U.S. Environmental Protection Agency

Marine Outboard and Personal Watercraft SI Engine Technologies and Costs

Preliminary Report

July 2006

021348

ICF INTERNATIONAL

Passion. Expertise. Results.

This page deliberately left blank.

U.S. Environmental Protection Agency

Marine Outboard and Personal Watercraft SI Engine Technologies and Costs

Final Report

July 2006

Prepared for
U.S Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, Michigan 48105

Prepared by:
Louis Browning and Seth Hartley
ICF International
394 Pacific
San Francisco, CA 94111
(415) 677-7100

021348

This page intentionally left blank.

Table of Contents

List of Figures

List of Tables

This page intentionally left blank.

1. Introduction

The United States Environmental Protection Agency's (USEPA) final rule on spark-ignited (SI) marine engines, published in August, 1996, established emission limits for marine gasoline outboard engines and SI engines used in personal watercraft and jet boat applications, resulting in cleaner and better performing marine engines. The standards set in 1996 included an increasingly strict regulation of HC and NOx emissions phased in from 1998 to 2006, but did not include a CO cap. In 2002 USEPA proposed a rule on evaporative emissions standards that included a notice of intent for future regulation of outboard and personal watercraft emissions. USEPA is now considering new emission standards for outboard and personal watercraft. The new standards under consideration would likely require technologies similar to those needed to meet new emission standards recently adopted by CARB. These would include the use of four-stroke engines or two-stroke engines with direct injection technologies.

In some cases, updated technology is expected to be implemented to reduce emissions, such as adding fuel injection technology or exhaust after-treatment. In other cases, migrating to cleaner technologies already in existence, such as moving from two- to four-stroke engines, will be required to meet new standards. The purpose of this report is to provide details on incremental technology and estimated costs for marine outboard and personal watercraft SI engines that could be fleet averaged to meet reduced emission levels. ICF International determined prices for technology packages for marine outboard SI engines, which include migrating from a base package of uncontrolled, carbureted two-stroke engines to direct fuel injection and indirect fuel injection systems for two-stroke engines, as well as migrating to four-stroke engines. For four-stroke engines, the base was taken as uncontrolled, carbureted engines, and advanced systems investigated were migration to throttle body injected and multipoint fuel injection systems. The addition of a three-way catalyst inside the exhaust manifold for four-stoke, multipoint fuel-injected engines was also investigated. Because the technology mix needed to comply with any new, lower emission standards for outboard marine and personal watercraft engines is not known and is likely to be achievable through a mix of technologies and engines, this array of technology packages are representative of what might be available on marine outboard and personal watercraft SI engines. All technology packages considered are open-loop systems and are available in some form on marine outboard or personal watercraft engines available today.

The cost estimates include fixed and variable costs and rely on information gathered from engine and equipment manufacturers and experience in costing other SI engine technologies. Representative engine models of different sizes are used to develop incremental technologies. Early drafts of the technology package descriptions and cost estimates were submitted for review to industry contacts. Their comments were incorporated in the results presented in this report.

The following sections discuss background information on marine outboard and personal watercraft SI engines (Section 2), describe baseline and advanced technologies (Section 3), and present the cost estimate methodologies (Section 4) and the results obtained (Section 5).

2. Background

Marine outboard and personal watercraft (PWC) engine manufacturers occasionally purchase engine blocks, but typically produce outboard and personal watercraft engine packages themselves. This includes installing fuel systems, exhaust and intake systems, and features that permit optimal performance as marine engines. This process includes waterproofing, adding a fuel system, gear packages, and exhaust systems. Engine manufacturers may also be watercraft manufacturers, particularly for PWC and jet boat applications, and in that capacity install their completed engines in boats.

Outboard and personal watercraft engines come in both four-stroke and two-stoke configurations. Fuel delivery in either can currently be carbureted, or fuel injected (port, throttle body, or direct fuel injected). Almost all systems are currently open loop, and they typically have no exhaust after-treatment, although at least one manufacturer sells a PWC system with a catalyst housed in the exhaust and a closed loop system. There are large variations of technologies currently used in outboard and PWC engines, including a range of fuel injection technologies, and engine powers ranging from less than 10 to over 300 hp. The largest emitting engines, 2-stroke carbureted, tend to be grouped toward smaller sizes, and are expected to be phased out over the next few years. Essentially all outboard and personal watercraft engines are gasoline powered. Three examples of outboard and PWC engines are shown in Figure 2-1, for a large two-stroke DFI outboard (Mercury's Optimax 225), a small, carbureted four-stroke outboard (Tohatsu's 9.8 hp Four-Stroke) and a four-stroke PWC (Yamaha's FX High Output model). According to the National Marine Manufacturers Association's (NMMA) estimates, shown in Table 2-1, the sales of outboard boats and engines, as well as PWC and jet boats all fell from 2000 to 2003, although most showed a modest increase in 2004, the most recent year of data. Outboard boats accounted for about 55% of the total mechanically propelled recreational boat sales in the United States in 2004, the largest fraction of any boat type. PWC accounted for about 20% of the total mechanically propelled recreation boat sales in 2004, while jet boats made up about 1%.

