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Nonroad Recreational Vehicle Technologies and Costs

Draft Final Report

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

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U.S. Environmental Protection Agency
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1. Introduction

This report assesses the economic implications of adopting emission controls on currently unregulated nonroad recreational vehicles as proposed by the United States Environmental Protection Agency (EPA). For the purposes of this effort, nonroad recreational vehicles are meant to include snowmobiles, all-terrain vehicles (ATVs), and off-road motorcycles.

Due to the importance of a national standard, the long-term economic results of employing emission controls must be understood, particularly in a currently uncontrolled market segment. Specific economic components examined in this report include hardware costs, fixed costs to manufacturers, and end-user fuel savings.

Nonroad recreational vehicles have several technical barriers that impact emission control costs. Because recreational vehicles are not subject to inspections, it is difficult to insure that emission controls are not tampered with or otherwise defeated. This is of particular concern for nonroad recreational vehicles equipped with catalysts. The rugged use of recreational vehicles requires that controls used on these platforms be engineered to meet demanding durability standards.

These challenges have been addressed in this report in two ways. Some potential technologies have been eliminated from consideration or limited to platforms that are well suited to their use. Durability testing and research costs incurred by vehicle manufacturers necessary to overcome these hurdles has been included in this costing effort.

2. Background

Recreational vehicles generally use either two-stroke or four-stroke gasoline engines, with displacements ranging between 50cc and 1000cc, and power ratings from 5hp to over 175hp. Annual production levels are shown in Table 2-1. In order to capture the variety of engine packages used by these vehicles, yet limit the permutations of cases examined, representative or "average" vehicles were developed based on vehicle populations and usage. As a result, each vehicle type is analyzed by engine type and displacement, independent of other nonroad vehicles.

Table 2-1. Vehicle Summary by Application

Vehicle Applications	Engine Type	Annual Production[1] (%)	Cooling	
			Air	Liquid
Snowmobiles	2-Stroke	100	--	--
	4-Stroke	--	70%	30%
All-Terrain Vehicles	2-Stroke	12	25%	75%
	4-Stroke	88	65%	35%
Off-Road Motorcycles	2-Stroke	63	65%	35%
	4-Stroke	37	80%	20%

These engines are categorized by engine type (two- or four-stroke) and engine displacement. It is estimated here that all engines use gasoline. This report focuses on seven representative vehicles: two each for ATVs and snowmobiles, and three off-road motorcycle packages. These average vehicles are summarized in Section 3, Table 3-1.

The nonroad vehicles considered in this report account for just under a million units in annual production. This volume in tandem with relatively high emissions levels for these uncontrolled vehicles results in a significant emissions inventory problem.

[1] "Control of Emissions From Nonroad Large Spark Ignition Engines, Recreational Engines (Marine and Land-Based) and Highway Motorcycles," Federal Register, Vol. 65, No. 236, Pages 76797-76829.

3. Technology Description

Currently nonroad recreational vehicles such as snowmobiles, all-terrain vehicles (ATVs), and off-road motorcycles are not subject to federal emission standards except in California. California currently regulates off-road motorcycles and ATVs to 1.2 g/km HC and 15 g/km CO for 1997 and later model years[2]. As such, these vehicles are virtually uncontrolled. The following sections describe current vehicle equipment and potential emissions controls.

3.1 Baseline Technologies

The baseline technologies listed below capture the representative or "average" vehicles present in the marketplace. While some exceptions to these characterizations exist, they represent a marginal fraction of vehicle production. This study is meant to support U.S. EPA rule-making for gasoline-powered, recreational, nonroad vehicles only. It is not intended to fully capture all nonroad vehicle activity. Two-stroke and four-stroke engines are covered by application below.

3.1.1 Two-Stroke Engines

Two-stroke engines power nearly all snowmobiles as well as 63% of off-road motorcycles, and 12% of ATVs. This extensive vehicle population, combined with elevated engine emissions, results in a significant emissions inventory problem. The emissions from two-strokes are many times higher than those of four-stroke power plants, particularly for unburned hydrocarbons and particulate matter. Fuel short-circuiting during the scavenging process causes significant amounts of fuel to escape the combustion process. This unburned fuel is directly emitted as hydrocarbon emissions. Traditional two-stroke engines also have increased hydrocarbon emissions that stem from routing the intake charge through the crankcase. In most cases, crankcase scavenged two-stroke engines mix lubricating oil with the fuel, which also contributes to hydrocarbon emissions.

Two-stroke engines used on snowmobiles typically have two or three cylinders, with total displacements between 300cc and 1000cc. Carburetion is the most common method of fuel delivery used on snowmobile engines, with most vehicles employing a carburetor for each engine cylinder. While carburetion is most common, several newer models employ electronic fuel injection (EFI). Engines with displacement less than 300cc are primarily air cooled, and engines with displacements greater than 550cc are generally liquid cooled.

[2] These California emissions standards for engines at or below 90cc begin with the 1999 model year.

ATV two-stroke engines are typically single cylinder and between 200cc and 500cc in displacement. A few entry-level models have smaller, single-cylinder engines with displacements of approximately 80cc. ATV engines are almost exclusively carbureted and mostly air cooled, though some larger displacement engines do employ liquid cooling.

Off-road motorcycles equipped with two-stroke cycle engines tend to have displacements between 125cc and 500cc. Several competition and entry-level models use smaller engines that vary between 50cc and 100cc. Cooling on off-road motorcycle engines varies, with larger engines using liquid cooling and smaller engines relying on air-cooling.

3.1.2 Four-Stroke Engines

Four-stroke engines are widely used in recreational vehicles. Approximately 88% of ATVs and 37% of off-road motorcycles have four-stroke power plants. Four-stroke engines have significantly lower emissions and fuel consumption as compared to two-stroke engines because of the differences in the scavenging process.

While a few niche-market snowmobiles use four-stroke engines, these vehicles represent a very small market segment. As such, this report does not consider snowmobiles equipped with four-stroke engines as a baseline technology.

