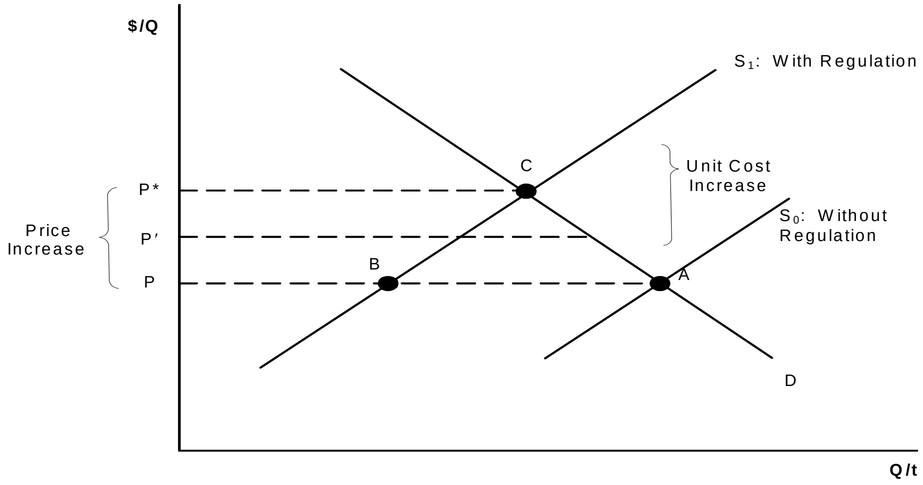
The choice of efficient model solution algorithms depends on several factors such as the number of markets included in the economic model, complexity of interactions between consumers and producers within these markets, and the software used to construct the model. To find the new market equilibrium 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.

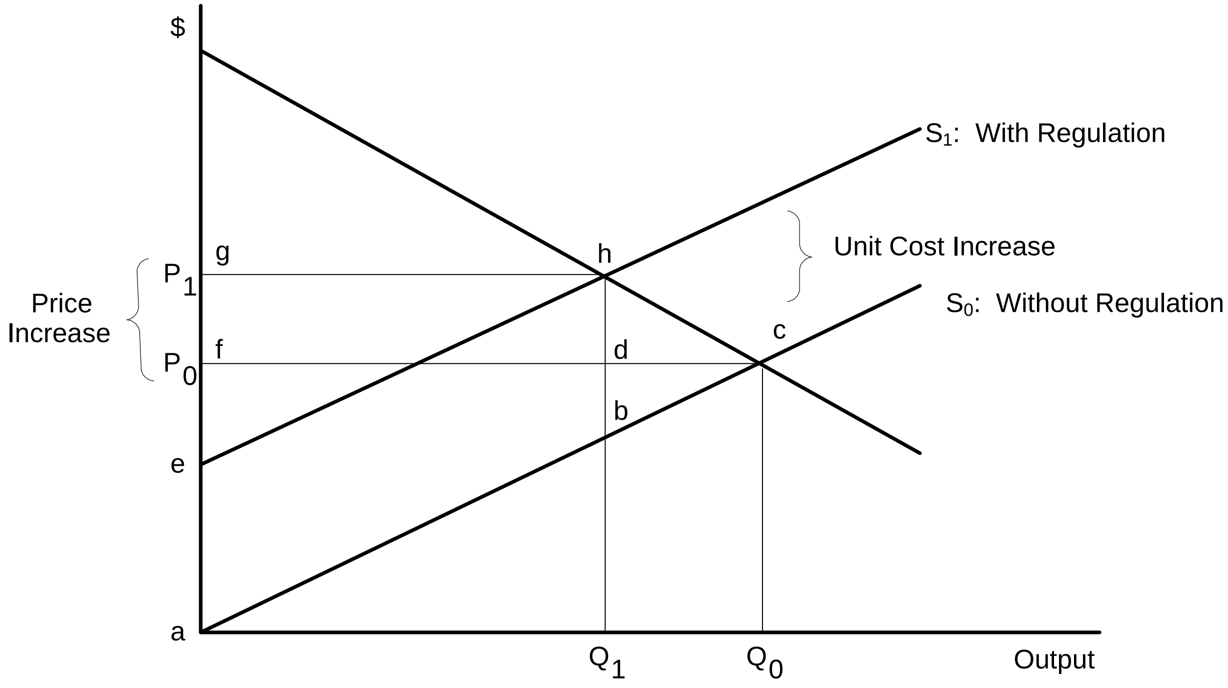
For affected supply, the change in producer surplus can be estimated with the following equation:

$$\Delta PS = Q_1 \bullet (\Delta p - c) - 0.5 \bullet \Delta Q \bullet (\Delta p - c). \tag{9D.9}$$

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change ($\Delta p - c$) 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	3.8	EPA econometric estimate Table 9E-4	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 336612
PWC	5.2	EPA econometric estimate Table 9E-5	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 336999
Small SI				
All lawn and garden equipment	10.0	EPA econometric estimate Table 9E-6	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 333112
Gensets/welders	8.8	EPA econometric estimate Table 9E-7	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 335312
All Engines	9.5	EPA econometric estimate Table 9E-3	Cobb-Douglas production function	Census of Manufacture, US Census Bureau; five years between 1972 and 1997; NAICS 333618

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); Manufacturing Industry Data from US Census Bureau:; 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-step approach to estimate the price elasticity of supply[14]. 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 manufacturers follow the Cobb-Douglas production function with a stochastic error term $U_{i\,t} \sim N(0, \sigma^2)$, recognizing that we have observations on plant i at time t

$$Q_{i\,t} = A_t\,(K_{i\,t})^{\alpha_K}\,(L_{i\,t})^{\alpha_L}\,(M_{i\,t})^{\alpha_M}\,e_{i\,t}^{U} \qquad (9E.1)$$

where

$Q_{i\,t}$ = total value of shipment on plant i at time t,
$K_{i\,t}$ = total capital stock, including both structure and equipment, on plant i at time t,
$L_{i\,t}$ = total plant hours on plant i at time t, and
M_{it} = cost of materials on plant i at time t.

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:

$$\ln Q_{i\,t} = \ln A_t + \alpha_K \ln K_{i\,t} + \alpha_L \ln L_{i\,t} + \alpha_M \ln M_{i\,t} + U_{i\,t} \qquad (E9.2)$$

Under the assumptions of a competitive market, 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:[15]

$$\text{Supply Elasticity} = (\alpha_L + \alpha_M) / (1 - \alpha_L - \alpha_M). \qquad (9E.3)$$

Our main regressions were carried out imposing the constant returns to scale assumption ($\alpha K+\alpha L+\alpha M=1$). We also tested regressions that did not constrain the three α parameters, and obtained very similar estimates for the parameters. The estimated returns to scale, given by the sum of the three α parameters, ranges from 1.01 to 1.03, supporting the assumption of constant returns. We estimate these regressions with and without including the dummies for single-plant firm and large plant. Table 9E-3 to Table 9E-7 present the estimated production function

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[14] Please refer to Supply Elasticity Estimation Report, Li, Chi. May 19, 2008. Memorandum to Docket EPA-HQ-OAR-2004-0008.

[15] Appendix 9F provides the derivation of this result.

coefficients for the five industries including the dummies for single-plant firm and large plant.

9E.1.1 Data Sets

The data used to estimate these elasticities comes from Census of Manufactures, conducted by the Census Bureau every five years between 1972 and 1997. We had access to the plant-level data at the Boston Census Research Data Center, and gathered data for all plants that were identified as belonging to the five industries being studied. The Census data provided us with information on output as measured by TVS (Plant's Total Value of Shipments), employment as measured by PH (Total Plant Hours), materials as measured by CM (Cost of Materials), and capital stock as measured by CAP (Total Capital Stock, including both Structure and Equipment) - the capital stock data are only available through 1997, which is why we do not include 2002 Census of Manufactures data in our analysis.

Based on comments from reviewers of an earlier supply elasticity analysis done for three other industries, we added two additional variables to the regression analysis, to control for possible differences across plants in their productivity levels. SINGLE is a dummy variable, indicating that the plant's firm owns no other manufacturing plants (a single-plant firm). BIG is a dummy variable, indicating that this plant has a number of employees larger than the median value for all other plants in this industry (approximately 50% of the plants in an industry should have BIG=1).

The data were examined in detail to identify outliers, measured in terms of unusual ratios between the values (e.g. unusually high or low shipments per worker hour, relative to the other plants in the industry) or unusual swings from one observation to the next. Those cases were then adjusted, based on their values in surrounding years or on the ratios between variables for other plants in the same industry, to avoid biasing the results while retaining all observations for the analysis.

One potential complication in working with the Census of Manufactures over this time period is the considerable change in industry definitions in 1997, when the Census Bureau shifted from SIC (Standard Industry Classification) codes to NAICS (North American Industry Classification System) codes. For these five industries there were some definitional concerns, but we were able to solve them reasonably accurately using a combination of SIC and NAICS industry codes and detailed product codes.

9E.1.2 Results of Supply Elasticity Estimation

By pooling data at establishment or plant level on selected years, we applied ordinary least square (OLS) procedure to estimate Eq. (9E.2) with two additional dummy variables. As shown in Tables 9E-3 through 9E-7, supply elasticity estimates for Small SI products range from 3.76 (Boat Building) to 9.96 (Lawn & Garden Equipment).