Figure 2-1 Examples of Outboard and PWC Configurations

Sources:

1. http://www.mercurymarine.com/mercury_225_optimax_saltwater.
2. http://tohatsu.com/outboards/9_8_4st.html.
3. http://www.yamaha-motor.com/products/unitinfo/3/wvr/37/350/0/yamaha_fx_high_output.aspx.

Table 2-1 Outboard and PWC Engines/Boat Sales Estimates (2000-2004) (NMMA)

Year	2000	2001	2002	2003	2004
Outboard Boats	241,200	217,800	212,000	207,100	216,600
Outboard Motors	348,700	299,100	302,100	305,400	315,300
Personal Watercraft	92,000	80,900	79,300	80,600	79,500
Jet Boats	7,000	6,200	5,100	5,600	5,600

Source: http://nmma.org/facts/boatingstats/2004/files/market1.asp

3. Technology Description

Because there is expected to be a mix of technologies implemented fleet-wide to meet possible future emissions standards of reduced HC+NOx and CO emissions, this study focuses on a range of technologies and develops incremental costs in migrating between these technologies. The baseline technologies are considered to be uncontrolled, carbureted two- and four-stroke engines. Advanced packages include direct fuel injection and indirect fuel injection systems for two-stroke engines, as well as migrating to four-stroke engines, and migration from carburetion to throttle body injected and multipoint fuel injected systems for four-stroke engines. The addition of a three-way catalyst inside the exhaust manifold for four-stoke, multipoint fuel injected engines was also included in the pricing. Common sizes of outboard and personal watercraft engines were used for costing purposes and these are shown in Table 3-1. Other engine models of similar sizes will have similar changes and costs. Note that not all manufacturers produce engines in these configurations and that not all configurations are available for all sizes today from any manufacturer. Where not available, estimates were made based on similar sized engines and comparable technology. Table 3-2 lists the advanced technology packages for 2 and 4 stroke engines.

Table 3-1 Engine Sizes Used for Costing

Engine Type	Horsepower	Displacement	Cylinders
Outboard Engines	9.9 hp	0.25 L	2
	40 hp	0.76 L	3
	75 hp	1.60 L	3
	125 hp	1.80 L	4
	225 hp	3.00 L	6
Personal Watercraft Engines	85 hp	1.65 L	2
	130 hp	1.85 L	3
	175 hp	2.50 L	4

Table 3-2 Advanced Technology Packages

2-stroke	Indirect Fuel Injection	Direct Fuel Injection	Migration to 4-stroke
4-stroke	Throttle Body Injection	Multipoint Fuel Injection	MPI with Oxidation Catalyst

3.1. Baseline Technologies

The baseline technologies considered for each of the five outboard and three PWC engine models consist of carbureted fuel delivery systems not calibrated for low emissions. This includes both 2-stroke and 4-stroke engine models. Note that a carbureted 4-stroke engine is also considered an advanced technology option for carbureted 2-stroke engines. Many manufacturers produce engines in both these configurations in a range of sizes, although new carbureted 2-stroke engines are expected to be phased out over the next few years. Currently, carbureted engines are more popular in smaller engine sizes to provide low-cost, entry-level marine engines for their clients.

Two-stroke engines fire every engine revolution and have fewer moving parts than their 4-stroke counterparts. This gives 2-stroke engines a high power to weight ratio. However, the fuel short circuiting inherent in conventional 2-strokes, the consumption of oil, and the reduced fuel efficiency and engine durability of conventional carbureted 2-stroke engines makes them much less environmentally friendly than 4-stroke engines. Carbureted 2-stroke engines are as much as 25-40% less efficient than comparable 4-strokes or direct fuel injected 2-strokes.