Many ATV models use four-stroke engine technology. These engines tend to be single-cylinder, carbureted units that vary in displacement between 200cc and 600cc. A small fraction of ATVs, primarily entry-level models, use smaller engines with displacements of 200cc or less. As a rule, these engines are also air cooled, though several larger displacement, high-output engines are liquid cooled.

Off-road motorcycles that use four-stroke engines generally have displacements between 200cc and 600cc. A few entry-level models use engines as small as 50cc, and some models have engines as large 780cc. These models represent a small fraction of vehicle production. These engines are typically assembled in air-cooled, carbureted, single-cylinder packages.

Table 3-1. Baseline Technology Summary

Engine Type	Snowmobiles	ATVs	ORMCs
Two-Stroke	400cc, Carbureted, Air-Cooled 700cc, Carbureted, Liquid-Cooled	50cc, Carbureted, Air-Cooled 250cc, Carbureted, Air-Cooled	50cc, Carbureted, Air-Cooled 125cc, Carbureted, Air-Cooled 250cc, Carbureted, Air-Cooled
Four-Stroke	--	90cc, Carbureted, Air-Cooled 400cc, Carbureted, Liquid-Cooled	90cc, Carbureted, Air-Cooled 250cc, Carbureted, Air-Cooled 400cc, Carbureted, Liquid-Cooled

3.2 Advanced Technologies

The technologies in this report are focused on reducing hydrocarbon and carbon monoxide emissions. This is not meant to discount the impact from oxides of nitrogen, but the discussion of these and other species is beyond the purview of this report. Moreover, this report is aimed solely at cost issues and is not a feasibility study. As such, any listed emission reduction percentages are provided to give the reader a general sense of the impacts that are possible; they do not represent definitive research and testing. Several of the emission control techniques listed are already in place on nonroad and on-highway vehicles. As such the projected development costs are relatively small. [See Section 4 for details.]

3.2.1 Engine Modification

Two-stroke engine modifications include exhaust tuning, optimizing bore/stroke ratios, optimizing intake, scavenge, and exhaust port shape and size, and port placement. These modifications increase trapping efficiency and reduce fuel short-circuiting, which directly reduces hydrocarbon emissions. In addition, optimized swirl, squish, and tumble will provide better combustion of the intake charge. Engine modifications can result in a 30-40%[3] reduction in hydrocarbon emissions from two-stroke engines and reduce fuel consumption by about 10%[3]. By reducing over fueling, however, exhaust temperatures are increased and some care must be taken to prevent a reduction in engine life. As discussed here, we would expect 2-stroke engine modifications to include durability improvements as well as more precise atomization and improved fuel delivery. Improved fuel control is covered in the discussions of Advanced Carburetion, Electronic Fuel Injection, and Direct Fuel Injection.

[3]Estimates based on confidential conversations with vehicle manufacturers and technology vendors.

3.2.2 Advanced Carburetion (for Two-Stroke Engines)

Hydrocarbon emissions can be reduced with improved fuel atomization. By changing the jets and venturi in existing carburetor designs, fuel atomization can be refined without resorting to more expensive fuel injection systems. This reduces droplet fall-out and wall wetting, thereby decreasing hydrocarbon emissions. While the emissions reductions from advanced carburetion are relatively modest, they cost very little and can be employed on virtually any carbureted engine. Hydrocarbon emissions are estimated to decrease 5%-10%[3] and fuel consumption by approximately 3-5%[3] with advanced carburetion.

3.2.3 Electronic Fuel Injection (EFI)

EFI can provide significant reductions in HC emissions through better fuel atomization and better transient control. In addition, if the fuel injection system is sequential, (i.e., fuel individually injected to each intake port at the proper time), wall wetting is greatly reduced. Furthermore, injection of the fuel can be timed to minimize fuel short-circuiting during scavenging. Positioning a fuel injector at each intake port also minimizes fuel mal-distribution between cylinders. A potential fuel economy improvement also results. Implementing fuel injection on nonroad vehicles requires an electronic control module (ECM) to time and phase fuel delivery. In addition to the ECM, fuel injection systems also require a medium-pressure (20-40 psi) fuel pump, a fuel pressure regulator, and more extensive fuel plumbing than carbureted engines. In addition to mechanical hardware, fuel injection systems also require sensors and wiring that add to the overall system cost. Hydrocarbon emission reductions due to EFI are estimated between 15%-30%[3] as compared to conventional carburetion. Fuel consumption is expected to decrease by 5-15%[3] using EFI instead of conventional carburetors.

3.2.4 Direct Fuel Injection

Direct fuel injection technology delivers fuel directly to the combustion chamber. When installed on two-stroke engines, direct injection systems can eliminate fuel short-circuiting, significantly reducing unburned hydrocarbon emissions. Direct injection systems require many of the components used in EFI systems - an ECM, a fuel pump, and engine position sensors. Hydrocarbon emissions could be reduced between 50% and 75%[3] and fuel consumption between 25-30%[3] using direct injection techniques. Two basic direct injection strategies are examined in this report: air-assisted direct fuel injection and pump-assisted direct fuel injection.

Air-assisted direct fuel injection systems utilize an air pump in combination with a fuel metering solenoid to deliver fuel to the combustion chamber. Under this configuration, a transfer pump is used to send fuel from the tank to a metering valve located at the engine head. An air nozzle, supplied by an air pump, is combined with a fuel-metering valve and placed directly above the combustion chamber. When fuel is required, the metering valve releases a measured quantity of fuel in conjunction with a pulse of pressurized air. The air pulse assists in atomizing the metered fuel, and the resulting mixture is forced directly into the engine cylinder. The timing of these events are controlled by an ECM equipped with appropriate sensors for engine position/speed, throttle position, intake air temperature, and barometric pressure.

