CHAPTER 5: Estimated Costs

This chapter describes our approach to estimating the cost of complying with emission standards. We start with a general description of the approach to estimating 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.

5.1 Methodology

We developed the costs for individual technologies using information provided by ICF, Incorporated and Arthur D. Little, as cited below. The technology characterization and cost figures reflect our current best judgment based on engineering analysis, information from manufacturers, and the published literature. The analysis combines cost figures including markups to the retail level.

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 manufacturers' overhead and profit.[1] For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. All costs are in 2001 dollars.

The analysis presents an estimate of costs that would apply in the first year 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 therefore no longer part of the cost calculation. Second, manufacturers are expected to learn over time to produce the engines with the new technologies at a lower cost. Because of relatively low sales volumes, manufacturers are less likely to put in the extra R&D effort for low-cost manufacturing. As production starts, assemblers and production engineers will then be expected to find significant improvements in fine-tuning the designs and production processes. Consistent with analyses from other programs, we reduce estimated variable costs by 20 percent beginning with the third year of production and an additional 20 percent beginning with the sixth year of production.[2] We believe it is appropriate to apply this factor here, given that the industries are facing emission regulations for the first time and it is reasonable to expect learning to occur with the experience of producing and improving emission-control technologies.

Many of the engine technologies available to 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, as we describe for each type of engine below.

Even though the analysis does not reflect all the possible technology variations and options that are available to 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.

5.2 Cost of Emission Controls by Engine/Vehicle Type

5.2.1 Recreational Marine Diesel Engines

We have developed cost estimates for diesel engine technologies for several different applications in a series of reports.[3,4,5] This analysis adapts these existing cost estimates for recreational marine diesel engines with separate estimates for three different sizes of engines.

Recreational marine diesel engines invariably have counterpart engine models used for commercial application. Manufacturers will design, certify, and manufacture these commercial models to meet emission standards. The analysis projects that manufacturers will comply with the new emission standards generally by applying the same technologies for both commercial and recreational engines. The remaining effort to meet emission standards with the recreational models would be limited to applying new or improved hardware and conducting sufficient R&D to integrate the new technologies into marketable products. The analysis therefore does not consider fixed costs to develop the individual technologies separately.

One area where recreational engine designs differ is in turbocharging and aftercooling. To reach peak performance, recreational engines typically already use optimized turbochargers and seawater aftercooling, which offer the greatest potential for controlling NOx emissions.

We estimate the total cost impact of new emission standards by considering the cost of each of the anticipated technologies. The following paragraphs describe these technologies and their application to recreational marine engines. The analysis then combines these itemized costs into a composite estimate for the range of marine engines affected by the rulemaking.

Table 5.2.1-1 also includes information on product offerings and sales volumes, which is needed to calculate amortized fixed costs for individual engines. Estimated sales and product offerings were compiled from the PSR database based on historical 1997 information.

Table 5.2.1-1
Recreational Marine Diesel Engine Categories for Estimating Costs

Engine Power Ranges (kW)	Nominal Engine Power (kW)	Annual Sales	Models	Average Sales per Model
37 - 225	100	3,700	17	216
225 - 560	400	6,700	15	448
560 +	750	1,000	6	173

Manufacturers are expected to develop engine technologies not only to reduce emissions, but also to improve engine performance. While it is difficult to take into account the effect of ongoing technology development, EPA is concerned that assessing the full cost of the anticipated technologies as an impact of new emission standards would inappropriately exclude from consideration the expected benefits for engine performance, fuel consumption, and durability.[1] Short of having sufficient data to predict the future with a reasonable degree of confidence, we face the need to devise an alternate approach to quantifying the true impact of the new emission standards. As an attempt to take this into account, we present the full cost of the control technologies in this chapter, then apply a discount to some of these costs for calculating the cost-per-ton of the proposed emission standards, as described in Chapter 7.

5.2.1.1 Fuel Injection Improvements

All engines are expected to see significant improvements in their fuel injection systems. The smaller engines will likely undergo incremental improvements to existing unit injector designs. The analysis projects that engines rated over 600 kW will use common rail injection technology, which greatly increases the flexibility of tailoring the injection timing and profile to varying modes of operation. Better control of injection timing and increased injection pressure contribute to reduced emissions. Table 5.2.1-2 shows the estimated costs for these fuel injection improvements.

Table 5.2.1-2
Fuel Injection Improvements

	100 kW	400 kW	750 kW
Component costs	$63	$98	$205
Assembly, markup, and warranty	$32	$46	$59
Composite Unit Cost	$95	$144	$264

5.2.1.2 Engine Modifications

Manufacturers will be optimizing basic engine parameters to control emissions while maintaining performance. Such variables include routing of the intake air, piston crown geometry, and placement and orientation of injectors and valves. Most of these variables affect the mixing of air and fuel in the combustion chamber. Small changes in injection timing are also considered in this set of modifications. We expect, however, that manufacturers will complete this work for commercial marine diesel engines, so that the remaining effort will be focused on fine-tuning designs for turbocharger matching and other calibration-related changes. Fixed costs are amortized over a five-year period, using the sales volumes developed in Table 5.2.1-1, with

[1]While EPA does not anticipate widespread, marked improvements in fuel consumption, small improvements on some engines may occur.

forward discounting incorporated to account for manufacturers incurring these costs before the emission standards begin to apply. Table 5.2.1-3 shows the estimated per-engine costs for these modifications. These costs include the consideration manufacturers must give to offsetting any crankcase emissions routed to the exhaust. There is no estimated long-term cost to the engine modifications because manufacturers can fully recover the fixed costs, and we don't expect any increase in variable costs as a result of these improvements.

Table 5.2.1-3
Engine Modifications

	100 kW	400 kW	750 kW
Total fixed costs	$200,000	$200,000	$200,000
Fixed cost per engine	$244	$122	$244
Composite Unit Cost	$244	$122	$244

5.2.1.3 Certification and Compliance

We have significantly reduced certification requirements in recent years, but manufacturers are nevertheless responsible for generating a minimum amount of test data and other information to demonstrate compliance with emission standards. Table 5.2.1-4 lists the expected costs for different sizes of engines, including the amortization of those costs over five years of engine sales. Estimated certification costs are based on two engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information.

Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. Since these engines are currently not subject to any emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years.

Costs for production line testing are summarized in Table 5.2.1-5. These costs are based on testing 1 percent of total estimated sales, then distributing costs over the fleet. Listed costs for engine testing presume no need to build new test facilities, since we are proposing to waive production-line testing requirements for small-volume production. Few manufacturers, if any, will therefore need to build new test facilities.

Table 5.2.1-4
Certification

	100 kW	400 kW	750 kW
Total fixed costs	$30,000	$30,000	$40,000
Fixed cost per engine	$77	$93	$859
Composite Unit Cost	$37	$18	$49

Table 5.2.1-5
Costs for Production Line Testing

	100 kW	400 kW	750 kW
Cost per test	$10,000	$10,000	$15,000
Testing rate	1 %	1 %	1 %
Cost per engine	$100	$100	$150

5.2.1.4 Total Engine Costs

These individual cost elements can be combined into a calculated total for new emission standards by assessing the degree to which the different technologies will be deployed. As shown in Table 5.2.1-6, estimated costs for complying with the proposed emission standards increase with increasing power ratings. We expect each of the listed technologies to apply to all the engines that need to meet the new emission standards. Estimated price impacts range from $400 to $700 for the different engine sizes.

Characterizing these estimated costs in the context of their fraction of the total purchase price and life-cycle operating costs is helpful in gauging the economic impact of the new standards. The estimated first-year cost increases for all engines are at most 2 percent of estimated engine prices, with even lower long-term effects, as described above.