Four-stroke engines fire every other engine revolution, thus allowing a single complete stroke for both charging and clearing the combustion chamber. Conventional 4-stroke engines are heavier than their 2-stroke counterparts, but more fuel-efficient and produce fewer emissions by eliminating fuel short circuiting and isolating lubricating oil from the combustion process.

All baseline engines are carbureted. The technology behind carburetors has changed little over time. Generally, any improvement in the efficiency of carburetors has been obtained by reducing tolerances in the manufacturing process. Generally, carburetion provides fuel to multiple cylinders unevenly, has less control of air/fuel ratio particularly during transients, often is set rich of stoichiometric, and requires the user to operate a choke, all of which make carburetion less ideal than fuel injection. Carbureted systems are less expensive and mechanically and electrically simpler than fuel injected systems, however.

3.2. Advanced Technologies

A mix of advanced technologies is likely to be applied to the suite of new engines produced to comply with lower emission standards. As shown in Table 3-2, these packages differ for 2-stroke and 4-stroke engines. For both 2- and 4-stroke engines, fuel injection is likely to replace carburetion, while 2-stroke engines are likely to be replaced with cleaner 4-stroke engines. Two types of fuel injection systems are already established for each of the engine cycles, and are considered here: direct and indirect injection for 2-stroke engines and port and throttle body injection for 4-stroke engines. Additionally, exhaust after treatment with a three-way catalyst inserted into the exhaust manifold is considered for the port fuel injected 4-stroke engines. All engines configurations for outboard and PWC engines considered here are open loop without catalysts and closed loop with catalyst.

Note that in comparison of technologies, migration from 2-stroke carbureted to 4-stroke carbureted engines is considered. This is not really a migration to an advanced technology; however it will result in significant emissions reductions for the reasons discussed above. This comparison also appears below.

3.2.1 2-Stroke Direct Fuel Injection Technologies

Direct fuel injection (DFI) in 2-stroke engines reduces the problem of fuel short-circuiting that is responsible for the typically poor efficiency and emissions rate associated with 2-stroke engines. This is done by inducting air only into the combustion chamber and injecting fuel into the combustion chamber directly after the exhaust ports have been covered by the piston. Converting a conventional 2-stroke engine to a DI engine is accomplished by replacing the cylinder head with one that allows an injector beside the spark plug, removing the carburetor, and installing an additional higher pressure fuel pump, engine control module, and various sensors and wiring to properly meter the fuel delivery.

DFI technology has been adopted well by the market for its enhanced performance and fuel economy characteristics. It is most popular on larger outboard and personal watercraft engines, as it provides the good power to weight ratio associated with 2-stroke engines but improves greatly on the efficiency and emissions rate of the engine. There are currently three types of DFI systems: ETech (cam-assist) used by BRP and others, Orbital (air assist) used by Mercury Marine and others, and a proprietary Yamaha system. These systems differ primarily in the pressures under which they operate and the method used to atomize the fuel.

3.2.2 2-Stroke Indirect Fuel Injection

Indirect injection (IDI) for 2-stroke engines is very similar to throttle body injection for 4-stroke engines. In this case, the carburetor is replaced with a mixing chamber where the fuel, air, and oil are pre-mixed before being inducted into the combustion chamber. This system has advantages over conventional carbureted 2-stroke engines in that the air-fuel mixture is more precise for a given load, the fuel and oil are properly pre-mixed, and the system is generally less expensive. However, this technology does not necessarily deliver the enhanced emissions performance of direct injected 2-stroke engines because short circuiting is still possible.

Component-wise, IDI differs from DFI in the replacement of fuel metering solenoids with injectors, the addition of a fuel distributor, and the replacement of the air compressor and air regulator with a high pressure fuel pump and a pressure regulator.

3.2.3 4-Stroke Port (Multipoint) Fuel Injection

A port fuel injection (PFI) system includes an injector per cylinder, a fuel rail, a pressure regulator, an electronic control module (ECM), manifold air pressure and temperature sensors, an additional higher pressure fuel pump, a throttle assembly, a throttle position sensor, and a magnetic crankshaft pickup for engine speed.

PFI systems also require a cool fuel system in order to prevent vapor lock problems. When a boat's engine is turned off, its heat can turn the fuel in the fuel line into vapor. If an attempt is made to restart the engine, no fuel is supplied to the engine as the fuel injector cannot inject vapor and because of the positive vapor pressure in the fuel line, the pump will not pump liquid fuel into the line. Cooling the fuel using a cool fuel system will keep it in liquid state and eliminate the occurrence of vapor lock. Since fuel cooling is necessary for all fuel injected systems, it only becomes an emission-related cost if a manufacturer upgrades a carbureted system to a fuel injected system in order to meet emissions standards

In general, PFI systems provide better fuel distribution between cylinders than carbureted fuel systems. PFI allows for better fuel control during transients than carbureted engines.