Pump-assisted direct fuel injection is achieved using a high-pressure fuel pump to atomize and deliver fuel to the engine's combustion chamber. While these fuel pumps can be configured several ways, it is envisioned that the fuel will most likely be compressed using a fuel pump assembly similar to a diesel jerk pump. A jerk pump uses an eccentric cam lobe to squeeze a quantity of fuel in a chamber, pressurizing it. The pump's fuel outlet is routed to the engine head and terminated with a metering solenoid valve. The solenoid valve is actuated by the ECM, enabling precise timing of the injection event that can be continuously varied. Just as with air-assisted systems, the ECM must be linked to a sensor network that determines engine operation conditions.

3.2.5 Two-Stroke to Four-Stroke Engine Replacement

Another method to reduce hydrocarbon short-circuiting in two-stroke engines is to replace them with four-stroke engines. The costs to re-engineer a 2-stroke engine are significant as two-stroke engines lack several components found in four-stroke engines such as camshafts, poppet valves, and timing chains/gears/belts. Additionally, several two-stroke engine components require substantial re-design to be compatible with four-stroke engines. Realistically speaking, recreational vehicle manufacturers will use existing four-stroke engines, with some R&D to install the engine and optimize performance. These modifications and differences include changes to the clutch/transmission, engine mounts, and increased vehicle weight from four-stroke engines. Hydrocarbon emissions are estimated to decrease by 70-90%[3] and fuel consumption approximately 25%[3] over a carbureted two-stroke engine.

3.2.6 Four-stroke Calibration/Pulse-Air

Depending on the level of the standards adopted, some calibration work may be needed for four-stroke engines to comply. For example, several manufacturers offer off-road motorcycles in "California Compliant" and 49-state versions. The so-called California Compliant motorcycles meet the off-road CARB emissions requirements to be eligible for sale in the state. Often the difference between California Compliant and 49-state versions lies in minor modifications to valve or ignition timing, carburetor settings, or other such adjustments that require minimal additional hardware. In addition, pulse-air injection into the exhaust stream can also be used. Pulse-air injection mixes oxygen with the relatively high temperature hydrocarbons and carbon monoxide present in the exhaust. This combination of high temperature, residual gases, and oxidizer enables hydrocarbon and carbon monoxide to be reduced, or “burned up” between the combustion chamber and tailpipe exhaust.

It is proposed that four-stroke calibration and pulse-air systems be used to reduce nonroad vehicle emissions. This report estimates that such modifications come at the cost of additional engine testing and tuning, and a pulse-air valve. Four-stroke calibration/pulse-air can reduce hydrocarbon emissions by 10% to 40%[3] over an uncontrolled four-stroke engine. Fuel consumption is expected to be approximately the same as an uncontrolled four-stroke engine.

3.2.7 Oxidation Catalysts

Catalytic after-treatment is another technology that can be employed on recreational vehicles to achieve emission reduction. For the purposes of this study open loop, oxidation catalysts were costed assuming a 30-50% hydrocarbon reduction from baseline (i.e. uncontrolled) two-stroke engines and 50% for four-stroke engines. Catalyst volumes are estimated to be 50% of engine displacements to achieve desired hydrocarbon reductions. To be conservative, this report estimates that catalyst volumes would be no less than 100cc. While smaller catalysts, some as small as 10cc, have been explored on handheld devices such as chainsaws, this report does not believe that such devices are widely available for use. It is possible that catalysts smaller than 100cc may be practical. If these smaller catalysts are mass-produced, the figures listed here form an upper bound for the catalyst costs.

A precious metal loading of 1.8g/L was used based on SAE Paper 1999-01-3282 that identified a range of 1.76 to 2.11 g/L for catalysts using a 5:1 Platinum/Rhodium ratio. Detailed catalyst assumptions used in this report are shown in table 3-2. Lower precious metal loadings (~0.18 g/liter) might be used for two-stroke engine oxidation catalysts to minimize heat release that could result from the high hydrocarbon emissions characteristic of those engines.

Table 3-2. Oxidation Catalyst Characteristics

Catalyst size	50% of engine displacement with a minimum of 100cc
Substrate	Metallic, 100 cells per inch
Washcoat	50% ceria / 50% alumina Loading 160 g/liter
Precious Metals	Pt/Pd/Rd 5/0/1 Loading 1.8 g/liter

4. Cost Methodology

In order to determine the estimated cost of compliance with potential future emission regulations, representative models of snowmobiles, off-road motorcycles, and all-terrain vehicles were chosen among several manufacturers' engine lines and cost information was collected for each. No single model's costs were used to develop the estimates presented in this report, but rather representative averages of all costs collected were used for each technology.

Costs for the technologies discussed in Section 3 are presented in this section. These costs include hardware costs and fixed costs. Fuel economy improvement savings are also discussed. All costs represent the incremental costs for engines to meet the proposed emission standards.

4.1 Hardware Cost to Manufacturer

Component costs were developed for each technology discussed in Section 3. Separate costs were derived for each of the various engine displacements and vehicle types shown in Table 3-1. Manufacturer costs of components were estimated from various sources including confidential information from motorcycle, snowmobile, and ATV manufacturers, fuel systems manufacturers, and previous work performed by Arthur D. Little[4,5,6]. Dealer and parts supplier prices less various mark-ups were used to verify the range of component prices.

Catalyst prices were determined through a bottom up analysis similar to work done by in previous studies by Arthur D. Little[4,5,6]. This approach calculates costs based upon catalyst dimensions, precious metal loadings and washcoat loadings. The prices of precious metal per troy oz., washcoat, and steel per pound were similar to those used to develop Tier 2 standards for automobiles and light trucks. A medium scale production of catalysts of a similar size of several thousand units per year and an average labor time of one-half hour per unit including the time necessary to weld the catalyst to the muffler are estimated in this report. Because of the diversity of vehicle types and sizes, the catalyst manufacturers' process will be somewhat less automated than in the automotive industry. Labor rates used in this study are $17.50 per hour plus a 60 percent fringe rate for a total labor cost of $28 per hour.