Table 5.2.1-6
Diesel Engine Costs

	100 kW	400 kW	750 kW
Fuel injection upgrade	$95	$144	$264
Engine modifications	$244	$122	$244
Certification + PLT	$137	$118	$199
Total Engine Cost	$475	$384	$707

5.2.1.5 CI Marine Aggregate Costs

The above analyses developed incremental per-vessel cost recreational marine diesel engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for proposed emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold. Table 5.2.1-7 presents a summary of this analysis. As shown in the table, aggregate net costs stay between $2 million and $4 million.

Table 5.2.1.-7
Summary of Annual Aggregate Costs for Marine CI Engines (millions of dollars)

	2006	2010	2015	2020	2025
Total Costs	$3.0	$3.7	$2.2	$2.5	$2.7

To project annual sales, we started with the 1998 population estimates presented in Chapter 6. We then used the engine turnover rates and growth estimates to calculate annual sales. Table 5.2.1.-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.1.-8
Estimated Annual Sales of Recreational Marine Diesel Engines

Engine Power Range (kW)	1999	2006	2010	2020
37 - 225	5,160	6,330	7,000	8,700
225 - 560	1,580	1,900	2,140	2,660
560 +	180	220	240	300

To calculated annual aggregate costs, the sales estimates have been multiplied by the per-unit costs discussed above. These calculations take into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.2 Large Industrial Spark-Ignition Engines

We estimated the cost of upgrading LPG-fueled and gasoline-fueled and gasoline-fueled Large SI engines. We developed the costs for individual technologies in cooperation with ICF, Incorporated and Arthur D. Little.[6] The analysis combines these individual figures into a total estimated cost for each type of engine, including markups to the retail level. A composite cost based on the mix of engine types provides an estimated industry-wide estimate of the per-engine cost impact.

Gasoline-fueled Large SI engines continue to rely on traditional carburetor designs rather than incorporating the automotive technology innovations introduced to address emission controls. Since natural gas- and LPG-fueled engines use comparable technologies, the analysis presents a single set of costs for both fuels.

The anticipated technology development is generally an outgrowth of automotive technologies. Over the last thirty years, engineers in the automotive industry have made great strides in developing new and improved approaches to achieve dramatic emission reductions with high-performing engines. In more recent years, companies have started to offer these same technologies for industrial applications. Fundamental to this technology development is the electronically controlled fuel system and catalytic converters.

Electronically controlled fuel systems allow manufacturers to more carefully meter fuel into the combustion chambers. This gives the design engineer an important tool to better control power and emission characteristics over the whole range of engine operation. Careful control of air-fuel ratio is also essential for effective catalyst conversion. The catalyst converts the pollutants in the exhaust stream to harmless gases. We also consider development time to redesign the combustion chamber and intake air routing, as well as to combine the new control technologies and optimize engine calibrations. We include these efforts under the total R&D costs for each engine.

Gasoline engines can use either throttle-body or port-fuel injection. Manufacturers can likely reach the targeted emission levels using simpler throttle-body systems. However, the performance advantages and the extra assurance for full-life emission control from the more advanced port-fuel injection systems offer a compelling advantage. The analysis therefore projects that all gasoline engines will use port-fuel injection. The analysis does not take into account the performance advantages of port-fuel injection and therefore somewhat overestimates the cost impact of adopting new emission standards.

Gaseous-fuel engines have very different fuel metering systems due to the fact that LPG and natural gas evaporate readily at typical ambient temperatures and pressures. Manufacturers of these engines face a choice between continuing with conventional mixer technology and upgrading to injection systems. We are aware that manufacturers are researching gaseous injection systems, but we believe mixer technology will be sufficient to meet the proposed standards. All the data supporting the feasibility of emission standards for LPG engines is based on engines using mixer technology.

5.2.2.1 Engine Technology

Tables 5.2.2-1 and 5.2.2-2 show the estimated costs of upgrading each of the engine types. The cost figures are in the form of retail-price equivalent for an individual engine. The tables include individual cost estimates of the various components involved in converting a baseline engine to comply with emission standards. The cost of the catalyst is based on a precious metal loading of 2.8 g/liter (primarily palladium, with small amounts of platinum and rhodium) and a catalyst volume 60 percent of total engine displacement.

The analysis incorporates a cost for potential warranty claims related to the new technologies by adding 5 percent of the increase in hardware costs. The industry has gained enough experience with electronic fuel systems that we expect a relatively low rate of warranty claims for them. Catalysts have been used for many years, but not in Large SI applications, so these technologies may cause a somewhat higher rate of warranty claims.

Even without EPA emission standards, manufacturers will conduct the research and development needed to meet the 2004 emission standards in California. The R&D impact of new EPA standards is therefore limited to the additional burden of complying with the proposed 2007 requirements. Estimated costs for research and development are $175,000 for each engine family. This is based on about six months of time for an engineer and a technician on each fuel type for each engine family. We would expect initial efforts to require greater efforts, but cumulative learning would reduce per-family development costs for subsequent models. These fixed costs are increased by 7 percent to account for forward discounting, since manufacturers incur these costs before the new standards apply. Redesigning the first engine model will likely require significantly more time than this, but we expect the estimated level of R&D to be appropriate as an average level for the range of models in a manufacturer’s product line.

While there is no separate item in the following cost tables for positive-crankcase ventilation, the analysis takes these costs into account indirectly through the increased cost for the intake manifold and the overall development cost per engine family.

Table 5.2.2-1
Estimated Costs for an LPG-fueled Large SI Engine

	Baseline	Controlled
Hardware Cost to Manufacturer		
Regulator/throttle body	$50	$65
Intake manifold	$37	$37
Fuel filter w/ lock-off system	$15	$15
LPG vaporizor	$75	$75
Governor	$40	$60
Converter temperature control valve		$15
Oxygen sensor		$19
ECM		$100
Wiring/related hardware		$45
Fuel system total	$217	$431
Catalyst/muffler		$229
Muffler	$45	$0
Total Hardware Cost	$262	$660
Markup @ 29%	$76	$191
Warranty markup @5%		$20
Total component costs	$338	$871
Fixed Cost to Manufacturer		
R&D costs	$0	$175,000
Units/yr.	2,000	2,000
Amortization period (7 % discounting)	5	5
Fixed cost/unit	$0	$26
Total Costs	$338	$897
Incremental Total Cost		$559

Table 5.2.2-2
Estimated Per-Engine Costs for Gasoline-Fueled Large SI Engines

	Baseline	Controlled
Hardware Cost to Manufacturer		
Carburetor	$51	$0
Injectors (each)		$17
Number of injectors		4
Pressure Regulator		$11
Fuel filter	$3	$4
Intake manifold	$35	$50
Fuel rail		$13
Throttle body/position sensor		$60
Fuel pump	$15	$30
Oxygen sensor		$19
ECM		$150
Governor	$40	$60
Air intake temperature sensor		$5
Manifold air pressure sensor		$11
Injection timing sensor		$12
Wiring/related hardware		$45
Fuel system total	$144	$538
Catalyst/muffler		$229
Muffler	$45	
Total Hardware Cost	$189	$767
Markup @ 29%	$55	$222
Warranty markup @5%		$29
Total Component Costs	$244	$1,018
Fixed Cost to Manufacturer		
R&D Costs	$0	$175,000
Units/yr.		1,750
Amortization period (7 % discounting)		5
Fixed cost/unit	$0	$30
Total Costs	$244	$1,048
Incremental Total Cost		$805

In addition to these estimated costs for addressing exhaust emissions, we have analyzed the costs associated with reducing evaporative emissions from gasoline-fueled engines and vehicles. This effort consists of three primary areas—permeation, diurnal, and boiling.

To reduce permeation losses, we expect manufacturers to upgrade plastic or rubber fuel lines to use automotive-grade materials. These fuel lines are readily available at a cost premium of about $0.25 per linear foot. If an installed engine has an average of four feet of fuel line, this translates into an increased cost of $1 per engine.