3.2.4 4-Stroke Throttle Body Fuel Injection

Throttle body injected (TBI) systems essentially replace a carburetor with a throttle body into which a precise amount of fuel is injected and mixed with air before induction into the combustion chamber. This allows reduced cost over PFI systems on 4-stroke engines as there is no need for a fuel rail and there are fewer injectors needed (typically one to two) for the engine (although they are typically larger and more expensive than those for PFI systems). TBI systems do not allow the same precise fuel distribution among cylinders as offered by PFI systems, but the performance is enhanced over traditional carbureted systems. TBI systems are also less expensive than PFI systems.

3.2.5 Electronic Control Modules

Electronic control modules (ECM) control fuel injection and ignition timing in uncontrolled fuel injected systems. Carbureted systems may also use an ignition control module (ICM), which has limited functions.

Currently, fuel injected systems' ECMs are 32-bit systems. Although fuel injected systems' ECMs will be required to perform more tasks to meet emissions standards, the 32-bit processors are still adequate for these additional requirements. A large portion of ECM costs are related to software development which is considered a fixed cost.

3.2.6 Catalysts

Three-way catalysts are likely to be incorporated only on some outboard and personal watercraft models as an additional control mechanism for emissions reduction. The catalyst envisioned for these engines is likely to be a small "brick" located inside the exhaust system with a volume about 35% of the total engine displacement. Although catalysts are not common on outboard and personal watercraft engines, at least one manufacturer (Yamaha) has provided high-end PWCs and jet boats with catalysts in the exhaust system for several model years. Southwest Research Institute has also tested catalysts in inboard engines and found that adequate emission reductions can be realized with reasonable catalyst life.

Table 3-3 describes the three-way catalysts envisioned for marine outboard engines and Table 3-4 for PWC engines. Platinum/Rhodium precious metal catalysts will most likely be used. A precious metal loading of around 1.0 gram per liter of catalyst size are expected to be used.

According to catalyst manufacturers, a ceramic substrate will be sufficiently strong to withstand the vibration and temperature variations marine systems are subjected to. To avoid underestimating costs, costs were calculated with the ceramic substrate mounted in a steel can. In practice, the substrate can be mounted with or without a shell in the exhaust system. One catalyst is envisioned per engine. The total cost of adding a catalyst includes the catalyst, housing and retooling the exhaust manifold, as well as labor, markup, and warranty costs.

Table 3-3 Catalyst Characteristics for Outboard Engines

Engine Size	9.9 hp Engine	40 hp Engine	75 hp Engine	125 hp Engine	225 hp Engine
Catalyst Size	0.09 L	0.27 L	0.56 L	0.63 L	1.05 L
Substrate	Ceramic 400 cells per inch	Ceramic 400 cells per inch	Ceramic 400 cells per inch	Ceramic 400 cells per inch	Ceramic 400 cells per inch
Washcoat	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide
Precious Metals	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L

Table 3-4 Catalyst Characteristics for Personal Watercraft Engines

Engine Size	85 hp Engine	130 hp Engine	175 hp Engine
Catalyst Size	0.58 L	0.65 L	0.88 L
Substrate	Ceramic 400 cells per inch	Ceramic 400 cells per inch	Ceramic 400 cells per inch
Washcoat	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide	75% cerium 25% alumina oxide
Precious Metals	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L	Pt/Rh 4/1 Loading 1.0 g / L

4. Cost Methodology

In order to determine costs for technologies that manufacturers are likely to employ to comply with potential future emission regulations, representative models of the five outboard and three PWC engines described earlier 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.

The technologies described in Section 3 have benefits that go beyond emission control. Assigning the full incremental cost of these technologies as an impact of emissions standards may therefore overestimate the true cost of emission control. The costing described herein only focuses on emissions-related improvements and not performance-related ones. All costs are reported in 2005 dollars and represent the incremental costs associated with various technology packages engine manufacturers might employ in different aspects of their production lines to meet new emission standards.

4.1. Hardware Costs

The hardware cost to the manufacturers varies greatly with emission technology package. Generally, as engines and fuel delivery systems become more complicated, one of the largest incremental costs will be the enhancement of ECMs. Other fuel system components, such as air compressors, pressure regulators, injectors, and the various sensors used in the systems also add significant costs to the enhanced technology packages. Manufacturer prices of all components were estimated from various sources, including confidential information from engine manufacturers and previous work performed by ICF International on spark-ignited engine technology. Discounted dealer and parts supplier prices were used to verify the range of component prices, as were prices obtained directly from engine manufacturers.