Table 9E-3: Gasoline Engines: NAICS 333618 (SIC 3519) Internal Combustion Engines, Not Elsewhere Classified.

Number of Observations = 1454
Root Mean Square Error = 0.316

Supply Elasticity = 9.46

Variable	**Estimated Coefficients**	**t-statistic**
intercept	1.930	22.3
SINGLE	-0.120	- 4.4
BIG	0.059	2.1
ln K	0.096	4.6
ln L	0.284	13.1
ln M	0.621	27.0

Table 9E-4: Gasoline-Powered Boats: NAICS 336612 (SIC 3732) Boat Building and Repairing.

Number of Observations = 10521
Root Mean Square Error = 0.239

Supply Elasticity = 3.76

Variable	**Estimated Coefficients**	**t-statistic**
intercept	1.201	43.7
SINGLE	-0.045	-4.0
BIG	0.113	18.6
ln K	0.210	14.4
ln L	0.141	15.8
ln M	0.650	45.3

Table 9E-5: PWCs, ATVs, Snowmobiles: NAICS 336999 (SIC 3799) Transportation Equipment, Not Elsewhere Classified.

Number of Observations = 2326
Total R-square = 0.237

Supply Elasticity = 5.20

Variable	Estimated Coefficients	t-statistic
intercept	1.323	13.9
SINGLE	-0.069	-3.1
BIG	0.072	7.0
ln K	0.161	7.0
ln L	0.184	9.9
ln M	0.654	19.2

Table 9E-6: Small Handheld/Nonhandheld: NAICS 333112 (SIC 3524) Lawn and Garden Tractors and Home Lawn and Garden Equipment.

Number of Observations = 839
Root Mean Square Error = 0.232

Supply Elasticity = 9.96

Variable	Estimated Coefficients	t-statistic
intercept	1.162	12.3
SINGLE	-0.012	-0.5
BIG	0.033	1.3
ln K	0.091	4.5
ln L	0.156	7.3
ln M	0.753	23.4

Table 9E-7: Gensets and Marine Generators: NAICS 335312 (SIC 3621) Motors and Generators.

Number of Observations = 2681
Root Mean Square Error = 0.288

Supply Elasticity = 8.79

Variable	**Estimated Coefficients**	**t-statistic**
intercept	1.812	30.8
SINGLE	-0.096	-5.3
BIG	-0.041	-2.3
ln K	0.102	7.3
ln L	0.242	15.4
ln M	0.655	33.7

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

Dependent Variable-Regression	**Units Produced** **Small Generators (<5kW)**	**Units Produced** **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 final 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,

$$Q = L^{\alpha} K^{1-\alpha} \qquad (9F.1)$$

where Q = output, L = labor input, and K = capital input. The cost function is written as

$$TC = wL + rK \qquad (9F.2)$$

where w = wage rate or unit labor cost, r = interest cost or unit capital cost. From equation (9F.1), L can be written as,

$$L = Q^{1/\alpha} K^{(\alpha-1)/\alpha} \qquad (9F.3)$$

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

$$Q = (\alpha/w)^{\alpha/(1-\alpha)}\ P^{\alpha/(1-\alpha)}\ K \qquad (9F.4)$$

Taking log function on both sides,

$$\ln Q = \alpha/(1-\alpha)\ln(\alpha/w) + \alpha/(1-\alpha)\ln P + \ln K \qquad (9F.5)$$

The price elasticity of supply can be written as

$$Supply\ elasticity = \partial \ln Q/\partial \ln P = \alpha/(1-\alpha) \qquad (9F.6)$$

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.

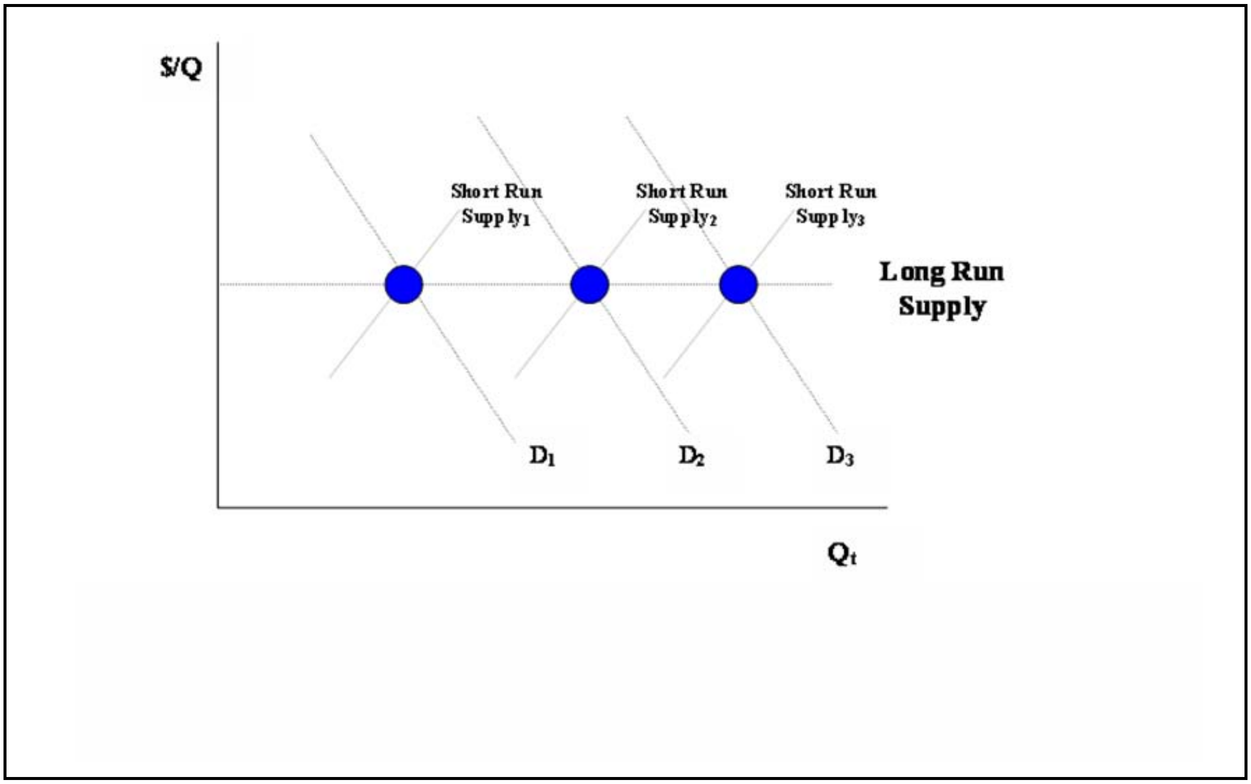

Figure 9G-1. Prices and Quantities in Long Run Market Equilibrium

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), and what the baseline equipment prices are used in the model. This appendix presents a sensitivity analysis for alternatives in the model. Three scenarios are examined:

- Scenario 1: alternative market supply and demand elasticity parameters
- Scenario 2: alternative baseline prices for lawn mower and tractor
- Scenario 3: alternative gasoline price for social costs
- Scenario 4: change in consumer's behavior due this rule

The results of these sensitivity analyses are presented below. The results from Scenario 1 are presented for 2014 (the highest cost year) only with 2005$. The 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 less than 0.5 percent. Total social costs are about the same across all sensitivity analysis scenarios, $444 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 76 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 66 to 98 percent.

With regard to the scenario of alternative baseline prices, although the difference in prices is about 27%and 52% 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.

A recent higher gasoline price will have the impacts to our analyses. A higher gasoline price is expected to increase the fuel savings estimated from primary analysis thus to reduce the net social cost of the final emission standards. In addition, we will describe qualitatively how the consumers would response to the fuel efficiency gains that result from applying technologies to achieve the evaporative emission standards being finalized in this rule in Scenario 4.

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 reflected 95 percent confidence interval.

Table 9H-1: Alternative Supply and Demand Elasticities Used in Sensitivity Analysis[a,b]

Parameter/Market	Upper Bound	Primary Case	Lower Bound
Supply Elasticities			
Engines			
Marine and Small SI	5.0	9.5	13.9
Equipment			
Marine SI			
All other vessel types	3.1	3.8	4.4
PWC	3.5	5.2	6.9
Small SI			
Small SI (handheld/nonhandheld)	5.1	10.0	14.8
Gensets/welders	6.2	8.8	11.4
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] For the demand elasticity, 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.
[b] For the supply elasticity, see Li, May 19, 2008, memorandum prepared for this Docket, "Supply Elasticity Estimation Report", for the interval estimates.