The standard related to diurnal emissions can be met with a fuel cap that seals the fuel tank, relieving pressure as needed to prevent the tank from bursting or collapsing. The estimated cost of upgrading to such a fuel cap is $8, based on the aftermarket cost of comparable automotive fuel caps.

Many Large SI engines are installed in equipment in a way that poses little or no risk of fuel boiling during engine operation. A few models are configured in a way that causes this to be a possibility, at least under extreme conditions. Preventing fuel boiling is primarily a matter of isolating the fuel tank from heat sources, such as the engine compartment and the exhaust pipe. Some additional material may be needed to reduce heat exposure, such as a simple metal shield or a fiberglass panel. Given several years to redesign engines and equipment, we believe that manufacturers can readily incorporate such changes into their ongoing R&D programs. To account for several hours of engineering effort and a small amount of material, we estimate that these costs averaged over the whole set of gasoline-fueled engines will come to about $1 per engine.

5.2.2.2 Operating Cost Savings

Introducing electronic closed-loop fuel control will significantly improve engine operation, with corresponding cost savings, in three areas— reduced fuel consumption, less frequent oil changes and tuneups, and delayed time until rebuild.

It may also be appropriate to quantify the benefit of longer total engine lifetimes. For example, passenger cars with low-emission engine technologies last significantly longer than they did before manufacturers developed and applied these technologies. In addition, engine performance (responsiveness, reliability, engine warm-up, etc.) will also improve with the new technologies. However, these benefits are more difficult to quantify and the analysis therefore does not take them into account.

Fuel consumption rates will improve as manufacturers no longer design engines for operation in fuel-rich conditions. Some current systems already operate at somewhat leaner air-fuel ratios than in previous years, but even in these cases, engines generally revert to richer mixtures when accelerating. Closed-loop fuel systems generally operate close to stoichiometry, which improves the engine's efficiency of converting the fuel energy into mechanical work. Information in the docket, including development testing, engineering projections, and user testimony, leads to an estimated 20-percent reduction in fuel consumption rates.[7,8,9] Table 5.2.2-3 shows the value of the estimated fuel savings. These values and calculations are based on our NONROAD emissions model.

Table 5.2.2-3
Estimated Fuel Savings from Large SI Engines

	LPG	Gasoline	Natural gas
Horsepower	66	52	65
Load factor	0.39	0.58	0.49
Annual operating hours, hr/yr	1,365	537	1,161
Lifetime, yr	12	12	13
Baseline bsfc, lb/hp-hr	0.507	0.605	0.507
Improved bsfc, lb./hp-hr	0.406	0.484	0.406
Fuel density	4.2 lb./gal	6.1 lb./gal	0.05 .g./ft^3
Fuel cost	$0.60/gal	$1.10/gal	$2.17/1000 ft^3
Annual fuel saved (gal/yr)	845	321	—
Annual fuel savings ($/yr)	$507	$353	$160
Lifetime Fuel Savings (NPV)	$4,333	$3,038	$1,427

In addition to the fuel savings, we expect Large SI engines to see significant improvements in reliability and durability. Open-loop fueling systems in uncontrolled engines are prone to drifting calibrations as a result of varying fuel quality, wear in engine components, changing ambient conditions, and other factors. Emission-control systems that operate with a feedback loop to compensate for changing conditions for a near-constant air-fuel ratio significantly reduces the following problems.

-incomplete (and eventually unstable) combustion
-absorption of fuel in lubricating oil
-deposits on valves, spark plugs, pistons, and other engine surfaces
-increased exhaust temperatures

Automotive engines clearly demonstrate that modern fuel systems reduce engine wear and the need for repairs.

This analysis incorporates multiple steps to take these anticipated improvements into account. First, oil change intervals are estimated to increase by 15 percent. Reduced fuel loading in the oil (and other improvements such as piston ring design) can significantly extend its working life. Similarly, tune-up intervals are estimated to increase by 15 percent. This results largely from avoiding an accumulation of deposits on key components, which allows for longer operation between regularly scheduled maintenance. Third, we estimate that engines will last 15 percent longer before needing overhaul. The reduced operating temperatures and generally reduced engine wear associated with closed-loop fuel systems account for this extended lifetime to rebuild. These quantitative estimates of maintenance-related savings are derived from observed changes in automotive performance when upgrading from carburetion to fuel injection. Table 5.2.2-4 summarizes the details of the methodology for converting these maintenance improvements into estimated cost savings over the lifetime of the engines.

Table 5.2.2-4
Maintenance

	LPG/ natural gas	Gasoline
Baseline oil change interval (hrs)	200	150
Improved oil change interval (hrs)	230	172.5
Cost per oil change ($)	$30	$30
Baseline tune-up interval (hrs)	400	400
Improved tune-up interval (hrs)	460	460
Cost per tune-up ($)	$75	$75
Baseline rebuild interval (hrs)	7,000	5,000
Improved rebuild interval (hrs)	8,050	5,750
Rebuild cost ($)	$800	$800
Baseline lifetime maintenance cost	$2,902	$2,573
Improved lifetime maintenance cost	$2,681	$2,354
Lifetime maintenance savings (NPV)	$221	$219

These large estimated fuel and maintenance savings relative to the estimated incremental cost of producing low-emitting engines raise the question of why normal market forces have failed to induce manufacturers to design and sell engines with emission-control technologies on the basis of the expected performance improvements. Since forklifts are the strongly dominant application using Large SI engines, this question effectively applies specifically to forklifts. We have observed that forklift users generally see their purchase as an expense that doesn't add value to a companies product, whether that applies to manufacturing, warehouse, or retail facilities. While operating expenses require no internal justification or decision-making process, purchasing new equipment involves extensive review and oversight by managers who are very sensitive to capital expenditures. This is reinforced by an April 2000 article in a trade publication, which quotes an engineering estimate of 20- to 40-percent improvement in fuel economy while stating that it is unclear whether purchasers will tolerate any increase in the cost of the product.[10] Market theory would predict that purchasers would select products with technologies that result in the lowest net cost (with some appropriate discount for costs incurred over time). It seems that companies have historically focused on initial costs to the exclusion of potential cost savings over time, which would account for the lack of emission-control technologies on current sales of Large SI engines.

This priority given to initial cost therefore affects the competitive decisions of engine manufacturers, who will be less willing to provide a more costly product than its competitors, even if the product would eventually provide substantial savings to the purchaser. Also, the initial costs of changing designs and using new technologies can serve as a deterrent to including newer cost-efficient technologies in established engine types.

In addition to the engine improvements described above, the costs associated with controlling evaporative emissions would be offset by savings from retaining more fuel that can be used to power the engine.

5.2.2.3 Compliance Costs

We estimate that certification costs come to $70,000 per engine family. We expect manufacturers to combine similar engines using different fuels in the same family. This expands the size of engine families, but calls for several tests to complete the certification process for each family. This includes six engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information. Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. This cost is therefore amortized over five years of engine sales, with an assumed volume of 3,000 engines per year from each engine family. This engine-family sales volume is larger than those presented for amortizing fixed costs above, because engine families will include multiple fuel types. The resulting cost for certification is $6 per engine. Since these engines are currently not subject to any EPA emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years. Since manufacturers already need to submit data for California certification, they will incur most of these costs independent of EPA requirements.

The proposal includes a requirement to do production-line testing on a quarterly basis. Manufacturers with sustained, good test results can greatly reduce testing rates. Manufacturers must generate and submit this test data to comply with the requirements adopted by California ARB. The EPA requirement for production-line testing therefore adds no test burden to manufacturers. Even with a transient duty cycle for certification, we are proposing to allow manufacturers to use only steady-state test procedures a the production line. We therefore fully expect that manufacturers will only need to send the “California” test data to EPA to satisfy requirements for production-line testing. The analysis therefore includes no cost for additional routine testing of production engines. In fact, the proposal includes a provision that would allow manufacturers to pursue alternate methods to show that production engines comply with emission standards, which may lead to lower testing costs.