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[4] Browning, Louis and Kassandra Genovesi. "Cost Estimates for Heavy-Duty Gasoline Vehicles," prepared for the U.S. Environmental Protection Agency, September 1998.

[5] Browning, Louis and Fanta Kamakaté. "Sterndrive and Inboard Marine SI Engine Technologies and Costs," prepared for the U.S.. Environmental Protection Agency, September 1999.

[6] Browning, Louis and Fanta Kamakaté. "Large SI Engine Technologies and Costs," prepared for the U.S. Environmental Protection Agency, November 2000.

All hardware costs are subject to a 29 percent mark up, which represents an average manufacturer mark up of technologies on new engine sales.[7] The 5 percent warranty markup was added to the incremental hardware cost to represent an overhead charge covering warranty claims associated with new parts.

4.2 Fixed Cost to Manufacturer

The fixed costs to the manufacturer consist of the cost of researching, developing and testing a new technology. They also include the cost of retooling the assembly line for the production of new parts. Research and development will focus on adapting emission controls to specific recreational nonroad applications, with significant engine calibration needed to optimize these controls over a large range of vehicle models and operating conditions. Two categories of R&D are used in this analysis. It is assumed that the manufacturer will apply a new technology to one engine line and then apply this experience to all its other engine lines. This base R&D is estimated at $60,333 per month which includes engine or vehicle test time utilizing 2 engineers and 3 technicians/vehicle operators as shown in Table 4-1. Testing costs include $1,250 per day for dynamometer costs and $500 per day for allocated test engine costs for 20 days of testing per month.

Table 4-1. Base R&D Costs

Cost Item	No	Cost per Month	Amount
Engineers	2	$4,167	$8,333
Techs/Operators	3	$2,500	$7,500
Total Salaries			$15,833
Fringe & Overhead		60%	$9,500
Test Costs			$35,000
Total Cost per Month			$60,333

The second phase will be optimizing this new technology on a specific engine line. This effort is estimated at $39,667 per month based upon engine or vehicle testing utilizing one engineer and 2 technicians/vehicle operators as shown in Table 4-2.

[7] Jack Faucett Associates. "Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula", Report No. JACKFAU-85-322-3, September 1985.

Table 4-2. Individual Engine Line R&D Costs

Cost Item	No	Cost per Month	Amount
Engineers	1	$4,167	$4,167
Techs/Operators	2	$2,500	$5,000
Total Salaries			$9,167
Fringe & Overhead		60%	$5,500
Test Time			$25,000
Total Cost per Month			$39,667

Durability testing is costed for several two-stroke engine technologies, as many of the technologies reduce over-fueling and we would expect manufacturers to conduct testing to ensure that an adequate level of durability remains. Durability testing is estimated at $19,000 per month, which includes field test time utilizing one engineer three-quarters time and two technicians/vehicle operators full time as shown in Table 4-3.

Table 4-3. Durability Testing Costs

Cost Item	No	Cost per Month	Amount
Engineers	0.75	$4,167	$3,125
Techs/Operators	2	$2,500	$5,000
Total Salaries			$8,125
Fringe & Overhead		60%	$4,875
Field Test Time			$6,000
Total Cost per Month			$19,000

Fixed costs are estimated to be recovered in five years with a cost of money of seven percent per annum. R&D and durability testing is estimated to occur over a three year period ending one year before vehicle production. The number of units per year, derived from confidential sales data from major manufacturers, was supplied by EPA. Five years is a typical length of time used in the industry to recover an investment in a new technology.

4.3 Fuel Economy

As discussed in Section 3, many of the technologies can lead to fuel cost savings for the user. An estimate of these savings is developed in this report by using engine characteristics such as annual use (hrs/year), load factors, and lifetime provided from the EPA nonroad inventory data[8]. These data are reproduced in Table 4-4.

Table 4-4. Load factors, Lifetimes, and Annual Use for Recreational Nonroad Vehicles

Vehicle Type	Load Factor	Annual Use (hrs per yr.)	Lifetime (years)
ATVs	0.34	350	13
Off-road Motorcycles	0.34	120	9
Snowmobiles	0.34	57	9

The brake specific fuel consumption (bsfc) was also provided by EPA. For off-road motorycles and ATVs, two-stroke bsfc was estimated at 1.05 lb/bhp-hr and four stroke bsfc was estimated at 0.79 lb/bhp-hr. For snowmobiles, we used a bsfc estimate of 1.66 lb/bhp-hr. The price of gasoline ($1.10/gallon) was based on year 2000 averages from the Energy Information Administration without highway taxes[9]. The taxes were estimated from national average data provided by the American Petroleum Institute[10] and U. S. DOE Transportation Energy Data Book[11].

Using the following formulas, an estimate of the yearly fuel consumption and yearly fuel cost for a 10% improvement in fuel economy is determined. Actual cost savings can be scaled from this value using the ratio of actual fuel consumption reductions to the 10% reduction calculated here. The present value of yearly fuel cost was calculated using a 7% interest rate per annum.

$$\text{Yearly Fuel Consumption (gal / year)} = \frac{\text{Hp} * \text{Load Factor} * \text{Annual Operation (hrs / yr)} * \text{bsfc (lb / bhp - hr)}}{\text{Fuel Density (lbs / gal)}}$$

$$\text{Yearly Fuel Cost (\$ / yr)} = \text{Yearly Fuel Consumption (gal / year)} * \text{Fuel Cost (\$ / gal)}$$

8 Wehrly, Linc, “Emissions Modeling for Recreational Vehicles” , EPA Memorandum EPA420-F-00-051, November 13, 2000.

9 US Energy Information Administration, “Monthly Energy Review, April 2001,” www.eia.doe.gov\emeu\mer.

10 Barnes, Tina. “Nationwide and State-by-State Motor Fuel Taxes”, American Petroleum Institute, May 1999.

11 Davis, Stacy. “Transportation Energy Data Book,” U.S. DOE, Oak Ridge National Laboratory, Edition 19, 1999.

4.4 Results

Table 4-5 shows estimated costs to consumers of engine modifications for two-stroke engines that would be used in snowmobiles. Modified pistons that enable better combustion and more resistance to damage from leaner mixtures are calculated to increase the cost of pistons in 400cc engines by $2 per piston and 700cc engine by $3 per piston. Changes to port locations and sizes are part of the tooling costs. Six months of calibration and engine testing and 6 months of durability testing would be applied to the first engine line to develop the technology and prevent durability issues from reducing over fueling, then three months of testing would be done to finish product development for each specific engine line.