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 0.3 percent. Absolute quantities vary but the percentage changes in output are negligible for the two scenarios. The change in total social surplus for 2014 also remains nearly unchanged across all scenarios and is approximately the same as for the rule ($444 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 1.4 and 4.7 percent, respectively, in the supply upper bound scenario compared to 2.0 and 6.6 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 4.5 and 15.4 percent, respectively, in supply upper bound scenario compared to 6.2 and 17.5 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	**$266.5**	2.4%	$249.3	2.2%	$273.5	2.5%
Equipment	$285.4	1.6%	$252.1	1.4%	$307.0	1.7%
Quantity						
Engines	-10,883	-2.7%	-9,385	-2.3%	-11,838	-2.9%
Equipment	-12,229	-3.2%	-10,684	-2.8%	-13,203	-3.5%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$10.5	6.2%	$17.4	10.2%	$7.7	4.5%
Change in equipment manufacturers surplus	$29.7	17.5%	$34.1	20.0%	$26.3	15.4%
Change in end user (households) surplus	$130.0	76.4%	$119.2	69.8%	$136.0	80.0%
Small SI						
Market-Level Impacts						
Price						
Engines	$13.7	8.3%	$13.5	8.1%	$13.8	8.3%
Equipment	$9.5	2.6%	$8.9	2.4%	$9.8	2.6%
Class I	$16.6	6.2%	$15.7	5.9%	$16.9	6.3%
Class II	$23.7	2.6%	$22.1	2.4%	$24.5	2.7%
HH	$0.3	0.2%	$0.3	0.1%	$0.4	0.2%
Quantity						
Engines	–303.992	–1.9%	–279,592	–1.7%	–314,636	–1.9%
Equipment	–360.310	–1.4%	–326,161	–1.2%	–367,250	–1.4%
Class I	–209,284	–2.1%	–194,465	–2.0%	–215,513	–2.2%
Class II	–101,104	–2.8%	–92,979	–2.6%	–104,638	–2.9%
HH	–49,992	–0.3%	–38,717	–0.2%	–47,100	–0.3%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$5.4	2.0%	$9.31	3.4%	$3.76	1.4%
Change in equipment manufacturers surplus	$18.1	6.6%	$30.4	11.1%	$12.9	4.7%
Change in end user (households) surplus	$250.2	91.4%	$234.1	85.5%	$256.9	93.9%
Subtotal Social Costs (million $)	$443.8		$444.4		$443.4	
Fuel Savings (million $)	$115.9		$115.9		$115.9	
Total Social Costs (million $)	$327.9		$328.6		$327.6	

[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 is 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	$266.5	2.4%	$290.5	2.7%	$255.7	2.3%
Equipment	$285.4	1.6%	$443.4	2.5%	$211.2	1.2%
Quantity						
Engines	-10,883	-2.7%	–905	–0.2%	–15,198	–3.7%
Equipment	-12,229	-3.2%	–934	–0.2%	–17,854	–4.7%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$10.5	6.2%	$0.9	0.5%	$14.7	8.7%
Change in equipment manufacturers surplus	$29.7	17.5%	$2.3	1.3%	$42.8	25.4%
Change in end user (households) surplus	$130.0	76.4%	$170.4	98.2%	$110.9	65.8%
Small SI						
Market-Level Impacts						
Price						
Engines	$13.7	8.4%	$14.0	8.4%	$13.5	8.2%
Equipment	$9.5	2.6%	$10.1	2.7%	$9.0	2.5%
Class I	$16.6	6.2%	$17.2	6.4%	$15.9	6.0%
Class II	$23.7	2.6%	$25.1	2.7%	$22.5	2.5%
HH	$0.3	0.2%	$0.3	0.2%	$0.3	0.2%
Quantity						
Engines	–303.992	–1.9%	–99,098	–0.6%	–486,671	–3.0%
Equipment	–360.310	–1.4%	–146,272	–0.6%	–558,525	–2.1%
Class I	–209,284	–2.1%	–66,388	–0.8%	–340,554	–3.3%
Class II	–101,104	–2.8%	–35,948	–1.9%	–156,182	–3.6%
HH	–49,992	–0.3%	–43,939	–0.3%	–61,788	–0.4%
Welfare Impacts (million $)						
Change in engine manufacturers surplus	$5.4	2.0%	$1.8	0.7%	$8.4	3.1%
Change in equipment manufacturers surplus	$18.1	6.6%	$6.2	2.3%	$28.3	10.4%
Change in end user (households) surplus	$250.2	91.4%	$267.3	97.1%	$235.4	86.5%
Subtotal Social Costs (million $)	$443.8		$448.8		$440.6	
Fuel Savings (million $)	$115.9		$115.9		$115.9	
Total Social Costs (million $)	$327.9		$333.0		$324.7	

[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 2014 compared to the primary case ($444 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 0.7 and 2.3 percent, respectively, in the demand lower bound scenario compared to 2.0 and 6.6 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 0.5 and 1.3 percent, respectively, in demand lower bound scenario compared to 6.2 and 17.5 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 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-4: Market Sensitivity Analysis for Alternative Baseline for Lawnmower & Tractor Prices in 2014 [a]

		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 (UL 125)								
Primary scenario	$218	$12.07	5.5%	–76,121	–1.1%	–$87.0	–$1.7	–$88.7
Low price scenario	$159	$12.03	7.6%	–104,068	–1.4%	–$86.5	–$1.7	–$88.2
Tractors (UL 250)								
Primary scenario	$1,937	$21.11	1.1%	–23,690	–1.1%	–$45.6	–$4.6	–$50.2
Low price scenario	$928	$20.98	2.3%	–49,134	–2.3%	–$45.1	–$4.5	–$49.6

[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-4, 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-4, 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.

9H.3 Alternative Gasoline Price for Social Costs

As discussed in 9.2.4.2, there are fuel savings attributed to the final emission control programs, reflecting the use of more fuel efficient technology to meet evaporative and exhaust emission requirements. These fuel savings are included in the social cost analysis because they are savings that accrue to society.

For the social costs analysis, EPA calculated fuel savings using the 2005 pre-tax price of gasoline of $1.81 per gallon and this value is held constant for each future years (see section 9.3.5). Because of the recent trend of increasing gasoline prices, we may be understating the fuel savings in our cost analysis. This is reflected in recent fuel price projections from the EIA's 2008 Annual Energy Outlook.[18] To investigate the sensitivity of the net social cost to future fuel prices, we used the AEO "reference case" and "high price case" scenarios, as described in section 6.7.1.

As indicated in Table 9H-5, comparing the AEO 2008 reference case with the primary case, the annual net social cost of the final standards is lower because of a higher fuel savings. The net present value of social cost decreases from $4.2 billion to $3.9 billion using a 3 percent discount rate. The net present value of social costs for the period of analysis falls from $2.7 billion to $2.6 billion using a 7 percent discount rate.

As shown in Table 9H-6, fuel savings are even higher in the AEO 2008 high price case. Based on these fuel price projections, the increased fuel savings estimates would actually be higher than the projected costs, once the new equipment is fully phased in. In comparison with the primary case, the net present value of social costs decreases from $4.2 billion to $2.0 billion using a 3 percent discount rate. Using a 7 percent discount rate, the net present value of social costs for the period of analysis falls from $2.7 billion to $1.6 billion**.**

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[18] Energy Information Administration, "Annual Energy Outlook 2008; with Projections to 2030," DOE/EIA-0383(2008), June 2008.

Table 9.H-5: Sensitivity of Gasoline Price to Net Social Cost -AEO 2008 Reference Case

Year	Total Engineering Costs	Total Social Costs	Fuel Savings	Net Social Costs	Net Social Costs
			AEO 2008 Reference Case Projected Gasoline Price	AEO 2008 Reference case Projected Gasoline Price	2005 Constant Gasoline Price (Primary Analysis)
2008	$54	$54	$5	$49	$51
2009	$127	$126	$11	$116	$118
2010	$271	$267	$24	$243	$248
2011	$329	$324	$52	$272	$280
2012	$442	$435	$80	$355	$365
2013	$445	$439	$105	$334	$344
2014	$450	$444	$126	$318	$328
2015	$412	$407	$140	$266	$273
2016	$409	$404	$153	$251	$253
2017	$398	$394	$168	$225	$229
2018	$403	$399	$184	$215	$221
2019	$408	$404	$204	$200	$213
2020	$413	$409	$221	$187	$207
2021	$418	$414	$228	$185	$203
2022	$423	$419	$241	$178	$198
2023	$428	$424	$251	$172	$194
2024	$433	$429	$259	$169	$191
2025	$438	$434	$269	$164	$189
2026	$443	$439	$278	$160	$188
2027	$449	$444	$287	$157	$187
2028	$454	$449	$297	$152	$186
2029	$459	$454	$306	$147	$185
2030	$464	$459	$314	$144	$186
2031	$469	$464	$319	$144	$186
2032	$474	$469	$324	$144	$187
2033	$479	$474	$329	$145	$188
2034	$484	$479	$333	$146	$189
2035	$489	$484	$337	$147	$190
2036	$494	$489	$341	$148	$192
2037	$499	$494	$345	$149	$193
NPV at 3%	$7,705	$7,617	$3,743	$3,873	$4,242
NPV at 7%	$4,559	$4,506	$1,956	$2,550	$2,731

Table 9.H-6: Sensitivity of Gasoline Price to Net Social Cost - AEO 2008 Higher Case