Three-way catalyst component information was obtained directly from catalyst manufacturers and current ICF work with three-way catalyst technology and costs for sterndrive and inboard SI engines. The prices of precious metal per troy ounce represent average prices over the last three years. Washcoat and steel prices represent current estimates. The labor cost is based upon a small scale production of catalysts of a similar size of 15,000 units per year and an average labor time of a half hour per unit, which includes the time necessary to install the catalyst in the exhaust manifold. To minimize costs, all manufacturers with similar-sized engines will most likely use a similar catalyst. Labor rates used are estimated $17.50 per hour plus a 60% fringe rate for a total labor cost of $28 per hour.

All hardware costs to the engine manufacturer are subject to a 29% mark-up which represents a typical mark-up of technologies on new engine sales[1]. This mark-up includes manufacturer overhead, manufacturer profit, dealer overhead and dealer profit. A separate supplier mark-up of 29% is also applied to the catalyst. The 5% warranty markup is added to the hardware cost to represent an overhead charge covering warranty claims associated with the new parts. This is a lower rate than what would be typically used because of the long history of similar electronic fuel injection systems in other applications.

4.2. Fixed Costs

The fixed costs to the manufacturer include the cost of researching, developing and testing a new technology. It also includes the cost of retooling the assembly line for the production of new parts. The fixed costs are listed separately for the development and durability testing costs. The advanced fuel system technology needed to reduce emissions is already in part present in a considerable share of many current product lines, thus further development needed is minimal.

The number of units per year per engine family and the number of years to recover are used to determine the fixed cost per unit in 2005 dollars. The present cost estimate uses the average engine sales shown in Table 4-1. The numbers of units per year are estimates derived from confidential information received from manufacturers. The numbers reflect the variation in average production between large and small businesses that share the market.

Five years is used as the length of time to recover an investment in new technology. This is a typical value for the marine outboard and personal watercraft industry.

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

Table 4-1 Production Levels (units per year)

Engine Type	Horsepower	Sales
Outboard Engines	9.9 hp	5,000
	40 hp	5,600
	75 hp	6,400
	125 hp	5,900
	225 hp	4,700
Personal Watercraft Engines	85 hp	1,700
	130 hp	5,300
	175 hp	1,000

4.3. Operating Costs

Migration from conventional 2-stroke engine technology to 4-stroke or direct-injection 2-stroke engine technology reduces fuel consumption from 15 to 40% due to less fuel short-circuiting. Fuel cost savings for use of 4-stroke and direct-injection 2-stroke engine technology over conventional 2-stroke engine technology have been analyzed using an average gasoline price of $1.92 per gallon[2]. Additionally, a price of $2.96 per quart was used for 2-stroke engine oil versus $2.31 per quart for 4-stroke engine oil. A load factor of 0.21 has been used along with an activity of 34.8 hours per year for outboard engines and 77.3 hours per year for personal watercraft. An average life of 9.9 years was used to calculate total fuel savings for PWC engines. For outboard engines, the average life ranged from 13.3 years for 225 hp engines to 26.1 years for 9.9 hp engines.[3] A discount rate of 3% per annum over the life of the engine was used to calculate present values.

[2] National average retail gasoline prices for 2005 without taxes from the Energy Information Administration.

This page intentionally left blank.

[3] Load factor, activity and lifetime values are consistent with values used in EPA's NONROAD model.

5. Results

Outboard and personal watercraft engine manufacturers were initially contacted to gather information on component costs for the technology packages under consideration. Preliminary cost estimates for the systems were later submitted for review to the same industry contacts. Their comments were incorporated in the final version of the cost estimates. These are presented in the tables at the end of this section.

Tables 5-1 to 5-5 show a detailed development of cost estimates for each of the technology packages for each engine and a comparison of the costs across technologies for similar sized engines for outboard engines. Tables 5-6 through 5-10 show a detailed development of cost estimates for each of the technology packages for personal watercraft.