Table 4-5. Snowmobile Engine Modification Costs for Two-Stroke Engines

Engine Modification Costs	400cc Baseline	400cc Modified	700cc Baseline	700cc 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%	$8	$7	$10	$13
Warranty Mark-up[a] @ 5%		$0		$0
Total Component Costs	**$36**	**$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.	4,600	4,600	4,600	4,600
Years to recover	5	5	5	5
Fixed cost/unit	$0	$12	$0	$12
Total Costs ($)	**$36**	**$51**	**$57**	**$81**
Incremental Total Cost ($)		**$15**		**$24**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$362,000	$0	$362,000
Durability Testing[c]	$0	$114,000	$0	$114,000
Total Base R&D Costs	$0	$476,000	$0	$476,000
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$59,500	$0	$59,500
Individual line R&D[d]		$119,000		$119,000
Total R&D per Engine Line	**$0**	**$178,500**	**$0**	**$178,500**

[a] Calculated on incremental hardware costs
[b] 6 months of base R&D
[c] 6 months of durability testing
[d] 3 months of individual engine line R&D

Table 4-6 shows estimated costs to consumers of carburetor modifications for two-stroke engines that would be used in snowmobiles. Modified jets and venturi are estimated at $5 per carburetor. Two months of calibration and engine testing and 3 months of durability testing would be applied to the first engine line to develop the technology, then one month of testing would be done to finish product development for each specific engine line.

Table 4-6. Modified Carburetor Costs for Snowmobiles

Modified Carburetion Costs	400cc		700cc	
	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[a] @ 5%		$1		$1
Total Component Costs	**$157**	**$171**	**$236**	**$256**
Fixed Cost to Manufacturer				
R&D Costs	$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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$57,000	$0	$57,000
Total Base R&D Costs	$0	$177,667	$0	$177,667
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$22,208	$0	$22,208
Individual line R&D[d]		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$61,875**	**$0**	**$61,875**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] 3 months of durability testing
[d] 1 month of individual engine line R&D

Table 4-7 shows estimated costs to consumers of electronic fuel injection systems on two-stroke engines. One throttle body will be used with an intake manifold and individual port injectors. Three months of calibration and engine testing and 3 months of durability testing would be applied to the first engine line to develop timed fuel injection systems that reduce over fueling, then one month of testing would be done to finish product development for each specific engine line.

Table 4-7. Electronic Fuel Injection Costs for Snowmobiles

Fuel Injection Costs	400cc Baseline	400cc Modified	700cc Baseline	700cc 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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$181,000	$0	$181,000
Durability Testing[c]	$0	$57,000	$0	$57,000
Total Base R&D Costs	$0	$238,000	$0	$238,000
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$29,750	$0	$29,750
Individual line R&D[d]		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$69,417**	**$0**	**$69,417**

[a] Calculated on incremental hardware costs
[b] 3 months of base R&D
[c] 3 months of durability testing
[d] 1 month of individual engine line R&D

Tables 4-8 and 4-9 show estimated costs to consumers for an air-assisted and pump-assisted direct injection system, respectively, that could be used on snowmobile two-stroke engines. As these technology would be developed by an outside vendor but would probably be built by the engine manufacturer, a 3% royalty is applied to the technology cost. Six months of calibration and engine testing and 6 months of durability testing would be applied to the first engine line to integrate an air-assist or pump-assist direct fuel injection system on a two-stroke engine, then three months of testing would be done to finish product development for each specific engine line.

Table 4-10 shows estimated costs to consumers for adding an oxidation catalyst to a two-stroke snowmobile engine. Similar costs could be applied to equipping two-stroke engines in other applications with oxidation catalysts. Three months of calibration and engine testing and 3 months of durability testing would be applied to the first engine line to integrate an oxidation catalyst, then one month of testing would be done to finish product development for each specific engine line.

Tables 4-11 and 4-12 show estimated costs to consumers for repowering two-stroke engines with four-stroke engines of equivalent power for snowmobiles and ATVs, respectively. Generally, a four-stroke snowmobile engine has a different torque curve than a two-stroke snowmobile engine and therefore a modified clutch is needed. In ATVs, however, the present transmission and clutch arrangement should be adequate for the four-stroke engine In this analysis, an off-the-shelf four-stroke engine will be used to replace the two-stroke engine, but engine mountings will need to be changed. Two months of calibration and engine testing would be applied to the first engine line to integrate a four-stroke engine into a two-stroke snowmobile or ATV, then two months of testing would be done to finish product development for each specific engine line. We are projecting no additional durability testing for the 4-stroke engines because the engines are likely to be off-the-shelf and 4-strokes generally have superior durability characteristics relative to 2-stroke engines.