Year	Total Engineering Costs	Total Social Costs	Fuel Savings	Net Social Costs	Net Social Costs
			AEO 2008 Higher Case Projected Gasoline Price	AEO 2008 Higher Case Projected Gasoline Price	2005 Constant Gasoline Price (Primary Analysis)
2008	$54	$54	$5	$49	$51
2009	$127	$126	$11	$115	$118
2010	$271	$267	$27	$240	$248
2011	$329	$324	$61	$263	$280
2012	$442	$435	$100	$336	$365
2013	$445	$439	$137	$302	$344
2014	$450	$444	$169	$274	$328
2015	$412	$407	$198	$209	$273
2016	$409	$404	$226	$179	$253
2017	$398	$394	$253	$141	$229
2018	$403	$399	$277	$122	$221
2019	$408	$404	$301	$102	$213
2020	$413	$409	$325	$84	$207
2021	$418	$414	$351	$63	$203
2022	$423	$419	$371	$47	$198
2023	$428	$424	$386	$37	$194
2024	$433	$429	$402	$27	$191
2025	$438	$434	$411	$23	$189
2026	$443	$439	$423	$16	$188
2027	$449	$444	$437	$7	$187
2028	$454	$449	$450	($2)	$186
2029	$459	$454	$464	($11)	$185
2030	$464	$459	$479	($20)	$186
2031	$469	$464	$487	($23)	$186
2032	$474	$469	$494	($25)	$187
2033	$479	$474	$501	($27)	$188
2034	$484	$479	$507	($29)	$189
2035	$489	$484	$514	($30)	$190
2036	$494	$489	$520	($31)	$192
2037	$499	$494	$525	($32)	$193
NPV at 3%	$7,705	$7,617	$5,585	$2,032	$4,242
NPV at 7%	$4,559	$4,506	$2,886	$1,620	$2,731

9H.4 Discussion of Fuel Savings Effects on EIA Analysis

The final evaporative and exhaust controls are expected to result in fuel savings for consumers due to the use of more fuel efficient technology to meet evaporative and exhaust emission requirements. Although these fuel savings represent a cost savings for consumers, our EIM model assumes that consumers do not consider these fuel savings in their purchasing decisions. As a result, the EIM model does not include a shift in the demand curve due to more fuel efficient products causing the demand curve in each small SI or marine SI equipment market to remain unchanged. This has been explained in Section 9.2.4.2. Although the fuel savings are not directly incorporated in the market model, the benefits to society are captured as an added line item to offset the total social costs of the program.

Figure 9H.1- (a) summarizes the EIA primary analysis that was presented earlier. The market equilibrium of a representative equipment market is at point A prior to the regulation (the baseline case). With the regulation, compliance costs lead to an upward shift in the market supply curve. The new market equilibrium is at point B (the primary case). In this case, the demand curve for the equipment remains unchanged; the regulatory program only influences the supply side of the market (e.g. additional costs of the program [S_0 to S_1]); and fuel savings are added as a line item to the social costs.

This section explores an alternative way to treat the fuel savings in the analysis by assuming consumers are fully aware of the fuel savings and realize that these improvements will lower the future cost of using equipment. Since many consumers may prefer more fuel efficient equipment, they may be willing to initially pay more for Small SI and Marine SI equipment because of these future operation savings. This leads to a change in demand and shifts the demand curve upward.

This concept may be described using illustrations of supply and demand curves. As indicated in Figure 9H.1-(b), if the fuel savings (lower costs of operating equipment) are incorporated in the model as a demand shift (D_A to D_C) that ultimately raises the quantity that buyers wish to purchase at a higher market price. The new equilibrium that includes this demand shift is at point C (the alternative case). Incorporating this demand shift in the model would lead to the following effects:

- *Equipment price and quantity*: Including the demand shift due to fuel savings in the model will increase the projected price and quantity in the equipment market relative to the primary case. Consumers are willing to purchase more Small SI and Marine SI equipment at a higher price because of fuel efficiency characteristics. Since the equipment has become more desirable, producers could sell these equipment at a higher price. In comparing with the primary case (P_B and Q_B), the new market equilibrium price and quantity (P_C and Q_C) in the alternative case are higher.

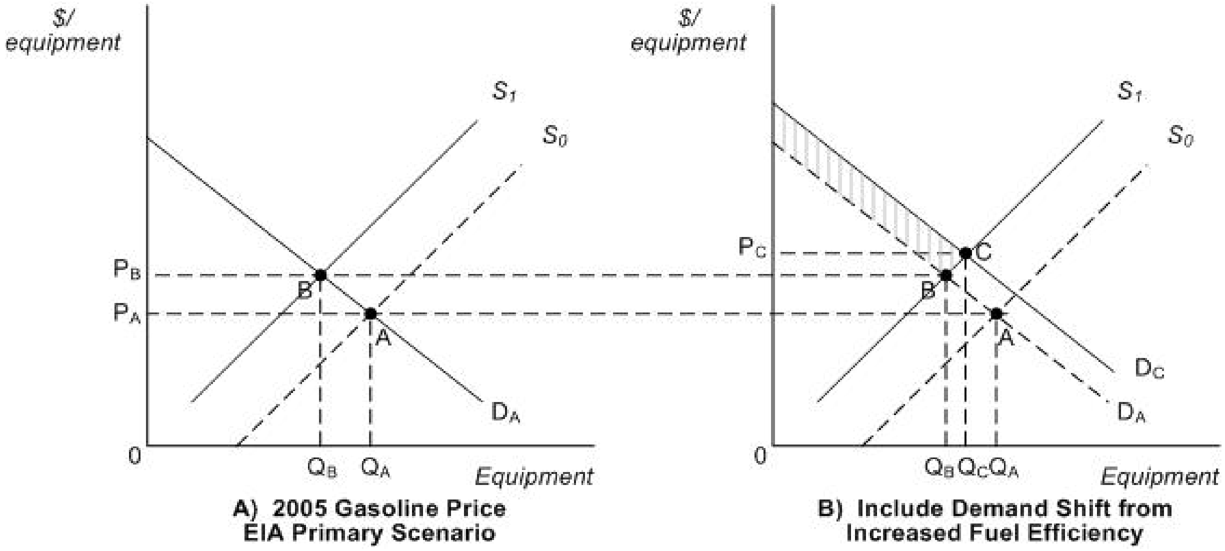
- *Fuel Savings*: At a given Q, consumers are willing to pay more for the equipment with fuel efficiency technology. The fuel savings are measured by difference in consumer's willingness to pay as indicated in the shaded area in Figure 9.H.1-(b)

- *Social costs*: Including the demand shift due to fuel savings will increase total social welfare as indicated in Figure 9.H.2. by the area GFBC. This is because consumers are willing to purchase more at a higher price and producers are charging more and selling more. Both consumer surplus and producer surplus are increased because the fuel efficient technology. The social cost is measured as the change in total social welfare and is now lower in the alternative case.

- *Distribution of social costs*: the primary case assumes all the fuel savings benefits are attributed to the consumer. In the alternative case, consumers and producers share these benefits since the demand shift leads to high equipment prices and higher sells. If producers are more responsive to equipment price changes than consumers (e.g. their supply elasticity is higher than the consumer's demand elasticity), they may receive a higher share of the fuel savings benefits in the form of higher profits from equipment sales.

The likelihood of consumers considering fuel savings in their purchasing decisions is dependent on the magnitude of the fuel savings relative to their income. For the small handheld equipment and lawnmowers used for personal lawn maintenance, operation cost savings would likely have a small influence on equipment purchase decisions. In contrast, for operators of large recreational boats or lawnmowers used by lawn care businesses, the additional gasoline cost savings could influence purchase decisions. While the directional effects of these decisions are discussed above, EPA does not have the sufficient data and information to quantify these effects.

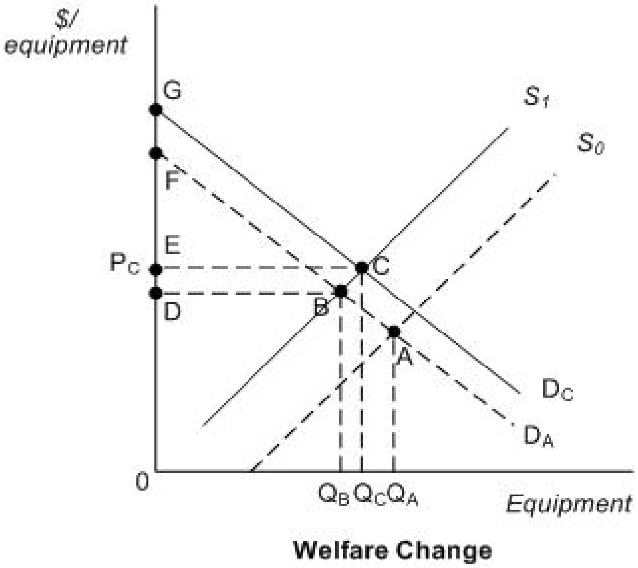
Figure 9.H.1: Demand Side Effect of Fuel Savings in the Equipment Market



A) 2005 Gasoline Price
EIA Primary Scenario

B) Include Demand Shift from
Increased Fuel Efficiency

Figure 9.H.2: Social Welfare Change



Welfare Change

CHAPTER 10: Small-Business Flexibility Analysis

This chapter presents our Small Business Flexibility Analysis (SBFA) which evaluates the impacts of the rule on small businesses. Prior to issuing our proposed rule, we analyzed the potential impacts of our program on small businesses. As a part of this analysis, we convened a Small Business Advocacy Review Panel (SBAR Panel or 'the Panel'), under the requirements of the Regulatory Flexibility Act (RFA), as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996, 5 USC 601 *et seq*. Through the Panel process, we gathered advice and recommendations from small entity representatives (SERs) who would be affected by the regulation. The Panel issued a report recommending that EPA consider and seek comment on a wide range of regulatory alternatives to mitigate the impacts of the rulemaking on small businesses. The Panel report has been placed in the rulemaking record.