The proposal allows us to select up to 25 percent of a manufacturers’s engine families for in-use testing. This means that a manufacturer would need to have eight engine families for us to be able to select two engine families in a given year. Since this is likely to be a rare scenario, we project an annual testing rate of one engine family per year for each manufacturer to assess the cost of the in-use testing program. The analysis includes the cost of testing in-use engines on a dynamometer, which requires:

- engine removal and replacement ($4,000)
- transport ($1,000)
- steady-state and transient testing ($15,000)

Testing six engines and adding costs for administration and reporting of the testing program leads to a total cost of about $125,000 for an engine family. These costs can be spread over a manufacturer’s total annual sales, which averages about 15,000 units for most companies. The resulting cost per engine is about $8.

As with production-line testing, we would expect in-use emission testing to simultaneously satisfy California ARB and EPA requirements. In certain circumstances, however, we may use our discretion to direct a manufacturer to do in-use testing on an engine family separately from California ARB. Since we expect this to be the exception, this analysis likely overestimates the cost impact of adopting federal requirements to do in-use testing. In fact, manufacturers may reduce their compliance burden with the optional field-testing procedures we are proposing. Table 5.2.2-5 shows the estimated costs from the various compliance programs.

Table 5.2.2-5
Cost of Compliance Programs

Compliance Program Element	Estimated Per-Engine Costs
Certification	$6
In-use testing	$8
Total	$14

5.2.2.4 Total Costs

Table 5.2.2-6 presents the combined cost figures for the different engine types and calculates a composite cost based on their estimated distribution. The estimated 2004 costs are based on the adding component costs and compliance costs. No R&D cost is estimated for manufacturers to do additional development work beyond what is necessary to comply with California ARB standards. Conversely, the estimated 2007 costs are based on R&D (and ongoing compliance costs), with no anticipated increase in component costs, except those related to reducing evaporative emissions. The estimated cost of complying with the proposed emission standards is sizable, but the lifetime savings from reduced operating costs nevertheless more than compensate for the increased costs

Table 5.2.2-6
Estimated First-Year Cost Impacts of New Emission Standards

Standards	Engine Type	Sales Mix of Engine Types	Increased Production Cost per Engine*	Lifetime Operating Costs per Engine (NPV)
2004	LPG	68%	$550	$-4,550
	natural gas	9%	$550	$-1,650
	gasoline	23%	$790	$-3,260
	Composite	—	$600	$-3,985
2007	LPG	68%	$40	—
	natural gas	9%	$40	—
	gasoline	23%	$55	**
	Composite	—	$45	—

*The estimated long-term costs decrease by about 35 percent.
**Gasoline-fueled engines would experience fuel savings due to evaporative emission control, but these are not quantified here.

5.2.2.5 Large SI Aggregate Costs

The above analyses developed incremental per-vessel cost estimates for Large SI engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for proposed emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the engines are operated over their lifetimes. Table 5.2.2-7 presents a summary of this analysis. As shown in the table, aggregate net costs generally range from $75 million to $90 million. Net costs decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used. Fuel savings are projected to more than offset the costs of the program starting by the second year of the program.

Table 5.2.2.-7
Summary of Annual Aggregate Costs and Fuel Savings for Large SI Engines
(millions of dollars)

	2004	2005	2010	2015	2020
Total Costs	$88	$90	$73	$76	$84
Fuel Savings	($49)	($96)	($313)	($431)	($490)
Net Costs	$38	($7)	($240)	($355)	($406)

To project annual sales, we started with the number of model year 2000 engines estimated by the NONROAD model for the 2000 calendar year. We then applied a growth rate of 3 percent of year 2000 sales (increasing by 3,900 units annually) to estimate future sales. Table 5.2.2.-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.2.-8
Estimated Annual Sales of Large SI Engines

2000	2004	2010	2020
130,000	145,600	169,000	208,000

To calculated annual aggregate costs, the sales estimates have been multiplied by the per-unit costs. Annual fuel savings have been calculated based on the reduction in fuel consumption expected from the proposed standards (as described in section 5.2.2.2 of this chapter) as calculated by the NONROAD model. The model takes into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.3 Recreational Vehicles

5.2.3.1 Technologies and Estimated Costs

We estimated costs separately for snowmobiles, ATVs, and off-highway motorcycles. Individual technology costs were developed in cooperation with EPA by ICF Incorporated and Arthur D. Little - Acurex Environmental.[11] Costs were prepared for a typical engine that falls within the displacement ranges noted below. Costing out multiple engine sizes allowed us to estimate any differences in costs for smaller vs. larger engines. The costs include a mark-up to the retail level. This Chapter also provides a brief overview of the technologies, with more information provided in Chapter 4. Costs are provided for both the baseline technology and the new technology (e.g., a two-stroke engine and a four-stroke engine), with the cost of the change in technology being the increment between the two costs.

The R&D costs shown are average costs. The first engine line R&D cost is expected to be significantly higher but the costs would be distributed across the manufacturer's entire product line.[12] To account for any additional warranty cost associated with a change in technology, we have added 5 percent of the incremental hardware cost.[13]

As noted in section 5.1, fixed costs are spread over the first five years of sales for purposed of the cost analysis, with the exception of new facility costs for ATV testing which are spread over 10 years. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used at least that long. We estimated that R&D and facility costs would be incurred three years prior to production on average and tooling and certification costs would be incurred one year prior to production. These fixed costs were then increased seven percent for each year prior to the start of production to reflect the time value on money.

To approximate average annual sales per engine line, we divided the total annual unit sales by estimated total number of engines lines industry-wide.[m] Based on limited sales data from individual manufacturers provided to EPA on a confidential basis, there appears to be a large distinction in sales volume between small engine and large engine displacements for ATVs. The cost analysis accounts for this difference by using a larger annual sales rate per engine line for large ATVs, as shown below.

As noted below, the fuel savings over the life of the vehicle due to some of the projected technology changes can be substantial and in some cases are projected to offset the cost of the emissions controls. As discussed below, these fuel savings would occur because 2-stroke powerplants are inefficient and the changes needed to reduce hydrocarbons also improve fuel

[m] Based on publicly available product information for the large manufacturers, we estimated 32 engine lines for snowmobiles, 43 lines for ATVs, and 42 lines for off-highway motorcycles.

consumption. Because the fuel savings can outweigh up front costs, one might question why manufacturers continue to use 2-stroke engines. Manufacturers have not made these changes in the absence of emissions standards for several likely reasons. Many customers generally do not place a high value on fuel economy compared to initial cost and engine simplicity. Manufacturers have built a customer base over many years using 2-stroke technology. The engines are relatively simple and the production costs are relatively low because the manufacturers have been building the engines for many years. To capture the fuel economy benefits, manufacturers would have to invest substantially in R&D and more complex powerplants in the face of uncertainty with regard to market acceptance of the new product. Such a move could also lower profits per vehicle. Considering all these factors, manufacturers choose to focus improvements in other areas such as increasing horsepower and overall vehicle design.

Snowmobiles

Snowmobiles are currently almost exclusively powered by carbureted 2-stroke engines. We are basing the cost analysis for Phase 1 standards on the use of engine modifications, carburetor improvements, and recalibration. Manufacturers are likely to be able to meet standards by leaning out the air/fuel mixture, improving carburetors for better fuel control and less production variation, and modifying the engine to withstand higher temperatures and potential misfire episodes attributed to enleanment. Engine modifications are also likely to be made to improve air/fuel mixing and combustion. A small number of models are equipped with electronic fuel injection and these models would not have carburetor improvement costs associated with them. Tables 5.2.3.-1 and 5.2.3.-2 provide estimates of variable and fixed costs associated with the technologies that form the basis of our cost analysis for Phase 1. Recalibration work is included as part of the R&D for the technologies. The incremental cost per unit for engine modifications is estimated to be $17 to $24, with modifications to the carburetor estimated to cost an additional $18 to $24 per engine.