As discussed above, migration from conventional 2-stroke engines to 4-stroke and direct-injection 2-stroke engines was also considered in the mix of available technologies. The results of this comparison are shown in Tables 5-4 for outboard engines and Table 5-9 for personal watercraft. Although carbureted 4-strokes are not considered an advanced technology, they do have significant emissions reductions and cost savings over carbureted 2-stroke engines. Also, because 4-strokes are common in the market today, no increased research and development or warranty costs are included in this comparison. Further, this comparison is not necessarily for carbureted to carbureted engine models. Particularly for larger engines, carburetion is less common. In these cases, the model comparison was between engine models with similar fuel delivery technologies available for engines of that size.

Table 5-11 details catalyst prices per unit. The total catalyst price depends on the number of units used for each engine, although the current layout envisions only one catalyst per engine. Manufacturer prices per unit vary between $33 and $93.

Table 5-12 describes the composition of the research and development costs. The research and development costs for engine manufacturers consist of the engineering design costs, the product development costs, and the prototype testing costs for the first engine line built. The actual cost per engine for research and development that is included in Tables 5-1 to 5-10 is based on six months of R&D at this rate. For systems with catalysts, another 3 months of R&D are included. The design and development costs are essentially engineer and technician hours plus prototype testing costs. This may increase in the future as a result of new emission standards. Base engineer salaries are taken as $66,000 per year and base technician

Table 5-1 2-Stroke Direct Fuel Injected Outboard Marine Gasoline Engines

Carb - > DFI Costs	9.9 hp, 2 cyl		40 hp, 3 cyl		75 hp, 3 cyl		125 hp, 4 cyl		225 hp, 6 cyl	
	Carb	DFI	Carb	DFI	Carb	DFI	Carb	DFI	Carb	DFI
Carburetor	$28	N/A	$38	N/A	$45	N/A	$55	N/A	$80	N/A
Number Required	1		3		3		3		3	
Fuel Metering Solenoid (each)		$18		$20		$22		$24		$26
Number Required		2		3		3		4		6
Air Compressor		$80		$100		$120		$140		$165
Air Regulator		$15		$15		$17		$20		$22
Throttle Body/Position Sensor		$30		$35		$35		$40		$50
Intake Manifold	$8	$13	$10	$15	$11	$20	$15	$25	$15	$30
Fuel Pump	$7	$10	$10	$10	$15	$10	$16	$10	$18	$10
ECM		$85		$90		$95		$100		$105
Air Intake Temperature Sensor		$5		$5		$5		$5		$5
Manifold Air Pressure Sensor		$10		$10		$11		$11		$11
Injection Timing Sensor/Timing Wheel		$5		$8		$9		$10		$10
Wiring/Related Hardware		$20		$30		$30		$50		$60
Hardware Cost to Manufacturer	**$43**	**$309**	**$134**	**$378**	**$161**	**$418**	**$196**	**$507**	**$273**	**$624**
Labor @ $28 per hour	$1	$14	$2	$17	$2	$21	$2	$24	$3	$28
Labor overhead @ 40%	$1	$6	$1	$7	$1	$8	$1	$10	$1	$11
OEM markup @ 29%	$13	$95	$40	$116	$48	$130	$58	$157	$80	$192
Warranty Markup @ 5%		$13		$12		$13		$16		$18
Total Component Costs	**$58**	**$437**	**$176**	**$530**	**$211**	**$590**	**$257**	**$713**	**$357**	**$873**
Fixed Cost to Manufacturer										
R&D Costs	$0	$679,956	$0	$692,712	$0	$704,832	$0	$718,440	$0	$738,482
Tooling Costs	$0	$150,000	$0	$150,000	$0	$150,000	$0	$150,000	$0	$150,000
Units/yr.	5,000	5,000	5,600	5,600	6,400	6,400	5,900	5,900	4,700	4,700
Years to recover	5	5	5	5	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$46**	**$0**	**$42**	**$0**	**$37**	**$0**	**$41**	**$0**	**$52**
Total Costs ($)	**$58**	**$483**	**$176**	**$572**	**$211**	**$627**	**$257**	**$753**	**$357**	**$925**
Incremental Total Cost ($)		**$425**		**$396**		**$415**		**$496**		**$568**

R&D Costs	**Carb**	**DFI**	**Carb**	**DFI**	**Carb**	**DFI**	**Carb**	**DFI**	**Carb**	**DFI**
R&D Costs	$0	$474,611	$0	$474,611	$0	$474,611	$0	$474,611	$0	$474,611
Durability Testing	$0	$205,346	$0	$218,101	$0	$230,221	$0	$243,829	$0	$263,871
Total R&D per Engine Line	**$0**	**$679,956**	**$0**	**$692,712**	**$0**	**$704,832**	**$0**	**$718,440**	**$0**	**$738,482**