In the proposal, EPA proposed provisions consistent with each of the Panel's recommendations and sought comments on all of the small business provisions. We received a number of comments during the comment period after we issued the proposal. A summary of all comments pertaining to the small business provisions can be found in our Summary and Analysis of Comments document contained in the public docket for this rulemaking. A list of the small business provisions being adopted with the final rule is presented in section 10.7 below.

10.1 Overview of the Regulatory Flexibility Act

In accordance with section 603 of the RFA, EPA prepared an initial regulatory flexibility analysis (IRFA) for the proposed rule and convened a Small Business Advocacy Review Panel to obtain advice and recommendations of representatives of the regulated small entities in accordance with section 609(b) of the RFA (see 72 FR 28098, May 18, 20007). A detailed discussion of the Panel's advice and recommendations is found in the Panel Report contained in the docket for this rulemaking. A summary of the Panel's recommendations is presented at (72 FR 28098).

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.

For purposes of assessing the impacts of this action on small entities, a small entity is defined as: (1) a small business as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of smaller 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.

After considering the economic impacts of today's final rule on small entities, we believe that this action will not have a significant economic impact on a substantial number of small entities. The small entities directly regulated by this final rule cover a wide range of small businesses including engine manufacturers, equipment manufacturers, boat manufacturers, fuel tank manufacturers, and fuel hose manufacturers. No small governmental jurisdictions or small non-profits are impacted by this final rule. We have determined that 61 small businesses will experience an impact of greater than 1 percent. These 61 companies represent less than 5 percent of the small business identified by EPA.

Despite the determination that this rule will not have a significant economic impact on a substantial number of small entities, we have prepared a Small Business Flexibility Analysis that has all the components of a final regulatory flexibility analysis (FRFA). An FRFA examines the impact of the final rule on small businesses along with regulatory alternatives that could reduce that impact. The Small Business Flexibility Analysis is presented in this chapter.

10.2 Need for and Objective of the Rulemaking

A detailed discussion on the need for and objectives of this final rule are located in the preamble to the final 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 adopts controls on exhaust and evaporative emissions from Small SI engines and equipment and Marine SI engines and vessels.

10.3 Summary of Significant Public Comments

In the proposal, EPA proposed provisions consistent with each of the Panel's recommendations and sought comments on all of the small business provisions (see 72 FR 28245, May 18, 2007). As noted earlier, we received a number of comments during the comment period after we issued the proposal. A summary of all comments pertaining to the small business provisions can be found in our Summary and Analysis of Comments document contained in the public docket for this rulemaking. A few changes have been made to some of the proposed flexibilities in response to the comments as well as other changes made in the rulemaking. Those changes are noted in section 10.7.1 below.

10.4 Definition and Description of Small Entities

Small entities include small businesses, small organizations, and small governmental jurisdictions. As noted earlier, for the purposes of assessing the impacts of a 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 10.4-1); (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 10.4-1 provides an overview of the primary SBA small business categories that will be affected by this regulation.

Table 10.4-1: 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.

10.4.1 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.

10.4.2 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.

10.5 Type and Numbers of Small Entities Affected

As noted above, for each sector impacted by this final rule, 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.

10.5.1 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.

10.5.2 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, and Nissan. Two companies qualify as a small business under the SBA definitions. Tohatsu makes outboard engines. The other small business is Surfango which makes a small number of motorized surfboards and has certified their product as a PWC.

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 14 marine fuel tank manufacturers in the United States that qualify as small businesses under the SBA definition. These manufacturers include five rotational molders, two 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.

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 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.

10.6 Reporting, Recordkeeping, and 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 adopting for manufacturers subject to this final rule will include testing, reporting, and record keeping requirements for manufacturers of engines, equipment, and vessels, and will 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 generally continuing 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 planning to apply similar reporting, record keeping, and compliance requirements to those for OB/PWC engine manufacturers. Testing requirements for engine manufacturers will include certification emission (including deterioration factor) testing and production line testing. Reporting requirements will include emission test data and technical data on the engines. Manufacturers will also need to keep records of this information.

Because of the new evaporative emission requirements, there will be new reporting, record keeping and compliance requirements for Small SI equipment manufacturers. Small SI equipment manufacturers participating in the transition program will 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 will include certification emission testing. Reporting requirements will include emission test data and technical data on the designs. Manufacturers will also need to keep records of this information.

10.7 Steps Taken to Minimize the Impact on Small Entities

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 were 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 included 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 were focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations can be found in the SBREFA Final Panel Report.[1]

A list of the small business provisions being adopted with the final rule are presented in the following section.

10.7.1 Small SI Exhaust Emission Standards

Described below are the regulatory alternatives being adopted with the final rule related to the Small SI nonhandheld engine exhaust emission standards.

10.7.1.1 Regulatory Flexibility Options for Nonhandheld Engine Manufacturers

The following section contains a discussion of the provisions in the final rule for small business nonhandheld engine manufacturers.

Additional Lead Time for Nonhandheld Engine Manufacturers - Small-volume engine manufacturers can delay implementation of the Phase 3 exhaust emission standards for two years (see §1045.145). Small-volume engine manufacturers will 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, small-volume engine manufacturers can 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 - Small-volume engine manufacturers will be able to 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 adopting actual levels for the assigned deterioration factors with this final rule. 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 expects to provide guidance to engine manufacturers specifying the levels of the assigned deterioration factors for small-volume engine manufacturers.

Production Line Testing Exemption - Small-volume engine manufacturers will be exempt from the production-line testing requirements for all of their nonhandheld engine families (see §1054.301).

Broader Definition of Engine Family - Small-volume engine manufacturers may use a broader definition of engine family than generally applies 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. With this final rule, we are allowing small-volume engine manufacturers to group all of their nonhandheld 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 retaining 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 above, EPA is also allowing engine manufacturers which exceed the production cut-off level of 10,000 units 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

The following section contains a discussion of the provisions in the final rule for small business nonhandheld equipment manufacturers.

Additional Lead Time for Small SI Equipment Manufacturers - Small-volume equipment manufacturers will 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 can 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 adopting 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 adopting provision that allow small-volume equipment manufacturers to 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 can potentially use Phase 2 engines on all their Class II equipment for two years (consistent with the SBAR Panel's recommendation) or they may, for example, sell half their Class II equipment with Phase 2 engines for four years.

Simplified Engine Certification for Equipment Manufacturers - We are adopting a simplified engine certification procedure for small-volume equipment manufacturers. (As discussed in Section V.E.4 of the preamble, we are also adopting 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 adopting a simplified engine certification process for small-volume equipment manufacturers (see §1054.612). Under such a simplified certification process, the equipment manufacturer will 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 is representative for the equipment manufacturer's configuration.

Eligibility for the Small Business Flexibilities - EPA is retaining 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 above, EPA will also 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 will 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 regulatory alternatives being adopted with the final rule related to the SD/I engine exhaust emission standards.

Additional Lead Time for SD/I Engine Manufacturers - We are adopting 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). These dates provide 1 year of additional leadtime for small businesses producing ≤373 kW SD/I engines and 3 years of additional leadtime for small businesse producing >373 kW SD/I engines compared the implementation dates for large manufacturers.

Exhaust Emission ABT - We are adopting an averaging, banking, and trading (ABT) credit program for exhaust emissions from ≤373 kW SD/I marine engines (see part 1045, subpart H). Under the proposal, the ABT program would have applied to >373 kW SD/I engines as well. However, as described in section 3.4 of the Summary and Analysis of Comments document for the Final Rule, we are adopting different standards for high performance SD/I engines than originally proposed. High performance (>373 kW) SD/I engines are required to meet the new standards without the use of an ABT program.

Early Credit Generation for ABT - We are adopting 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 noted above, give small-volume manufacturers of SD/I engines ≤373 kW ample opportunity to bank emission credits prior to the implementation date of the standards and provide greater incentive for more small business engine manufacturers to introduce advanced technology earlier than would otherwise occur. Because the ABT program being adopted with the final rule only applies to SD/I engines ≤373 kW, the early credit provisions will not apply to high-performance (>373 kW) SD/I engines.

Assigned Emission Rates for High Performance (>373 kW) SD/I Engines - In the proposal, we noted that in the case where an engine manufacturer is using emission credits to comply with the standard, the manufacturer will still need to test engines to calculate how many emission credits are needed. In order to minimize this testing burden, we proposed to allow manufacturers to use assigned baseline emission rates for certification based on previously generated emission data. As discussed in section 3.4 of the Summary and Analysis of Comments document for the Final Rule, we are adopting less stringent standards for high-performance (>373 kW) SD/I engines that do not allow for the use of the ABT program for demonstrating compliance with the standards. Therefore, we are not adopting baseline HC+NOx and CO emission rates for high-performance SD/I engines since the proposed levels were higher than the standards being adopted and therefore, are of no use without an ABT program.

Alternative Standards for High Performance (>373 kW) SD/I Engines - In the proposal, EPA cited concerns raised by small businesses that catalysts had not been demonstrated on high-performance engines and that they may not be practicable for this application and therefore requested comments on the need for and level of alternative standards for high-performance marine engines. As described in section 3.4 of the Summary and Analysis of Comments document for the Final Rule, we are adopting a less stringent set of exhaust emission standards for high performance (>373 kW) SD/I engines than originally proposed. These standards are not expected to result in the use of catalysts on high performance (>373 kW) SD/I engines.