Table 4-8. Air Assisted Direct Injection System Costs for Snowmobiles

Air Assisted DI Costs	400cc Baseline	400cc Modified	700cc Baseline	700cc 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[a] @ 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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$362,000	$0	$362,000
Durability Testing[c]	$0	$114,000	$0	$114,000
Total Base R&D Costs	$0	$476,000	$0	$476,000
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$59,500	$0	$59,500
Individual line R&D[d]		$119,000		$119,000
Total R&D per Engine Line	**$0**	**$178,500**	**$0**	**$178,500**

[a] Calculated on incremental hardware costs
[b] 6 months of base R&D
[c] 6 months of durability testing
[d] 3 month of individual engine line R&D

Table 4-9. Pump-Assisted Direct Fuel Injection System Costs for Snowmobiles

Pump Assisted DI Costs	400cc Baseline	400cc Modified	700cc Baseline	700cc 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[a] @ 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	4,600
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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$362,000	$0	$362,000
Durability Testing[c]	$0	$114,000	$0	$114,000
Total Base R&D Costs	$0	$476,000	$0	$476,000
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$59,500	$0	$59,500
Individual line R&D[d]		$119,000		$119,000
Total R&D per Engine Line	**$0**	**$178,500**	**$0**	**$178,500**

[a] Calculated on incremental hardware costs
[b] 6 months of base R&D
[c] 6 months of durability testing
[d] 3 month of individual engine line R&D

Table 4-10. Two-Stroke Engine Catalyst Costs for Snowmobiles

Two-Stroke Catalyst Costs	400cc Baseline	400cc Modified	700cc Baseline	700cc Modified
Hardware Costs				
Oxidation Catalyst		$44		$52
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$1		$1
OEM markup @ 29%		$13		$16
Warranty Mark up[a] @ 5%		$2		$3
Total Component Costs	$0	$61	$0	$73
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**	**$5**
Total Costs ($)	**$0**	**$66**	**$0**	**$78**
Incremental Total Cost ($)		**$66**		**$78**

R&D Costs	Baseline	Modified	Baseline	Modified
Base R&D Costs for 1st Engine line[b]	$0	$181,000	$0	$181,000
Durability Testing[c]	$0	$57,000	$0	$57,000
Total Base R&D Costs	$0	$238,000	$0	$238,000
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$29,750	$0	$29,750
Individual line R&D[d]		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$69,417**	**$0**	**$69,417**

[a] Calculated on incremental hardware costs
[b] 3 months of base R&D
[c] 3 months of durability testing
[d] 1 month of individual engine line R&D

Table 4-11. Two-Stroke to Four Stroke Conversion Costs for Snowmobiles

Conversion to Four-Stroke Costs	400cc -> 600cc 2-Stroke	400cc -> 600cc 4-Stroke	700cc -> 950cc 2-Stroke	700cc -> 950cc 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[a] @ 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	4,600
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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$0	$0	$0
Total Base R&D Costs	$0	$120,667	$0	$120,667
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$15,083	$0	$15,083
Individual line R&D[d]		$79,333		$79,333
Total R&D per Engine Line	**$0**	**$94,416**	**$0**	**$94,416**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] No durability testing
[d] 2 months of individual engine line R&D

Table 4-12. Two-Stroke to Four Stroke Conversion Costs for ATVs

Four-Stroke Conversion Costs	50cc -> 90cc 2-Stroke	50cc -> 90cc 4-Stroke	250cc -> 400cc 2-Stroke	250cc -> 400cc 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[a] @ 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	15,000
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**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$0	$0	$0
Total Base R&D Costs	$0	$120,667	$0	$120,667
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$15,083	$0	$15,083
Individual line R&D[d]		$79,333		$79,333
Total R&D per Engine Line	**$0**	**$94,416**	**$0**	**$94,416**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] No durability testing
[d] 2 months of individual engine line R&D

Table 4-13 shows estimated costs to consumers for calibrating an uncontrolled four-stroke ATV engine to meet projected standards. Four-stroke calibration/pulse-air can be accomplished with minimal hardware changes, except for the addition of a pulse air valve. Two months of calibration and engine testing would be applied to the first engine line to integrate the pulse-air valve and recalibrate an uncontrolled four-stroke engine to meet emission standards, then one month of testing would be done to finish product development for each specific engine line. Since this is a minor addition and recalibration of a four-stroke engine, no durability testing will be needed .

Table 4-14 shows estimated costs to consumers for adding an oxidation catalyst to a uncontrolled four-stroke ATV engine. Similar costs could be applied to equipping four-stroke engines in other applications with oxidation catalysts. Two months of calibration and engine testing and 2 months of durability testing would be applied to the first engine line to integrate an oxidation catalyst, then one month of testing would be done to finish product development for each specific engine line.

Table 4-15 shows estimated costs to consumers for repowering two-stroke off-road motorcycle engines with four-stroke engines of equivalent performance. In this analysis, an off-the-shelf four-stroke engine will be used to replace the two-stroke engine, but mountings will need to be changed. The transmission on off-road motorcycles should be able to handle a 4-stroke engine. Two months of calibration and engine testing would be applied to the first engine line to integrate a four-stroke engine into a two-stroke off-road motorcycle, then two months of testing would be done to finish product development for each specific engine line. We are projecting no additional durability testing for the 4-stroke engines because the engines are likely to be off-the-shelf and 4-strokes generally have superior durability characteristics relative to 2-stroke engines.

Table 4-16 shows estimated costs to consumers for calibrating an uncontrolled four-stroke off-road motorcycle engine to meet emission standards. Four-stroke calibration can be accomplished with minimal hardware changes, except for the addition of a pulse-air valve. Two months of calibration and engine testing would be applied to the first engine line to integrate the pulse-air valve and recalibrate an uncontrolled four-stroke engine to meet emission standards, then one month of testing would be done to finish product development for each specific engine line. Since this is a minor addition and recalibration of a four-stroke engine, no durability testing will be needed.