Table 5-2 2-Stroke Indirect Fuel Injected Outboard Marine Gasoline Engines

Carb - > IDI Costs	9.9 hp, 2 cyl		40 hp, 3 cyl		75 hp. 3 cyl		125 hp, 4 cyl		225 hp, 6 cyl	
	Carb	IDI	Carb	IDI	Carb	IDI	Carb	IDI	Carb	IDI
Carburetor	$28	N/A	$38	N/A	$45	N/A	$55	N/A	$80	N/A
Number Required	1		3		3		3		3	
Injectors (each)		$17		$17		$17		$17		$17
Number Required		2		3		3		4		6
Fuel Distributor		$10		$12		$15		$20		$25
Pressure Regulator		$15		$15		$20		$30		$35
Intake Manifold	$8	$13	$10	$15	$11	$17	$15	$35	$15	$35
Throttle Body/Position Sensor		$30		$35		$35		$40		$50
Fuel Pump	$7	$20	$10	$20	$15	$30	$16	$40	$18	$45
ECM		$85		$90		$95		$100		$105
Air Intake Temperature Sensor		$5		$5		$5		$5		$5
Manifold Air Pressure Sensor		$10		$10		$11		$11		$11
Injection Timing Sensor		$7		$8		$9		$10		$10
Wiring/Related Hardware		$20		$30		$30		$40		$60
Hardware Cost to Manufacturer	**$43**	**$249**	**$134**	**$291**	**$161**	**$318**	**$196**	**$399**	**$273**	**$483**
Labor @ $28 per hour	$1	$7	$2	$8	$2	$11	$2	$12	$3	$14
Labor overhead @ 40%	$1	$3	$1	$3	$1	$4	$1	$5	$1	$6
Markup @ 29%	$13	$75	$40	$88	$48	$96	$58	$121	$80	$146
Warranty Markup @ 5% (a)		$10		$8		$8		$10		$11
Total Component Costs	**$58**	**$344**	**$176**	**$398**	**$211**	**$437**	**$257**	**$546**	**$357**	**$659**
Fixed Cost to Manufacturer										
R&D Costs	$0	$679,956	$0	$692,712	$0	$704,832	$0	$718,440	$0	$738,482
Tooling Costs	$0	$100,000	$0	$100,000	$0	$100,000	$0	$100,000	$0	$100,000
Units/yr.	5,000	5,000	5,600	5,600	6,400	6,400	5,900	5,900	4,700	4,700
Years to recover	5	5	5	5	5	5	5	5	5	5
Fixed cost/unit	$0	$43	$0	$39	$0	$35	$0	$38	$0	$49
Total Costs ($)	$58	$387	$176	$438	$211	$472	$257	$585	$357	$708
Incremental Total Cost ($)		$329		$262		$260		$328		$351

R&D Costs	Carb	IDI	Carb	IDI	Carb	IDI	Carb	IDI	Carb	IDI
R&D Costs	$0	$474,611	$0	$474,611	$0	$474,611	$0	$474,611	$0	$474,611
Durability Testing	$0	$205,346	$0	$218,101	$0	$230,221	$0	$243,829	$0	$263,871
Total R&D per Engine Line	$0	$679,956	$0	$692,712	$0	$704,832	$0	$718,440	$0	$738,482