Furthermore, we are not adopting NTE standards for high-performance SD/I engines (See §1045.105). This is consistent with the SBAR Panel recommendation that NTE standards not apply to any high-performance SD/I engines.

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 adopting provisions that allow small businesses to group all of their high performance (>373 kW) SD/I engines into a single engine family for certification, subject to good engineering judgment (see §1045.230). A manufacturer will need to perform emission tests only on the engine design that will be most likely to exceed the emission standard.

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 (>373 kW) 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 adopting less restrictive specifications and tolerances, for small businesses testing high performance (>373 kW) SD/I engines, which would allow the use of portable emission measurement equipment (see §1065.901(b)). This will facilitate less expensive testing for these small businesses without having a negative effect on the environment.

Reduced Testing Requirements for SD/I Engine Manufacturers - We are adopting provisions to allow small-volume engine manufacturers to use an assigned deterioration factor to demonstrate compliance with the standards for the purposes of certification rather than doing service accumulation and additional testing to measure deteriorated emission levels at the end of the regulatory useful life (see §1045.240). EPA is not specifying actual levels for the assigned deterioration factors in this final rule. EPA intends to analyze available emission deterioration information to determine appropriate deterioration factors for SD/I engines. The data will likely include durability information from engines certified to California ARB's standards and may also include engines certified early to EPA's standards. Prior to the implementation date for the SD/I standards, EPA will provide guidance to engine manufacturers specifying the levels of the assigned deterioration factors for small-volume engine manufacturers.

We proposed to exempt small-volume manufacturers of SD/I engines from the production -line testing requirements. As noted in section 3.10 of the Summary and Analysis of Comments document for the Final Rule, we are dropping the production-line testing requirements for all engine manufacturers including large manufacturers. Therefore, no production-line testing will be required of any SD/I engine manufacturer (see §1045.301).

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 adopting criteria based on the number of employees. SD/I engine manufacturers that have no more than 250 employees will be considered a small business for the purposes of the flexibilities being adopted with the final rule. We originally proposed criteria based on a production cut-off of 5,000 SD/I engines per year. However, engine manufacturers commented that it was more appropriate to use an employee level than a production level for defining which companies are small businesses. We believe a 250 employee limit should be roughly consistent with the production level we targeted in our proposal, although some manufacturers would likely be able to produce more than 5,000 units. Under the small-volume engine manufacturer definition being adopted for the final rule, there will be no option to consider the production volume instead of the 250 employee count.

10.7.3 Small SI and Marine SI Evaporative Emission Standards— Flexibility Alternatives for Equipment, Vessel, and Fuel Tank Manufacturers

Described below are the regulatory alternatives being adopted with the final rule related to the evaporative emission standards for Small SI engines and equipment and Marine SI engines and vessels. The provisions discussed below applied 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 flexibility provisions being adopted for fuel tank manufacturers apply regardless of whether the manufacturer was a small business or not.

Consideration of Appropriate Lead Time - We are adopting an implementation schedule that we believe provides sufficient lead time for blow-molded and marine rotational molded fuel tanks. For Small SI equipment, we are establishing tank permeation implementation dates of

2011 for Class II equipment and 2012 for Class I equipment. For marine fuel tanks, we are implementing the tank permeation standards in 2011 with an additional year (2012) for installed fuel tanks which are typically rotational-molded marine fuel tanks (see §1054.110 and §1045.107).

With regard to the diurnal requirements for marine vessels, we are providing an additional year of lead time, compared to the proposal. This means that the diurnal standard willll apply beginning with the 2011 model year. In addition, we are adopting an interim allowance program that will give additional time for a limited number of boats. Under this program, each boat builder will be allowed to sell these boats without the diurnal emission controls that would otherwise be required. Specifically, each boat builder will have a total of 1,200 allowances that may be used, at the manufacturer's discretion, for boats produced before December 31, 2012. These allowances are intended to help boat builders engage in an orderly transition to the new standards and will only be available for boats produced in 2011 and 2012. This allowance program applies only to boats with installed fuel tanks that are expected to use carbon canisters to meet the diurnal emission standards. Therefore, it does not apply to portable fuel tanks or personal watercraft. This provision will apply to both small and large businesses because we believe that even large businesses may have specific, small-volume models where additional lead time may be especially helpful due to atypical design constraints. For very small companies, we expect that this allowance program will result in an additional year, or even two, of lead time for them to address potential installation issues related to carbon canisters.

Fuel Tank ABT and Early Incentive Program - We are adopting an ABT program for fuel tank permeation and an early-allowance program for fuel tank permeation. In the proposal, we requested comment on including service tanks in the ABT program. (Service tanks are fuel tanks sold as replacement parts for in-use equipment.) Based on comments received, we do not believe it is appropriate to include such tanks in the ABT program. Equipment manufacturers will be required to demonstrate that their equipment models meet the evaporative emission standards. If the certified equipment uses a fuel tank included in the ABT program, the credits generated were based on a useful life of five years. Therefore, if the tank being replaced is less than five years old, the replacement tank would result in double counting of some of the credits. While manufacturers could potentially gather information to account for the age of the fuel tank being replaced, we do not want to complicate the provisions of the ABT program and therefore we are not including replacement tanks in the fuel tank ABT program.

Broad Definition of Evaporative Emission Family for Fuel Tanks - We are adopting provisions that allow fuel tank emission families to be based on type of material (including additives such as pigments, plasticizers, and UV inhibitors), emission control strategy, and production methods. This would allow fuel tanks of different sizes, shapes, and wall thicknesses can be grouped into the same emission family (see §1045.230 and §1054.230). In addition, Small SI and Marine SI fuel tanks could be allowed in the same emission family if the tanks meet these criteria. Manufacturers therefore will 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.

Compliance Progress Review for Marine Fuel Tanks - We believe the 2012 fuel permeation standards are technologically feasible for rotationally-molded marine fuel tanks. This conclusion is supported by data presented in the Regulatory Impact Analysis. In addition, several rotationally-molded tank manufacturers support EPA's proposed standards and implementation dates and have provided information to support their positions. However, several other rotationally-molded tank manufacturers are not as far along in their technological progress toward meeting the standards and are not certain about their ability meet the EPA requirements in 2012. To address this situation, these manufactures requested that EPA perform a technical review in 2010 to determine whether the compliance dates should be adjusted. However, for the reasons discussed above, we believe that the tank permeation standards have been demonstrated to be technologically feasible in the 2012 time frame and do not look favorably upon the request for a technology review of the permeation standard.

Nevertheless, we are concerned about the potential long-term impacts on the small businesses that have not yet developed technology that meets the requirements. During the next few years, EPA intends to hold periodic progress reviews with small businesses that rotationally mold fuel tanks. The purpose of these progress reviews will be to monitor the progress of individual companies towards compliance with the tank permeation standards and to provide feedback as needed. Rather than conducting a broad program with the entire industry, we will conduct separate, voluntary reviews with each interested company. These sessions will be instrumental to EPA in following the progress for these companies and assessing their efforts and potential problems.

To help address small business concerns, we expect we would rely on the small volume manufacturer hardship relief provisions contained in 40 CFR 1068.250, and described in the following section. In the event that a small business is unsuccessful in the 2012 model year and seeks hardship relief, the progress reviews described above would provide an important foundation in determining whether a manufacturer has taken all steps to comply with the permeation standards in a timely and orderly manner.

Design-Based Certification - We are adopting design-based certification for carbon canisters for boats. For the carbon canisters, the design requirement 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 adopting design-based certification for certain fuel tanks. For fuel tanks, we will allow design-based certification for metal tanks as well as plastic fuel tanks with a continuous EVOH barrier.

The National Marine Manufacturers Association (NMMA) 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 NMMA membership. We will allow this data to be used as part of EPA certification as long as it is collected consistent with the test procedures and other requirements described in this final rule.

Additional Lead Time for Small SI Fuel Hose Requirement - We proposed an implementation date of 2008 for Small SI hose permeation standards for non-handheld equipment (see §90.127). Given that we are not adopting the final rule until mid-2008, we have delayed the implementation of the low permeation fuel line requirement until 2009 for nonhandheld equipment. However, we are keeping the 2009 implementation date for low-permeation fuel line for small businesses producing Small SI nonhandheld equipment. We believe the 2009 date is feasible for all equipment manufacturers, given that fuel line meeting the low permeation standards is already widely available and manufacturers selling most types of nonhandheld equipment in California were required to use such hose starting in 2007 or 2008.

10.7.4 Hardship Provisions—Regulatory Flexibility Options for Engine, Equipment, Vessel, and Fuel System Component Manufacturers

The following section summarizes the hardship provisions we are adopting 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).

Unusual Circumstances Hardship - Under the unusual circumstances hardship provision, manufacturers can apply for hardship relief if circumstances outside their control cause the failure to comply and if failure to sell the subject engines or equipment will jeopardize the company's solvency (see §1068.245). The terms and time frame of the relief will depend on the specific circumstances of the company and the situation involved. As part of its application for hardship, a company will be required to provide a compliance plan detailing when and how it will achieve compliance with the standards. This hardship provision will be available to all business engine manufacturers, equipment manufacturers, vessel manufacturers, and fuel system component manufacturers, regardless of size.