Table 5.2.3.-1. Snowmobile Engine Modification Costs for Two-Stroke Engines

	< 500 cc		> 500 cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Improved Pistons	$10	$12	$12	$15
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$20	$24	$36	$45
Labor @ $28 per hour	$6	$6	$8	$8
Labor Overhead @ 40%	$2	$2	$3	$3
Manufacturer Mark-up @ 29%	$6	$7	$10	$13
Warranty Mark-up @ 5%		$0		$0
Total Component Costs	$34	$39	$57	$69
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4600	4600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	$0	$12	$0	$12
Total Costs	$34	$51	$57	$81
Incremental Total Cost		$17		$24

Table 5.2.3-2. Modified Carburetor Costs for Snowmobiles

	< 500 cc		> 500 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Carburetor	$60	$65	$60	$65
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$120	$130	$180	$195
Labor @ $28 per hour	$1	$1	$2	$2
Labor Overhead @ 40%	$1	$1	$1	$1
Manufacturer Mark-up @ 29%	$35	$38	$53	$57
Warranty Mark-up @ 5%		$1		$1
Total Component Costs	**$157**	**$171**	**$236**	**$256**
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$61,875	$0	$61,875
Tooling Costs	$0	$5,000	$0	$5,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$4**	**$0**	**$4**
Total Costs	**$157**	**$175**	**$236**	**$260**
Incremental Total Cost		**$18**		**$24**

Manufacturers may use an expanded mix of technologies to meet Phase 1 standards. If manufacturers are successful in developing and deploying advanced technologies for snowmobiles such as 4-stroke engines and 2-stroke direct injection in the Phase 1 time frame, the mix of technologies for Phase 1 would be somewhat different. These technologies paths would provide much lower CO and HC emissions, as discussed in Chapter 4. Although these technologies would increase the cost of the engines, they would also potentially provide the consumer with greatly improved fuel economy, reliability, and in the case of direct injection, performance. For these reasons, we would expect manufacturers to continue to develop these advanced technologies and implement them when they are ready.

The cost analysis for the Phase 2 standards is based primarily on the use of direct fuel injection 2-stroke engines and 4-stroke engines for a portion of the fleet. We would expect that by the 2010 time frame these two technologies will be developed and able to be used on a significant fraction of the fleet. For cost purposes, we are projecting that 4-stroke engines are likely to be equipped with electronic fuel injection systems to optimize emissions and overall performance of these engines. Therefore we are including electronic fuel injection costs for 4-strokes. Tables 5.2.3.-3 through 5.2.3.-6 provide costs for direct injection systems (both air assisted direct injection and pump assisted direct injection) and for converting from a 2-stroke to 4-stroke engine.

Table 5.2.3-3. Air Assisted Direct Injection System Costs for Snowmobiles

	< 500 cc		> 500cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Fuel Metering Solenoid (each)		$15		$15
Number Required		2		3
Air Pump		$25		$25
Air Pump Gear		$5		$5
Air Pressure Regulator		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Electric Fuel Pump	$5	$5	$5	$5
Fuel Pressure Regulator		$3		$3
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$324	$185	$339
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$100	$55	$107
Royalty @ 3%		$10		$10
Warranty Mark-up @ 5%		$10		$8
Total Component Costs	**$164**	**$464**	**$243**	**$493**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$12**	**$0**	**$12**
Total Costs	**$164**	**$476**	**$243**	**$505**
Incremental Total Cost		**$312**		**$262**

Table 5.2.3-4. Pump-Assisted Direct Fuel Injection System Costs for Snowmobiles

	< 500cc		> 500cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Nozzle/Accumulator (each)		$33		$33
Number Required		2		3
High-Pressure Cam Fuel Pump		$20		$25
Cam Pump Gear		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Fuel Transfer Pump	$5	$5	$5	$5
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$347	$185	$385
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$106	$55	$120
Royalty @ 3%		$10		$12
Warranty Mark-up @ 5%		$11		$10
Total Component Costs	**$164**	**$494**	**$243**	**$556**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,600	4,600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$12**	**$0**	**$12**
Total Costs	**$164**	**$506**	**$243**	**$568**
Incremental Total Cost		**$342**		**$325**

Table 5.2.3-5. Two-Stroke to Four Stroke Conversion Costs for Snowmobiles

	< 500 cc		> 500 cc	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4-Stroke**
Engine	$400	$700	$650	$1,170
Clutch	$50	$75	$80	$120
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$136	$233	$217	$383
Warranty Mark up @ 5%		$16		$28
Total Component Costs	**$606**	**$1,053**	**$967**	**$1,730**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$20,000	$0	$20,000
Units/yr.	4,600	4,600	4,600	4600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$7**	**$0**	**$7**
Total Costs	**$606**	**$1,060**	**$967**	**$1,737**
Incremental Total Cost		**$454**		**$770**

Table 5.2.3-6. Electronic Fuel Injection Costs for Snowmobiles

Fuel Injection Costs	400cc		700cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Injectors (each)		$12		$12
Number Required		2		3
Pressure Regulator		$10		$10
Intake Manifold		$30		$35
Throttle Body/Position Sensor		$35		$35
Fuel Pump	$5	$20	$5	$20
ECM		$100		$100
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$10		$10
Injection Timing Sensor		$5		$5
Wiring/Related Hardware		$10		$10
Hardware Cost to Manufacturer	**$125**	**$249**	**$185**	**$266**
Labor @ $28 per hour	$1	$4	$2	$6
Labor Overhead @ 40%	$1	$2	$1	$3
Manufacturer Mark-up @ 29%	$37	$72	$54	$77
Warranty Mark-up[a] @ 5%		$6		$4
Total Component Costs	**$164**	**$333**	**$242**	**$356**
Fixed Cost to Manufacturer				
R&D Costs	$0	$69,417	$0	$69,417
Tooling Costs	$0	$10,000	$0	$10,000
Units/yr.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$5**
Total Costs ($)	**$164**	**$338**	**$242**	**$361**
Incremental Total Cost ($)		**$174**		**$119**

We have estimated the incremental cost of going from carbureted 2-stroke to direct injection to range from $262 to $342 per engine and conversion to 4-stroke to be about $454 to $770. Electronic fuel injection for snowmobiles is estimated to incrementally cost $174 to $119. It should be noted that the overall consumer costs for these advanced technologies would be substantially lower after the fuel economy improvements are taken into account. Estimates of the fuel savings are provided below.

Manufacturers are likely to concentrate the use of the above technologies on the more expensive or performance oriented models. We are projecting that 50 percent of models will be equipped with either direct injection or 4-stroke engines. We anticipate that remaining models would consist of Phase 1 technologies with some further optimization. We are projecting the use of pulse air systems with recalibration on the portion of snowmobile engines that are not equipped with advanced technology systems. Pulse air would provide a small incremental emission reduction for these engines and help manufacturers meet the Phase 2 average HC and CO standards. As shown in Table 5.2.3.-7, we have estimated pulse air to cost about $16. Catalysts are also a potential option for snowmobiles. However, we believe manufacturers are more likely to focus on developing the advanced technologies noted above, which provide the consumer with substantial benefits in addition to lower emissions. Therefore, have we not included catalyst costs in our cost estimates.

