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

Final Regulatory Impact Analysis

Chapter 6
Costs of Control

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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	BaselineE mission 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 long term	$0.62 $0.50	$0.77 $0.63	$3.10 $2.52	NA
sulfonation[a,b]: short term long term	$0.64 $0.52	$1.25 $1.01	$1.40 $1.16	NA
non-continuous platelets[a]	$0.17	$0.22	$0.51	NA
multi-layer[a]: short term EVOH long term	$4.13 $2.01	$4.08 $1.98	$3.80 $1.75	NA
multi-layer[c]: short term PA11 long term	NA	NA	NA	$5.54 $3.40
multi-layer[c]: CBT	NA	NA	NA	$5.77
thermo-forming[b]: short term long term	$0.36 $0.20	$0.53 $0.29	$1.50 $0.82	NA
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 long term	$1.26 $1.01	$1.32 $1.06	$2.56 $2.08	$5.69 $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]

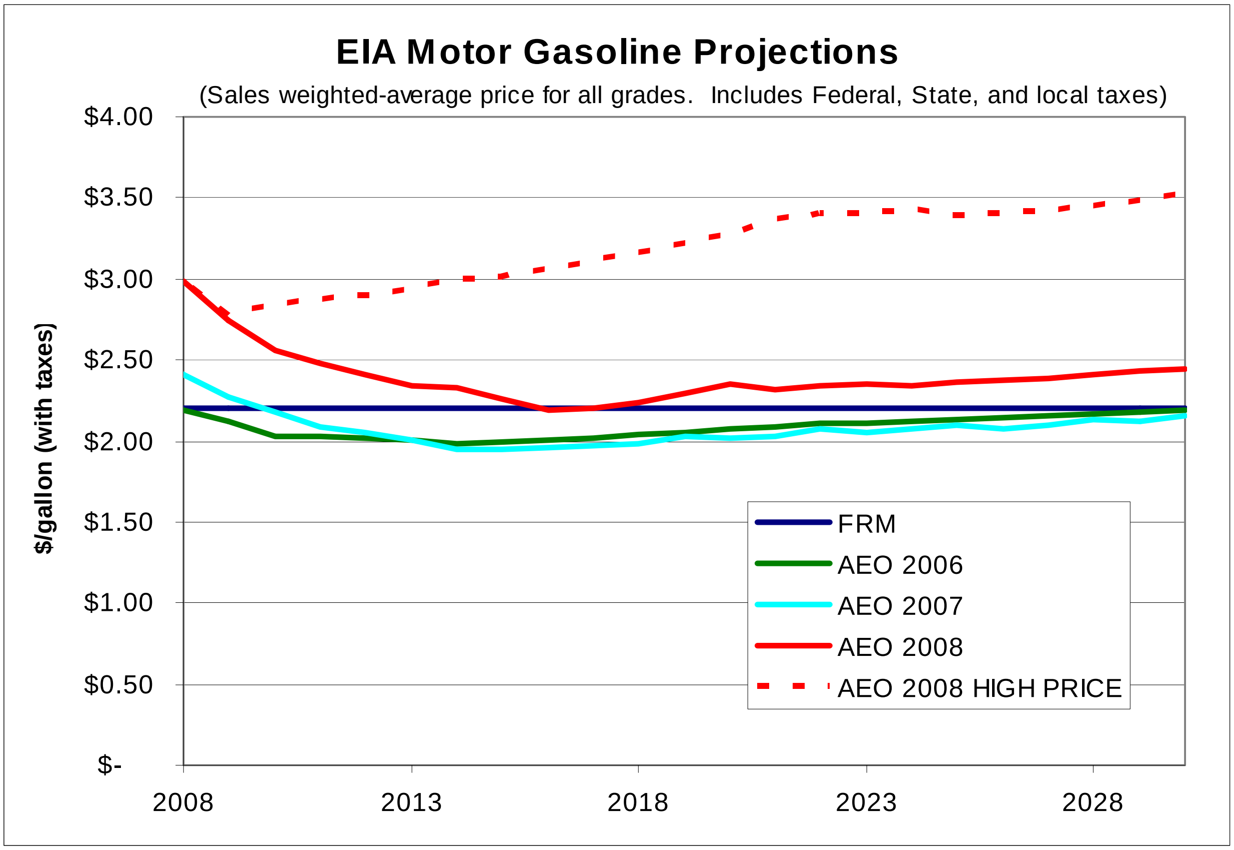

Table 6.7-2 presents our fuel savings estimates for this rule and presents a comparison with modified estimates using the EIA fuel price projections. Consistent with the above discussion, we adjusted the fuel price estimates to remove taxes on motor gasoline. Compared to the primary EPA estimate, using 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 Increase % Increase	$511 $28 5%	$417 $21 5%	$342 $24 7%	$328 $28 8%	$416 $39 9%
10 Year Average Precious Metal Prices					
Cost Increase % Increase	$479 -$4 -1%	$393 -$3 -1%	$314 -$4 -1%	$296 -$4 -1%	$371 -$6 -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 Increase % Increase	$5.18 ($0.85) -15%	$68 ($14) -17%
20% Increase in Material Costs		
Cost Increase % Increase	$6.40 $0.86 15%	$95 ($14) 17%

Marine fuel tanks that are installed in marine vessels are primarily rotationally-molded out of cross-link polyethylene. However, many fuel tank are also made of aluminum. Very large fuel tanks (typically greater in size than rotationally-molded fuel tanks) are often made out of fiberglass. Marine fuel tank manufacturers making rotationally-molded fuel tanks have expressed the concern that if the costs were to increase too high, that many boat builders would switch to using aluminum fuel tanks. Based on conversations with industry, plastic fuel tanks sell for about 2/3 to 3/4 the price of aluminum fuel tanks.