Economic Hardship - Under the economic hardship provision, small business manufacturers can petition EPA for limited additional lead time to comply with the standards (see §1068.250). A manufacturer will have to make the case that it has taken all possible business, technical, and economic steps to comply, but the burden of compliance costs will have a significant impact on the company's solvency. Hardship relief may include requirements for interim emission reductions and/or purchase and use of emission credits. The length of the hardship relief will be established during the initial review and will likely need to be reviewed annually thereafter. As part of its application for hardship, a company will be required to provide a compliance plan detailing when and how it will achieve compliance with the standards. This hardship provision will 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 Rulemaking

The following section summarizes the economic impact on small businesses of the new 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 new 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 new 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 Final RIA with the exception of the costs used for Small SI engine and equipment manufacturers. A description of the inputs used for each affected industry sector (except small SI engine and equipment manufacturers) 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 small SI engine and equipment manufacturers, we relied on the costs from the proposal instead of the final rule. The basic cost inputs for the final rule (e.g., the cost of the various technologies, the number of engine and equipment models, etc.) have not changed from the proposal. However, recent certification data suggests that a number of Class II engines may be able to comply with the standards without the use of a catalyst. Our cost analysis for the final rule reflects this change and results in significantly lower costs for Class II. Because we project that more than half of the engines in Class II will use catalysts, but we do not know which engines small business equipment manufacturers will purchase for their equipment, we believe it is appropriate to continue using the higher costs associated with the proposal rather than the final rule cost numbers in gauging the potential costs of the new standards on small manufacturers. We believe this approach will result in an overestimation of the impacts (i.e., a conservative estimate) of the new standards on small SI engine and equipment manufacturers.

For OB/PWC engine manufacturers, EPA identified two small businesses. One of the small businesses identified by EPA manufactures personal watercraft today using four-stroke engines with certified emission levels below the new standards, so we project negligible incremental costs resulting from our rule. The other small business manufactures outboard engines. Several of their currently certified engines already comply with the new standards, while the remaining engines would need to be recalibrated, which we project would cost on the order of less than $10 per engine. Given the cost of personal watercraft and outboard engines, we therefore believe the impact of the rule is well below one percent of revenues for both of these OB/PWC engine manufacturers.

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 new 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, all of the small businesses are projected to 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 new 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 14 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 new low permeation fuel hose requirements will not apply to the fill neck), we have not included this manufacturer in our analysis. Of the 14 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 new regulations on small businesses impacted by the 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	2	0	0
Manufacturers of Marine SD/I engines < 373 kW	4	5	0
Manufacturers of Marine SD/I engines > 373 kW (high-performance)	19	0	0
Boat Builders	>1,000	0	0
Manufacturers of Fuel Hose and Fuel Tanks for Marine SI Vessels	14	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	380 plus >1,000 boat builders	43	18

After considering the economic impacts of today's final rule on small entities, we believe this action will not have a significant economic impact on a substantial number of small entities. The small entities directly regulated by this final rule cover a wide range of small businesses including engine manufacturers, equipment manufacturers, boat manufacturers, fuel tank manufacturers, and fuel hose manufacturers. Small governmental jurisdictions and small organizations as described above will not be impacted. We have determined that the estimated effect of the rule is to impact 43 companies with costs between one and three percent of revenues, and 18 additional companies with costs over three percent of revenues. These 61 companies represent less than 5 percent of the total number of small businesses impacted by the new regulations. All remaining companies (over 1,000 of them) would be impacted with costs by less than one percent of revenues. It should be noted that this estimate is based on the highest level of estimated cost in the first years of the program. We estimate substantially lower long-term costs as manufacturers learn to produce compliant products at a lower cost over time.

For a complete discussion of the economic impacts of the final rulemaking, see Chapter 9, the Economic Impact Analysis chapter, of this Final 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 - Determination of No SISNOSE,” EPA memorandum from Phil Carlson to Alex Cristofaro, March 13, 2008. (Docket Identification EPA-HQ-OAR-2004-0008-____.)

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 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 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 rule, unless otherwise specified. For example, the more stringent recreational marine exhaust standards for OB/PWC are evaluated as follow-on requirements to the new 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 rule, 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 rule. 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, a less stringent HC+NOx emission standard for Class I spark-ignition engines. The standard of 10 g/kW-hr is readily achievable with reasonably priced emission control technology. Furthermore, the lead time for implementing the 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 final standards. 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 final standards. Cooling for the slightly more active OHV catalyst would be supplied by the engine improvements anticipated for this rule, 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 final standards. However, for the same reasons previously stated for Class I engines, we rejected this alternative from further consideration; the standards are 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 new 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 new standards. 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 standards for marine auxiliary engines include a CO standard that would require the use of highly efficient catalytic control. This 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 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 standards for OB/PWC are based on technology that manufacturers are already certifying and selling nationwide. To meet the new requirements, manufacturers would continue to sell this technology and discontinue their sale of high-emitting old technology carbureted two-stroke engines. Because the standards can be met with existing technology, we do not believe that there is an alternative between the new 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 an addition tier of standards 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 use an equation of 28 - 0.45 × rated power(kW) to maintain a continuous curve function. This alternative also considers a lower CO standard of 200 g/kW-hr for engines greater than 40 kW with an adjusted standard of 500 - 7.5 × 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 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 2010 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. Many of the SD/I marine engines with catalysts described in Chapter 4 had HC+NOx emission rates appreciably below 5 g/kW-hr, even with deteriorated catalysts. In the development testing for this 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 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 originally proposed a standard based on the use of catalysts and then 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. However, manufacturers commented that catalysts are not be practical for these engines due to the high exhaust flow rates, high emission rates, and low useful life period between rebuild. In the final rule, we are establishing standards that can be met through the use of engine controls, similar to the alternative standard that was analyzed in the proposal. Because we do not consider catalyst-based standards to be feasible for high-performance engines at this time, we are not modeling a more stringent alternative.

11.1.2 Alternative Evaporative Emission Requirements

11.1.2.1 Small SI Engines

For Small SI engines, we are finalizing both permeation and venting emission standards. The permeation standards are for fuel tanks and fuel lines. We believe that the 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 finalizing standards for running loss[1] but not for diurnal emissions. We are not finalizing any type of venting emissions control for handheld equipment.

For a less stringent alternative, we considered not requiring running loss emission control for non-handheld Small SI engines. These requirements would be deleted from the rule and thus modeled as being deleted in the years otherwise required.

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 venting emission standards. For marine vessels, we are adopting diurnal emission standards for all vessel types. For portable fuel tanks and PWC fuel tanks, the control technology of a sealed system with pressure relief is fairly straightforward and commonly used today. However, we anticipate that the 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.[2] For a more stringent scenario, 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

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[1] We anticipate that running loss control measures will also reduce diffusion emissions.

[2] Note that PWC already meet the 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.

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	Standard	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 standard
	2	Class II	• 8 g/kW-hr HC+NOx • Begins 2011	more	• 3.5 g/kW-hr HC+NOx • Begins 2015 in lieu of standard
	3	OB/PWC	• Decreases with power output (P) • 2008 California HC+NOx equation • CO g/kW-hr equation is 500-5Pfor <40 kW • 300 g/kW-hr CO for >40kW • Begins 2010	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 2010 standards
	4	SD/I <373 kW	• 5 g/kW-hr HC+NOx • 75 g/kW-hr CO • Begins 2010[a]	less	• 10 g/kW-hr HC+NOx • 150 g/kW-hr CO • Same effective dates as standard
	5			more	• 2.5 g/kW-hr HC+NOx • 75 g/kW-hr CO • Begins 2012 in lieu of standards[a]

[a] 2011 for certain engine blocks. 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	Standard	less/ more	Alternative Description
Evap	6	HH diurnal/ running loss	• None	more	• Begins 2012
	7	Class I & Class II running loss	• Running loss is a "zero emission" design standard • Class I begins 2012 and Class II begins 2011	less	• No running loss
	8	Class I & Class II diurnal	• None	more	• Requirement would begin in 2012 for Class I and 2011 for Class II
	9	Installed marine fuel tank diurnal	• 0.4g/gal/day HC trailerable boat • 0.16 g/gal/day HC non-trailerable boat • Begins 2011	less	• No diurnal for 2010
	10			more	• More stringent test procedure. If charcoal canister is used, active purge required. • Would begin 2011
	11	Portable marine fuel tank diurnal	• Diurnal is a "zero emission" design standard • Begins 2010	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 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 final standard. The only exception to this is the second phase of OB/PWC standards where costs are incremental to the final standard. 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 final standards. For current SV engines they would need to utilize larger and more active catalysts than considered in the analysis for the final standards, or convert to OHV design and use a slightly larger catalyst or more active catalyst than for the final 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)
Standard		
Class I	$10-$26	$10-$12
Class II	$17-$60	$12-$30
More Stringent		
Class I	$17-$23	$12-$18
Class II	$110-$149	$76-$89

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)
Standard	OB PWC	$291 $359	$224 $272
More Stringent	OB PWC	$388 $528	$275 $392
Incremental Cost[a]	OB PWC	$102 $169	$51 $120

[a] Incremental cost is presented here because the more stringent alternative for OB/PWC includes the primary standard in 2010 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.