Table 5.2.3.-7. Calibration/Pulse-Air Costs for Snowmobiles

	Baseline	**Modified**
Hardware Costs		
Pulse Air Valve		$8
Labor @ $28 per hour		$1
Labor overhead @ 40%		$0
Markup @ 29%		$3
Warranty Mark up @ 5%		$0
Total Component Costs	**$0**	**$12**
Fixed Cost to Manufacturer		
R&D Costs		$54,750
Tooling Costs		$10,000
Units/yr.		4,600
Years to recover		5
Fixed cost/unit		**$4**
Total Costs	**$0**	**$16**
Incremental Total Cost		**$16**

All-terrain Vehicles (ATVs)

ATVs are primarily equipped with carbureted 4-strokes, with 2-stroke engines used primarily in small displacement and sport models. For the first phase of standards, we expect manufacturers to phase out the use of 2-stroke engines. In addition, we are also projecting that recalibration and pulse air systems would be used on about 25 percent of the models for Phase 1 to ensure that the fleet meets the standards on average. Pulse air systems are currently used on a few ATV and off-highway motorcycles models to meet California standards. We do not believe that the level of the standards would require the use of pulse air beyond 25 percent, given that only a few models in California are currently equipped with the technology. Using these technologies may give the manufacturer more flexibility in calibrating for performance on some models.

We are basing our technology projection on what manufacturers have done to meet the California emissions standards. We believe this to be the most likely technology path for manufacturers because 4-strokes are accepted in the market and provide consumers with fuel economy and reliability benefits. Substantial new R&D and major changes in technology would be needed to allow 2-stroke engines to meet the proposed Phase 1 standards. Because manufacturers would be able to carry over certification from the California emissions control program, manufacturers would already have many models equipped with 4-strokes that would meet the proposed Phase 1 standards.

For Phase 2, we are projecting that manufacturers would significantly increase the use of pulse air systems, from 25 percent for Phase 1 to 75 percent for phase 2. We would expect that the remaining emissions reductions would be achieved through recalibration and the use of oxidation catalysts on a fraction of ATVs models.

Catalysts have not been used to date on ATVs, but we would expect that their use on some ATV models would be attractive for manufacturers in complying with Phase 2 standards. Using a catalyst to control emissions would allow manufacturers to calibrate more for performance. Catalysts are typically sized at about half the engine displacement and typically achieve at least about a 50 percent reduction in emissions.

For purposes of the cost analysis, we are projecting catalyst use for 50 percent of ATV models. We believe that this is conservatively high because manufacturers have substantial lead-time to optimize engine emissions performance and may be able to achieve Phase 2 standards using catalysts on fewer models.

Tables 5.2.3.-8 through 5.2.3-10 provide cost estimates for the ATV technologies discussed above. Table 5.2.3.-11 provides a breakdown of the estimated costs of the catalyst. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $220 to $350, depending on engine size. Costs for a mechanical pulse air system and recalibration is estimated to be about $13 to $16 per unit. The cost of a catalyst system is estimated to be about $60. As shown in the tables below, fixed costs for larger displacement models are spread over a significantly larger annual unit sales volume to account for the relatively high average number of unit sales per engine line for these products.

Table 5.2.3.-8 Two-Stroke to Four Stroke Conversion Costs for ATVs

	< 200 cc		> 200 cc	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4 Stroke**
Hardware Costs				
Engine	$400	$550	$500	$750
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$122	$168	$151	$226
Warranty Mark up @ 5%		$8		$13
Total Component Costs	**$542**	**$755**	**$671**	**$1,018**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$15,000	$0	$18,000
Units/yr.	4,200	4,200	15,000	15000
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$7**	**$0**	**$2**
Total Costs	**$542**	**$762**	**$671**	**$1,020**
Incremental Total Cost		**$220**		**$349**

Table 5.2.3.-9. Four-stroke Calibration/Pulse-Air Costs for Four-Stroke ATVs

	≤ 200 cc		> 200 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Pulse Air Valve		$8		$8
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$0		$0
Markup @ 29%		$3		$3
Warranty Mark up @ 5%		$0		$0
Total Component Costs	**$0**	**$12**	**$0**	**$12**
Fixed Cost to Manufacturer				
R&D Costs		$54,750		$54,750
Tooling Costs		$8,000		$10,000
Units/yr.		4,200		15000
Years to recover		5		5
Fixed cost/unit		**$4**		**$1**
Total Costs	**$0**	**$16**	**$0**	**$13**
Incremental Total Cost		**$16**		**$13**

Table 5.2.3.-10. Oxidation Catalyst Costs for 4-Stroke ATV

	≤ 200 cc		> 200 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Oxidation Catalyst		$39		$44
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$1		$1
OEM markup @ 29%		$12		$13
Warranty Mark up @ 5%		$2		$2
Total Component Costs	**$0**	**$55**	**$0**	**$61**
Fixed Cost to Manufacturer				
R&D Costs		$59,500		$59,500
Tooling Costs		$10,000		$12,000
Units/yr.		4,200		15,000
Years to recover		5		5
Fixed cost/unit		**$5**		**$1**
Total Costs	**$0**	**$60**	**$0**	**$62**
Incremental Total Cost		**$60**		**$62**

Table 5.2.3-11. Oxidation Catalyst Cost Breakdown

Catalyst Characteristic	Unit	Value
Washcoat Loading	g/L	160
% ceria	*by wt.*	*50*
% alumina	*by wt.*	*50*
Precious Metal Loading	g/L	1.8
% Platinum	*by wt.*	*83.3*
% Palladium	*by wt.*	*0.0*
% Rhodium	*by wt.*	*16.7*
Labor Cost	$/hr	$28.00

Material	**$/troy oz**	**$/lb**	**$/g**	**Density (g/cc)**
Alumina		$5.00	$0.011	3.9
Ceria		$5.28	$0.012	7.132
Platinum	$412		$13.25	
Palladium	$390		$12.54	
Rhodium	$868		$27.91	
Stainless Steel		$1.12	$0.002	7.817

Catalyst Volume (cc)	100	200	350
Substrate Diameter (cm)	4	6	8
Substrate	$6.93	$7.87	$9.27
Ceria/Alumina	$0.18	$0.36	$0.63
Pt/Pd/Rd	$2.83	$3.97	$6.95
Can (18 gauge 304 SS)	$0.43	$0.64	$0.93
Substrate Diameter (cm)	4.00	6.00	8.00
Substrate Length (cm)	8.0	7.1	7.0
Working Length (cm)	10.8	9.9	9.8
Thick. of Steel (cm)	0.121	0.121	0.121
Shell Volume (cc)	12	16	21
Steel End Cap Volume (cc)	4	8	14
Vol. of Steel (cc) w/ 20% scrap	19	29	42
Wt. of Steel (g)	150	227	328
TOTAL MATERIAL COST	**$10.37**	**$12.85**	**$17.78**
LABOR	**$14.00**	**$14.00**	**$14.00**
Labor Overhead @ 40%	$5.60	$5.60	$5.60
Supplier Markup @ 29%	$8.69	$9.90	$11.69
Manufacturer Price	**$38.66**	**$44.02**	**$52.01**

Off-highway Motorcycles

Currently, off-highway motorcycles are about 65 percent 2-stroke, with many of the 2-stroke engines used in competition and youth models. We are projecting essentially the same mix of technologies for off-highway motorcycle as for ATVs (Phase 1), discussed above. As with ATVs, we would expect that standards would be met primarily through the use of 4-stroke engines. Manufacturers may also use pulse air systems and recalibration on a fraction of their models to ensure their overall fleet meets the standards. We have estimated their use for off-highway motorcycles at about 25 percent. We do not believe that the level of the standards would require the use of pulse air beyond 25 percent, given the only a few models in California are currently equipped with the technology. As discussed in 5.2.3.4 below, vehicles used solely for competition are exempt from standards and we would expect some 2-stroke competition models to remain in the market.

Tables 5.2.3.-12 and 5.2.3.-13 provide cost estimates for off-highway motorcycles technologies for three engine displacement ranges. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $220 to $360, depending on engine size. Costs for a mechanical pulse air valve system and recalibration is estimated to be about $17 per unit.