One manufacturer of multi-layer rotationally-molded fuel tanks with a nylon inner layer has stated that they sell these fuel tanks at a price about 50 percent higher than traditional mono-layer fuel tanks. Although this puts the plastic tanks into the price range of metal fuel tanks, there are other downstream costs that would also need to be considered. Boat builders have indicated that it is common for aluminum fuel tanks to corrode when exposed to water. For this reason, they typically include a large access panel to the fuel tank when metal fuel tanks are used. The use of an access panel greatly reduces the cost of replacing a fuel tank if necessary. This access panel adds cost and complexity to the boat and may affect where the fuel tank can be positioned in the boat. Boat manufacturers have indicated that, when plastic fuel tanks are used, the only access required is to the hose connections on one end of the fuel tank.

In addition to the cost of an access panel for removing corroded tanks, the cost of replacing the fuel tank must be considered. This would essentially double the price of the metal tank, even without considering labor costs. In addition, fuel spills could create other damage in the boat or even a safety hazard. Repeated problems with fuel tank corrosion could hurt the reputation of the boat builder and leave them open to litigation. For these reasons, many boat builders that have already chosen to use plastic fuel tanks would be expected to continue to use these fuel tanks, even if they were roughly the same cost as metal fuel tanks.

We analyzed at two effects that could have an impact on our estimate of the price of low permeation plastic fuel tanks. It seems unlikely that a high cost drop box would be necessary given that one manufacturer is already producing multi-layer tanks without using a drop box. In addition, the CBT technology is designed to not require the use of a drop box. While material costs may fluctuate, it is not likely that a 20 percent increase in nylon would be observed. The volume of this material sold is large and this rule would not be expected to limit availability of the material. In addition, manufacturers have indicated that nylon prices have not risen greatly with increased petroleum costs. Even with a 20 percent material price increase it seems unlikely that boat builders would switch to using metal tanks. Manufacturers using plastic tanks have indicated that they do so more for durability advantages with respect to corrosion than for a price savings. In addition, the life time cost savings of plastic fuel tanks would outweigh the material price increase. These lifetime cost savings include the installation of access ports to allow replacement of the tanks, actual replacement of corroded tanks, and customer perception of poor quality if tanks were to corrode.

Chapter 6 References

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