For the more stringent case, we consider a larger catalyst size with a higher precious metal loading for engines. 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 these scenarios because, in each case, all engines are anticipated to use electronic fuel injection. Table 11.2-3 compares the per-engine cost estimates for the primary, less stringent, and more stringent alternatives. As discussed above, we do not including high-performance engines in this analysis.

Table 11.2-3: SD/I <373 kW Per-Engine Cost Estimates (Without Fuel Savings)
Sales Weighted Averages

	Short Term (years 1-5)	Long Term (years 6-10)
Standard	$355	$266
Less Stringent	$200	$149
More Stringent	$431	$333

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 controls for nonhandheld equipment. For the more stringent case, we add the incremental costs of diurnal emission control for all nonhandheld engines and diurnal emission and running loss control 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)
Standard	Aggregate	$3.27	$2.46
	Handheld	$0.82[a]	$0.69[a]
	Class I	$3.05	$2.20
	Class II	$6.73	$5.16
Less Stringent		$1.86	$1.34
Aggregate		$0.82[a]	$0.69[a]
	Handheld	$1.13	$0.67
	Class I	$4.50	$3.38
	Class II		
More Stringent	Aggregate	$6.76	$5.25
	Handheld	$4.40	$3.55
	Class I	$6.01	$4.57
	Class II	$11.08	$8.64

[a] Values reflect the final 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
Standard	Aggregate	1.4	$2.36	$2.17
	Handheld	0.2	$0.33	$0.31
	Class I	0.8	$1.41	$1.31
	Class II	4.7	$6.53	$5.96
Less Stringent		0.9	$1.53	$1.41
Aggregate		0.2[a]	$0.33[a]	$0.31[a]
	Handheld	0.5	$0.92	$0.85
	Class I	3.0	$4.16	$3.80
	Class II			
More Stringent	Aggregate	1.5	$2.63	$2.41
	Handheld	0.3	$0.49	$0.46
	Class I	0.9	$1.53	$1.41
	Class II	5.3	$7.32	$6.69

[a] Values reflect the final 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)
Standard	Aggregate	$55	$45
	portable	$12	$8
	PWC	$17	$11
	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 final 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
Standard	Aggregate	28	$42	$33
	portable	13	$20	$17
	PWC	9	$14	$12
	installed	38	$54	$42
Less Stringent		20	$30	$24
Aggregate		11	$17	$14
	portable	9[a]	$14[a]	$12[a]
	PWC	26	$37	$29
	installed			
More Stringent	Aggregate	30	$44	$34
	portable	13[a]	$20[a]	$17[a]
	PWC	9[a]	$14[a]	$12[a]
	installed	39	$57	$44

[a] Values reflect the final 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	Standard	Scenario	Alternative
Exhaust	1	Class I	$10-$26	more	$17-$23
	2	Class II	$17-$60	more	$110-$149
	3[a]	OB/PWC	$-	more	$70
	4	SD/I <373 kW	$360	less	$216
	5			more	$435
Evap	6[b]	HH	$-	more	$3.58
	7	Class I & Class II	$4.32	less	$2.30
	8[b]	Class I & Class II	$-	more	$3.45
	9	Installed marine fuel tank	$74	less	$42
	10			more	$94
	11	Portable marine fuel tank	$12	less	$11

[a] Costs are presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss for handheld.

Table 11.2-9 summarizes the 30-year net present value for costs for the standards 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 Program Options with a 7 Percent Discount Rate (Million 2005$)

Source	Alt	Target	Standard	Scenario	Alternative
Exhaust	1	Class I	$1,228	more	$1,558
	2	Class II	$1,146	more	$4,040
	3[a]	OB/PWC	$-	more	$347
	4	SD/I <373 kW	$343	less	$194
	5			more	$388
Evap	6[b]	HH	$-	more	$318
	7	Class I & Class II	$718	less	$394
	8[b]	Class I & Class II	$-	more	$570
	9	Installed marine fuel tank	$250	less	$144
	10			more	$310
	11	Portable marine fuel tank	$8	less	$7

[a] Costs are presented incremental to the final standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss for handheld.

Table 11.2-10: 30-Year Net Present Value Cost Summary for Alternative Program Options with a 3 Percent Discount Rate (Million 2005$)

Source	Alt	Target	Standards	Scenario	Alternative
Exhaust	1	Class I	$2100	more	$2,944
	2	Class II	$1831	more	$7,366
	3[a]	OB/PWC	$-	more	$556
	4	SD/I <373 kW	$541	less	$304
	5			more	$626
Evap	6[b]	HH	$-	more	$544
	7	Class I & Class II	$1,180	less	$630
	8[b]	Class I & Class II	$-	more	$962
	9	Installed marine fuel tank	$413	less	$239
	10			more	$512
	11	Portable marine fuel tank	$12	less	$11

[a] Costs are presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss 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 final standards. 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 Program Options with a 7 Percent Discount Rate (Million Tons)

Source	Alt	Target	Standard	Scenario	Alternative
Exhaust	1	Class I	0.73	more	0.63
	2	Class II	1.05	more	1.27
	3[a]	OB/PWC	0	more	0.26
	4	SD/I <373 kW	0.33	less	0.22
	5			more	0.32
Evap	6[b]	HH	0	more	0.04
	7	Class I & Class II	1.04	less	0.63
	8[b]	Class I & Class II	0	more	0.12
	9	Installed marine fuel tank	0.36	less	0.26
	10			more	0.38
	11	Portable marine fuel tank	0.07	less	0.06

[a] Tons reduced are presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss for handheld.

Table 11.3-2: 30-Year Net Present Value Emission Reduction Summary for Alternative Program Options with a 3 Percent Discount Rate (Million Tons)

Source	Alt	Target	Standard	Scenario	Alternative
Exhaust	1	Class I	1.33	more	1.22
	2	Class II	1.90	more	2.52
	3[a]	OB/PWC	0	more	0.50
	4	SD/I <373 kW	0.64	less	0.42
	5			more	0.65
Evap	6[b]	HH	0	more	0.07
	7	Class I & Class II	1.83	less	1.09
	8[b]	Class I & Class II	0	more	0.21
	9	Installed marine fuel tank	0.70	less	0.50
	10			more	0.73
	11	Portable marine fuel tank	0.13	less	0.11

[a] Tons reduced are presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss 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 final standards. 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 final standards. 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 Final Standards and Alternatives Without Fuel Savings, 7 Percent Discount Rate ($/ton) 2005$

Source	Alt	Target	Standard	Scenario	Alternative
Exhaust	1	Class I	$1,680	more	$2,540
	2	Class II	$1,086	more	$3,170
	3[a]	OB/PWC	$790	more	$1,340
	4	SD/I <373 kW	$1,030	less	$880
	5			more	$1,210
Evap	6[b]	HH	NA	more	$8,150
	7	Class I & Class II	$690	less	$630
	8[b]	Class I & Class II	NA	more	$4,900
	9	Installed marine fuel tank	$690	less	$550
	10			more	$820
	11	Portable marine fuel tank	$115	less	$120

[a] Cost effectiveness of more stringent alternative is presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss for handheld.

Table 11.4-2: Comparison of Cost Effectiveness for Final Standards and Alternatives Without Fuel Savings, 3 Percent Discount Rate ($/ton) 2005$

Source	Alt	Target	Standard	Scenario	Alternative
Exhaust	1	Class I	$1,580	more	$2,410
	2	Class II	$965	more	$2,930
	3[a]	OB/PWC	$670	more	$1100
	4	SD/I <373 kW	$840	less	$720
	5			more	$970
Evap	6[b]	HH	NA	more	$7,620
	7	Class I & Class II	$640	less	$580
	8[b]	Class I & Class II	NA	more	$4560
	9	Installed marine fuel tank	$590	less	$500
	10			more	$700
	11	Portable marine fuel tank	$100	less	$100

[a] Cost effectiveness of more stringent alternative is presented incremental to the standards for OB/PWC because, for this alternative, a second stage of standards is considered in 2012 beyond the final standards.

[b] Only considers standards for venting emission control which are not in the final standards. The venting emission standards considered here are diurnal for Class I and Class II and diurnal/running loss 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 final 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 final standards.

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 final standards. 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 final standards. For the analytical period we considered, the final standards provide more emission reductions than the alternative by 202,600 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 47,000 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 4 g/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. We are expecting engine manufacturers to meet the final 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 final standards. 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 final standards. For the 30 year analytical period we considered, the final rule provides fewer overall emission reductions than the alternative, but between 2011 and 2020 the final rule gives 150,300 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 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

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 final 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.

11.5.2 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 emissions control 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. This emission control approach is 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 finalizing 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 final standards are 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 engineering design-based certification provisions. Eliminating these requirements would not meaningfully affect the cost effectiveness of the marine evaporative program. Not finalizing 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 finalizing 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 did not model alternative scenarios, as discussed above. 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 SD/I	4.05	1.26	4.00	1.03	96.3	1.35	345

11A.2 Evaporative Emission Factors

As discussed above, no changes in the 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 final rule. 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 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 final rule.

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	0.67	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 final 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 final 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 finalizing 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 final 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 did not model the use of catalysts for reasons discussed above. 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 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 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.