5.2.3.2 Operating Cost Savings

Snowmobiles

Both direct injection and conversion from two-stroke to 4-stroke yield substantial fuel economy benefits. Typical 2-stroke engines have relatively poor fuel economy performance because a portion of the combustion mixture passes through the engines unburned. Because 4-stroke and direct injection 2-stroke engine designs essentially do not allow this to occur, they provide better fuel economy as well as substantially lower HC emissions. We have estimated fuel savings based on a 25 percent reduction in fuel consumption, based on typical performance of these technologies. Lifetime fuel costs are provided in Table 5.2.3.-14.[14, 15]

Table 5.2.3.-14. Fuel Cost for Snowmobiles

Engine	Baseline 2-Stroke		Advanced Technology Engines (25% savings)	
	small	large	small	large
Engine power	75	125	75	125
Load Factor	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	57	57	57	57
Lifetime, yr	9	9	9	9
BSFC, lb/bhp-hr	1.66	1.25	1.66	1.25
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	396	659	297	494
Yearly Fuel Cost ($/yr)	$435	$725	$326	$544
Lifetime Fuel Cost (NPV)	**$2,835**	**$4,725**	**$2,126**	**$3,543**

* Excluding taxes

ATVs and Off-highway Motorcycles

Conversion from 2-stroke to 4-stroke engines would yield a fuel economy improvement for ATVs and off-highway motorcycles. Tables 5.2.3.-15 and 5.2.3.-16 provide estimates of fuel consumption for both 2-stroke and 4-stroke engines. We have estimated that switching from a 2-stroke to a 4-stroke engine would reduce fuel consumption by about 25 percent. Lifetime fuel savings for ATVs resulting from switching from a 2-stroke to a 4-stroke engine is estimated to be $234 for a small displacement engine and $1,166 for a large displacement engine. For off-highway motorcycles, the projected lifetime fuel savings range from $63 to $311.

Table 5.2.3.-15. Fuel Cost for ATVs

Engine	2-Stroke		4-Stroke	
	small	large	small	large
Engine power	5	25	5	25
Load Factor	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	350	350	350	350
Lifetime, yr	13	13	13	13
BSFC, lb/bhp-hr	1.05	1.05	0.79	0.79
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	102	512	77	385
Yearly Fuel Cost ($/yr)	$113	$563	$85	$424
Lifetime Fuel Cost (NPV)	**$942**	**$4,708**	**$708**	**$3,542**

* Excluding taxes

Table 5.2.3.-16. Fuel Cost Savings for Off-highway Motorcycles

Engine	2-stroke			4-stroke		
	small	med.	large	small	med.	large
Engine power	5	12	25	5	12	25
Load Factor	0.34	0.34	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	120	120	120	120	120	120
Lifetime, yr	9	9	9	9	9	9
BSFC, lb/bhp-hr	1.05	1.05	1.05	0.79	0.79	0.79
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	35	84	176	26	63	132
Yearly Fuel Cost ($/yr)	$39	$93	$193	$29	$70	$145
Lifetime Fuel Cost (NPV)	**$252**	**$604**	**$1,258**	**$189**	**$454**	**$947**

* Excluding taxes

It should be noted that conversion to 4-stroke engines would also result in savings in oil consumption and improvements in durability. In a 2-stroke engine, oil is added to the gasoline in order to lubricate the engine, resulting in a faster oil use rate than in a 4-stroke engine. Also, 4-stroke engines have increased durability compared to 2-strokes, resulting in less frequent major engine repairs. We have not attempted to quantify the resulting cost savings, but the savings would provide a benefit for the consumer.

5.2.3.3 Compliance Costs

We estimate ATV and off-highway motorcycle chassis-based certification to cost about $25,000 per engine line, including $10,000 for engineering and clerical work and $15,000 for durability and certification testing. For snowmobile engine-based certification, we estimate costs to be about $30,000, recognizing that engine testing is somewhat more expensive than vehicle testing due to the time needed to set up the engine on the test stand. As with other fixed costs, we amortized the cost over 5 years of engine sales to calculate per unit certification costs shown in Table 5.2.3.-17. The actual certification costs for ATVs and off-highway motorcycles are likely to be lower than those shown in the table above because manufacturers are likely to use certification data generated for the California program.

Table 5.2.3.-17 Estimated Per Unit Certification Costs

	Snowmobiles	ATVs		Off-highway Motorcycles
units/year	4,600	4,200	15,000	3,500
certification costs	$1.70	$1.55	$0.42	$1.86

We have estimated that manufacturers would be required to test about 0.2% of production to meet production line testing requirements. Using per test costs of $2,500 for vehicle testing and $5,000 per test for engine testing, we estimate a per unit cost for production line testing of $5 for off-road motorcycles and ATVs and $10 for snowmobiles.

In general, we expect manufacturers would be able to use existing test facilities. For manufacturers that do not have sufficient chassis testing capabilities for ATVs, we would expect them to carry over engine-based certifications from the California program during Phase 1 of the ATV standards. Because the option of carrying over California engine test data would not be available for Phase 2 standards, manufacturer could be required to conduct chassis testing of ATVs. Therefore, we have estimated the cost of new chassis testing facilities to be included in the cost of the Phase 2 standards. The costs are based on an estimate provided by one manufacturer that a full test cell would cost $2 million to build. We have estimated that on average manufacturers would need two such facilities to conduct testing. The costs will vary somewhat among manufacturers depending on the state of their existing facilities and the number of vehicle families that must be certified. However, we believe that this is a generous estimate because some manufacturers would likely be able to upgrade existing test facilities instead of building new facilities.

By estimating $4 million per manufacturer, with 7 manufacturers, and amortizing the costs over 10 years (10 years x 546,000 units), we estimate an average per unit cost of $8.94. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used at least that long. It should be noted that these costs would be avoided if an adequate engine-based test procedure can eventually be developed and adopted for ATVs for Phase 2.

5.2.3.4 Recreational Vehicle Total Costs

The analysis below combines the costs estimated above into a total composite or average cost for each vehicle type. The composite analysis weights the costs by projecting the percentage of their use, both in the baseline and control scenario, to project industry-wide average per vehicle costs.

A summary of the estimated near-term and long-term per unit average incremental costs and fuel savings for recreational vehicles is provided in Table 5.2.3.-18. Long-term costs do not include fixed costs, which are retired, and include cost reductions due to the learning curve.

Table 5.2.3.-18 Total Average Per Unit Costs and Fuel Savings

	Snowmobile Phase 1	Snowmobile Phase 2	ATV Phase 1	ATV Phase 2	Off-highway Motorcycle
near-term costs	$55	$216	$60	$52	$151
long-term costs	$27	$125	$38	$28	$94
fuel savings (NPV)	$0	($509)	($102)	$0	($98)

Tables 5.2.3.-19 through 5.2.3.-23 provide the detailed average, or composite, per unit costs for snowmobiles (Phase 1 and Phase 2), ATVs (Phase 1 and Phase 2), and off-highway motorcycles. The composite costs are based on the estimated distribution of the different engine displacement ranges. We estimated an approximate distribution of sales among the displacement ranges using limited sales data provided by some manufacturers on a confidential basis and production data from Power Systems Research. Incremental costs are shown both for the near-term and long-term. Long term costs reflect the retirement of fixed costs and the affect of the learning curve, described in section 5.1.