Table 4-17 provides a summary of incremental costs for each technology for each platform. Table 4-18 shows bottom up catalyst costs to vehicle manufacturers for two-stroke and four-stroke

Table 4-13. Four-stroke Calibration/Pulse-Air Costs for Four-Stroke ATVs

Four-Stroke Calibration Costs	90cc 4-Stroke Baseline	90cc 4-Stroke Modified	400cc 4-Stroke Baseline	400cc 4-Stroke 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[a] @ 5%		$0		$0
Total Component Costs	**$0**	**$12**	**$0**	**$12**
Fixed Cost to Manufacturer				
R&D Costs	$0	$54,750	$0	$54,750
Tooling Costs	$0	$8,000	$0	$10,000
Units/yr.	4,200	4,200	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$4**	**$0**	**$1**
Total Costs ($)	**$0**	**$16**	**$0**	**$13**
Incremental Total Cost ($)		**$16**		**$13**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$0	$0	$0
Total Base R&D Costs	$0	$120,667	$0	$120,667
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$15,083	$0	$15,083
Individual line R&D[d]		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$54,750**	**$0**	**$54,750**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] No durability testing
[d] 1 month of individual engine line R&D

Table 4-14. Oxidation Catalyst Costs for 4-Stroke ATV

Four-Stroke Catalyst Costs	90cc 4-Stroke Baseline	90cc 4-Stroke Modified	400cc 4-Stroke Baseline	400cc 4-Stroke 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[a] @ 5%		$2		$2
Total Component Costs	**$0**	**$55**	**$0**	**$61**
Fixed Cost to Manufacturer				
R&D Costs	$0	$59,500	$0	$59,500
Tooling Costs	$0	$10,000	$0	$12,000
Units/yr.	4,200	4,200	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$1**
Total Costs ($)	**$0**	**$60**	**$0**	**$62**
Incremental Total Cost ($)		**$60**		**$62**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$38,000	$0	$38,000
Total Base R&D Costs	$0	$158,667	$0	$158,667
Engine lines per manufacturer	8	8	8	8
Base R&D per line	$0	$19,833	$0	$19,833
Individual line R&D[d]		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$59,500**	**$0**	**$59,500**

[a] Calculated on incremental hardware costs
[b] 3 months of base R&D
[c] 3 months of durability testing
[d] 1 month of individual engine line R&D

Table 4-15. Two-Stroke to Four Stroke Conversion Costs for Off-Road Motorcycles

Four-Stroke Conversion Costs	50cc -> 90cc		125cc -> 200cc		250cc -> 400cc	
	2-Stroke	4-Stroke	2-Stroke	4-Stroke	2-Stroke	4-Stroke
Hardware Costs						
Engine	$400	$550	$450	$650	$500	$750
Labor @ $28 per hour	$14	$21	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8	$6	$8
Markup @ 29%	$122	$168	$136	$197	$151	$226
Warranty Mark up[a] @ 5%		$8		$10		$13
Total Component Costs	**$542**	**$755**	**$606**	**$886**	**$671**	**$1,018**
Fixed Cost to Manufacturer						
R&D Costs	$0	$94,416	$0	$94,416	$0	$94,416
Tooling Costs	$0	$15,000	$0	$15,000	$0	$15,000
Units/yr.	3,500	3,500	3,500	3,500	3,500	3,500
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$9**	**$0**	**$9**	**$0**	**$9**
Total Costs ($)	**$542**	**$764**	**$606**	**$895**	**$670**	**$1,027**
Incremental Total Cost ($)		**$222**		**$289**		**$357**

R&D Costs	Baseline	Modified	Baseline	Modified	Baseline	Modified
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$0	$0	$0	$0	$0
Total Base R&D Costs	$0	$120,667	$0	$120,667	$0	$120,667
Engine lines per manufacturer	8	8	8	8	8	8
Base R&D per line	$0	$15,083	$0	$15,083	$0	$15,083
Individual line R&D[d]		$79,333		$79,333		$79,333
Total R&D per Engine Line	**$0**	**$94,416**	**$0**	**$94,416**	**$0**	**$94,416**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] No durability testing
[d] 2 months of individual engine line R&D

Table 4-16. Four-stroke Calibration/Pulse-Air Costs for Off-Road Motorcycles

Four-Stroke Calibration Costs	90cc 4-Stroke		200cc 4-Stroke		400cc 4-Stroke	
	Baseline	Modified	Baseline	Modified	Baseline	Modified
Hardware Costs						
Pulse Air Valve		$8		$8		$8
Labor @ $28 per hour		$1		$1		$1
Labor overhead @ 40%		$0		$0		$0
Markup @ 29%		$3		$3		$3
Warranty Mark up[a] @ 5%		$0		$0		$0
Total Component Costs	**$0**	**$12**	**$0**	**$12**	**$0**	**$12**
Fixed Cost to Manufacturer						
R&D Costs	$0	$54,750	$0	$54,750	$0	$54,750
Tooling Costs	$0	$8,000	$0	$8,000	$0	$8,000
Units/yr.	3,500	3,500	3,500	3,500	3,500	3,500
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$5**	**$0**	**$5**
Total Costs ($)	**$0**	**$17**	**$0**	**$17**	**$0**	**$17**
Incremental Total Cost ($)		**$17**		**$17**		**$17**

R&D Costs	**Baseline**	**Modified**	**Baseline**	**Modified**	**Baseline**	**Modified**
Base R&D Costs for 1st Engine line[b]	$0	$120,667	$0	$120,667	$0	$120,667
Durability Testing[c]	$0	$0	$0	$0	$0	$0
Total Base R&D Costs	$0	$120,667	$0	$120,667	$0	$120,667
Engine lines per manufacturer	8	8	8	8	8	8
Base R&D per line	$0	$15,083	$0	$15,083	$0	$15,083
Individual line R&D[d]		$39,667		$39,667		$39,667
Total R&D per Engine Line	**$0**	**$54,750**	**$0**	**$54,750**	**$0**	**$54,750**

[a] Calculated on incremental hardware costs
[b] 2 months of base R&D
[c] No durability testing
[d] 1 month of individual engine line R&D

Table 4-17. Technology Incremental Cost Summary

Snowmobiles	Incremental Technology Costs	
Advanced Technologies	**400cc 2-cylinder**	**700cc 3-cylinder**
Engine Modifications[a]	$15	$24
Modified Carburetor[a]	$18	$24
Electronic Fuel Injection[a]	$174	$119
Direct Injection[a,b]	$327	$294
Oxidation Catalyst[a]	$66	$78
Conversion to Four-Stroke[a,c]	$454	$770

[a] Baseline engine packages use uncontrolled carburetors.
[b] Direct injection costs reported are the average of air and pump assisted systems.
[C] 400cc 2-stroke -> 600cc 4-stroke; 700cc 2-stroke -> 950cc 4-stroke

ATVs	Incremental Technology Costs	
Advanced Technologies	**50cc single cylinder**	**250cc single cylinder**
Conversion to Four-Stroke[a,b]	$220	$349
Four-Stroke Calibration/Pulse-Air [c]	$16	$13
Oxidation Catalyst[c]	$60	$62

(1) Baseline Two-stroke engine with uncontrolled carburetors.
(2) 50cc 2-stroke -> 90cc 4-stroke; 250cc 2-stroke -> 400cc 4-stroke
(3) Baseline Four-stroke engine with uncontrolled carburetors

Off Road Motorcycles	Incremental Technology Costs		
Advanced Technologies	**50cc single cylinder**	**125cc single cylinder**	**250cc single cylinder**
Conversion to Four-Stroke[a,b]	$222	$289	$357
Four-Stroke Calib/Pulse-Air[c]	$17	$17	$17

(1) Baseline Two-stroke engine with uncontrolled carburetors.
(2) 50cc 2-stroke -> 90cc 4-stroke; 125cc 2-stroke -> 250cc 4-stroke,; 250cc 2-stroke -> 400cc 4-stroke
(3) Baseline Four-stroke engine with uncontrolled carburetors

Table 4-18. Oxidation Catalyst Costs for Two-Stroke and Four-Stroke Engines

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)	4.0	6.0	8.0
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 MAT. 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**

R&D Costs[a]	2-stroke	4-stroke
Base R&D Costs for 1st Engine line	$181,000	$120,667
Durability Testing	$57,000	$38,000
Total Base R&D Costs	$238,000	$158,667
Engine lines per mfr	8	8
Base R&D per line	$29,750	$19,833
Individual line R&D	$39,667	$39,667
Total R&D per Engine Line	**$69,417**	**$59,500**

[a] Typical R&D costs to integrate oxidation catalyst

engines. Three different sizes of catalysts are shown. Precious metal costs were taken from the 2007 heavy-duty vehicle rule analysis.[12]

Average fuel cost savings for snowmobiles, ATVs and off-road motorcycles are shown in Tables 4-19, 4-20, and 4-21, respectively, for a 10% reduction in fuel consumption. These savings can be scaled relative to actual fuel consumption reductions due to new technologies.

[12] EPA, "Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements," EPA420-R-00-026, December 2000.

Table 4-19. Fuel Cost Savings for Snowmobiles

Engine	2-Stroke 400cc		2-Stroke 700cc	
Fuel Economy	**Baseline**	**Improved**	**Baseline**	**Improved**
_ .	75	75	125	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	1.49	1.66	1.49
BSFC improvement		10%		10%
Fuel Density (lbs/gal)	6.1	6.1	6.1	6.1
Fuel Cost ($/gal)	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	396	356	659	593
Yearly Fuel Cost ($/yr)	$435	$392	$725	$653
Present Value of Fuel Cost ($)	**$2,835**	**$2,551**	**$4,725**	**$4,252**
Incremental Fuel Cost ($)		**-$284**		**-$473**

Table 4-20. Fuel Cost Savings for ATVs

Engine	2-Stroke 50cc		2-Stroke 250cc		4-Stroke 90cc		4-Stroke 400cc	
Fuel Economy	**Baseline**	**Improved**	**Baseline**	**Improved**	**Baseline**	**Improved**	**Baseline**	**Improved**
_ .	5	5	25	25	5	5	25	25
Load Factor	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	350	350	350	350	350	350	350	350
Lifetime, yr	13	13	13	13	13	13	13	13
BSFC, lb/bhp-hr	1.05	0.95	1.05	0.95	0.79	0.71	0.79	0.71
BSFC improvement		10%		10%		10%		10%
Fuel Density (lbs/gal)	6.1	6.1	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	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	102	92	512	461	77	69	385	347
Yearly Fuel Cost ($/yr)	$113	$101	$563	$507	$85	$76	$424	$381
Present Value of Fuel Cost ($)	**$942**	**$847**	**$4,708**	**$4,237**	**$708**	**$638**	**$3,542**	**$3,188**
Incremental Fuel Cost ($)		**-$95**		**-$471**		**-$70**		**-$354**

Table 4-21. Fuel Cost Savings for Off-Road Motorcycles

Engine	**2-Stroke 50cc**		**2-Stroke 125cc**		**2-Stroke 250cc**	
Fuel Economy	**Baseline**	**Improved**	**Baseline**	**Improved**	**Baseline**	**Improved**
_ .	5	5	12	12	25	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	0.95	1.05	0.95	1.05	0.95
BSFC improvement		10%		10%		10%
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	$1.10
Yearly Fuel Consumption (gal/yr)	35	32	84	76	176	158
Yearly Fuel Cost ($/yr)	$39	$35	$93	$83	$193	$174
Present Value of Fuel Cost ($)	**$252**	**$226**	**$604**	**$544**	**$1,258**	**$1,132**
Incremental Fuel Cost ($)		**-$26**		**-$60**		**-$126**

Engine	**4-Stroke 90cc**		**4-Stroke 200cc**		**4-Stroke 400cc**	
Fuel Economy	**Baseline**	**Improved**	**Baseline**	**Improved**	**Baseline**	**Improved**
_ .	5	5	12	12	25	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	0.79	0.71	0.79	0.71	0.79	0.71
BSFC improvement		10%		10%		10%
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	$1.10
Yearly Fuel Consumption (gal/yr)	26	24	63	57	132	119
Yearly Fuel Cost ($/yr)	$29	$26	$70	$63	$145	$131
Present Value of Fuel Cost ($)	**$189**	**$170**	**$454**	**$409**	**$947**	**$852**
Incremental Fuel Cost ($)		**-$19**		**-$45**		**-$95**