Table 5.2.3.-19 Estimated Average Costs For Snowmobiles (Phase 1)

		Cost	Lifetime Fuel Savings	Baseline	Control	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	engine modifications	$17	$0	0%	100%	$17	$0
	modified carburetor	$18	$0	0%	95%	$17	$0
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$46	$0
> 500 cc (70%)	engine modifications	$24	$0	0%	100%	$24	$0
	modified carburetor	$24	$0	0%	95%	$23	$0
	compliance	$12	$0	0%	100%	$12	$0
	total	--	--	--	--	$59	$0
Near Term Composite Incremental Cost		--	--	--	--	**$55**	**$0**
Long Term Composite Incremental Cost		--	--	--	--	**$27**	**$0**

Table 5.2.3.-20 Estimated Average Costs For Snowmobiles (Phase 2)

		Cost	Lifetime Fuel Savings	Baseline	Control	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$16	$0	0%	50%	$8	$0
	direct injection*	$327	($709)	0%	40%	$131	($284)
	electronic fuel injection	$174	$0	5%	15%	$17	$0
	4-stroke engine	$455	($709)	1%	10%	$41	($64)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$209	($348)
< 500 cc (70%)	pulse air/recalibration	$16	$0	0%	50%	$8	$0
	direct injection*	$294	($1,181)	0%	40%	$118	($472)
	electronic fuel injection	$119	$0	5%	15%	$12	$0
	4-stroke engine	$770	($1,181)	1%	10%	$69	($106)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$219	($578)
Near Term Composite Incremental Cost		--	--	--	--	**$216**	**($509)**
Long Term Composite Incremental Cost		--	--	--	--	**$125**	**$0**

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 5.2.3.-21 Estimated Average Costs For ATVs (Phase 1)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$220	$234	8%	100%	$202	($215)
	pulse air/recalibration	$16	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$213	($215)
> 200 cc (85%)	4-stroke engine	$349	$1,166	93%	100%	$24	$82
	pulse air/recalibration	$13	$0	0%	25%	$3	$0
	compliance	$6	--	0%	100%	$6	--
	total	--	--	--	--	$33	($82)
Near Term Composite Incremental Cost		--	--	--	--	**$60**	**($102)**
Long Term Composite Incremental Cost		--	--	--	--	**$38**	**($102)**

Table 5.2.3.-22 Estimated Average Costs For ATVs (Phase 2)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$220	$234	100%	100%	$0	$0
	pulse air/recalibration	$16	$0	25%	75%	$8	$0
	oxidation catalyst	$60	$0	0%	50%	$30	$0
	compliance	$16	--	0%	100%	$16	--
	total	--	--	--	--	$54	$0
> 200 cc (85%)	4-stroke engine	$349	$1,166	100%	100%	$0	$0
	pulse air/recalibration	$13	$0	25%	75%	$7	$0
	oxidation catalyst	$62	$0	0%	50%	$31	$0
	compliance	$14	--	0%	100%	$14	--
	total	--	--	--	--	$52	$0
Near Term Composite Incremental Cost		--	--	--	--	**$52**	**$0**
Long Term Composite Incremental Cost		--	--	--	--	**$28**	**$0**

Table 5.2.3.-23 Estimated Average Costs For Off-highway Motorcycles (Non-competition models only)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 125 cc (37%)	4-stroke engine	$222	$63	82%	100%	$40	($11)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$51	($11)
125 < 250 cc (21%)	4-stroke engine	$289	$150	30%	100%	$202	($105)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$213	($105)
≥ 250 cc (42%)	4-stroke engine	$357	$311	45%	100%	$196	($171)
	pulse air/recalibration	$17	$0	0%	25%	$4	$0
	compliance	$7	--	0%	100%	$7	--
	total					$207	($171)
Near Term Composite Incremental Cost		--	--	--	--	**$151**	**($98)**
Long Term Composite Incremental Cost		--	--	--	--	**$94**	**($98)**

Currently, off-highway motorcycles are about 63 percent 2-stroke with many of the 2-stroke engines used in competition and youth models. In recent years, more high performance and competition models have been successfully introduced with 4-stroke engines and there appears to be a trend toward increased use of 4-stroke engines. Models used solely for competition are exempt from CAA requirements and we expect some 2-stroke competition models would continue to be sold under this exemption. For purposes of the cost analysis, we have estimated that 29 percent of all off-highway motorcycles would be exempt as competition models and that these models would be equipped with 2-stroke engines. We have based the estimate of exempt models on the our estimate of the current use of 2-strokes in the motocross market. We believe the emissions standards would be reasonably achievable for 4-stroke engines, especially with averaging, and that manufacturers would elect to certify all 4-stroke models in order to market them to the widest possible consumer base.

To account for the competition model exemption in the calculation of average costs, we have adjusted the percentage of 2-stroke engines from the overall baseline percentage of off-highway motorcycle sales using the 29 percent estimate noted above. This adjustment is necessary in order to determine the average costs for only those off-highway motorcycles that would be covered by the program. Table 5.2.3.-24 provides our estimate of the baseline percentage of 2-strokes in overall sales and the percentage of the non-competition model sales.

Table 5.2.3.-24 Estimated Off-highway Motorcycle Percent 2-stroke Engine Usage

Displacement	Overall Baseline 2-stroke percentage	Baseline 2-stroke percentage Excluding Competition Models
< 125 cc	42%	18%
125 to 249 cc	79%	70%
> 250 cc	68%	55%

5.2.3.5 Recreational Vehicle Aggregate Costs

The above analyses developed incremental per vehicle cost estimates for snowmobiles, ATVs, and off-highway motorcycles. Using these per vehicle costs and projections of future annual sales, we have estimated total aggregate annual costs for the recreational vehicles standards. The aggregate costs are presented on a cash flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the vehicle is operated over its life. Table 5.2.3.-25 presents a summary o f the results of this analysis. As shown in the table, aggregate net costs increase from about $40 million in 2006 to about $70 million in 2010 when the program is fully phased in. Net costs are projected then to decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used. Fuel savings are projected to more than offset the costs of the program starting in 2013.

Table 5.2.3.-25 Summary of Annual Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
Snowmobiles	$8.49	$39.50	$25.00	$26.28	$27.62
ATVs	$27.16	$78.46	$56.81	$51.93	$51.93
Off-highway Motorcycles	$8.81	$13.12	$11.63	$12.22	$12.85
Total	$44.46	$131.08	$93.45	$90.43	$92.40
Fuel Savings	($4.98)	($60.55)	($153.06)	($211.20)	($227.22)
Net Costs	$39.47	$70.53	($59.62)	($120.77)	($134.83)

To project annual sales, we started with 1999 sales estimates provided by industry organizations. We then adjusted the numbers and applied sales growth estimates consistent with the modeling performed to estimate total emissions (see Section 6.2.4.1.1). For ATVs, we added 70,000 units to account for sales from companies not included in the industry organization estimates. Sales growth for snowmobiles and off-highway motorcycle sales is projected to be about one percent per year. The off-road motorcycle sales were reduced by 29 percent to account for the exemption of competition models. ATVs are modeled differently because recent sales growth rates have been significantly higher than one percent but are at rates not likely to be sustained indefinitely. We project that ATV sales will continue to grow at a higher rate over the next few years but will level off by 2006. Table 5.2.3.-26 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.3.-26 Estimated Annual Recreational Vehicle Sales

	1999	2006	2010	2020
Snowmobiles	148,000	158,676	166,235	182,394
ATVs	616,000	838,102	838,102	838,102
Off-highway motorcycles*	105,790	113,421	118,027	130,375

* Non-competition only

To calculated annual aggregate costs, the sales estimates have been multiplied by the per unit costs. Fuel savings have been calculated using the NONROAD model to calculate the shift in use from 2-stroke to 4-stroke vehicles, and also direct injection 2-strokes for snowmobiles, over time. The model takes into consideration vehicle sales and scrappage rates. The standards phase-in schedule for off-highway motorcycles (50/100% in 2006/2007) and ATVs (Phase 1: 50/100% in 2006/2007, Phase 2: 50/100% in 2009/2010) has also been taken into account. The detailed year-by-year analysis is provided in Chapter 7.

Chapter 5 References

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