Table 5-3 4-Stroke Electronic Fuel Injected Outboard Marine Gasoline Engines

Carb -> EFI Costs	9.9 hp, 2 cyl			40 hp, 3 cyl			75 hp. 3 cyl			125 hp, 4 cyl			225 hp, 6 cyl		
	Carb	TBI	PFI	Carb	TBI	PFI	Carb	TBI	PFI	Carb	TBI	PFI	Carb	TBI	PFI
Carburetor	$28	N/A	N/A	$38	N/A	N/A	$45	N/A	N/A	$55	N/A	N/A	$80	N/A	N/A
Number Required	1			3			3			3			3		
Injectors (each)		$21	$17		$21	$17		$21	$17		$21	$17		$21	$17
Number Required		1	2		1	3		1	3		2	4		2	6
Fuel Rail			$40			$55			$65			$70		$80	$80
Pressure Regulator		$10	$15		$10	$15		$15	$20		$20	$30		$25	$35
Intake Manifold	$8	$13	$13	$10	$15	$15	$11	$17	$17	$15	$25	$25	$15	$30	$30
Throttle Body/Position Sensor		$30	$30		$35	$35		$35	$35		$40	$40		$50	$50
Fuel Pump	$7	$15	$20	$10	$15	$20	$15	$20	$25	$16	$25	$30	$18	$30	$35
ECM		$85	$95		$90	$100		$95	$105		$100	$110		$105	$115
Air Intake Temperature Sensor		$5	$5		$5	$5		$5	$5		$5	$5		$5	$5
Manifold Air Pressure Sensor		$10	$10		$10	$10		$11	$11		$11	$11		$11	$11
Injection Timing Sensor		$5	$5		$8	$8		$9	$9		$10	$10		$10	$10
Wiring/Related Hardware		$20	$20		$30	$30		$30	$30		$40	$40		$60	$60
Hardware Cost to Manufacturer	**$43**	**$214**	**$287**	**$134**	**$239**	**$344**	**$161**	**$258**	**$373**	**$196**	**$318**	**$439**	**$273**	**$368**	**$533**
Labor @ $28 per hour	$1	$4	$4	$2	$4	$6	$2	$4	$6	$2	$4	$6	$2	$4	$6
Labor overhead @ 40%	$1	$2	$2	$1	$2	$3	$1	$2	$3	$1	$2	$3	$1	$2	$3
Markup @ 29%	$13	$64	$85	$40	$71	$102	$47	$77	$111	$58	$94	$130	$80	$108	$157
Warranty Markup @ 5%		$9	$12		$5	$11		$5	$11		$6	$12		$5	$13
Total Component Costs	**$58**	**$292**	**$390**	**$176**	**$321**	**$466**	**$211**	**$345**	**$503**	**$257**	**$424**	**$590**	**$356**	**$487**	**$712**
Fixed Cost to Manufacturer															
R&D Costs	$0	$679,956	$679,956	$0	$692,712	$692,712	$0	$704,832	$704,832	$0	$718,440	$718,440	$0	$738,482	$738,482
Tooling Costs	$0	$100,000	$125,000	$0	$100,000	$125,000	$0	$100,000	$125,000	$0	$100,000	$125,000	$0	$100,000	$125,000
Units/yr.	5,000	5,000	5,000	5,600	5,600	5,600	6,400	6,400	6,400	5,900	5,900	5,900	4,700	4,700	4,700
Years to recover	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$43**	**$45**	**$0**	**$39**	**$40**	**$0**	**$35**	**$36**	**$0**	**$38**	**$40**	**$0**	**$49**	**$51**
Total Costs ($)	**$58**	**$335**	**$435**	**$176**	**$360**	**$506**	**$211**	**$380**	**$539**	**$257**	**$462**	**$629**	**$356**	**$537**	**$763**
Incremental Total Cost ($)		**$277**	**$377**		**$185**	**$330**		**$169**	**$328**		**$206**	**$373**		**$181**	**$407**

R&D Costs	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**
R&D Costs	$0	$474,611	$474,611	$0	$474,611	$474,611	$0	$474,611	$474,611	$0	$474,611	$474,611	$0	$474,611	$474,611
Durability Testing	$0	$205,346	$205,346	$0	$218,101	$218,101	$0	$230,221	$230,221	$0	$243,829	$243,829	$0	$263,871	$263,871
Total R&D per Engine Line	**$0**	**$679,956**	**$679,956**	**$0**	**$692,712**	**$692,712**	**$0**	**$704,832**	**$704,832**	**$0**	**$718,440**	**$718,440**	**$0**	**$738,482**	**$738,482**

Table 5-4 Migration Costs from 2-stroke to 4-stroke Outboard Marine Engines

Conversion to 4 Stroke Costs	9.9 hp Carb->Carb		40 hp Carb->Carb		75 hp Carb->Carb		125 hp Carb->EFI		225 hp DFI->EFI	
	2 stroke	4 stroke	2 stroke	4 stroke	2 stroke	4 stroke	2 stroke	4 stroke	2 stroke	4 stroke
Engine	$900	$1,124	$2,101	$2,633	$3,076	$3,861	$4,195	$5,504	$6,339	$7,761
Markup @ 29%	$261	$326	$609	$764	$892	$1,120	$1,217	$1,596	$1,838	$2,251
Total Costs ($)	**$1,161**	**$1,450**	**$2,710**	**$3,397**	**$3,968**	**$4,981**	**$5,412**	**$7,100**	**$8,177**	**$10,012**
Incremental Total Cost ($)		**$289**		**$686**		**$1,013**		**$1,689**		**$1,834**

Table 5-5 Three-way Catalyst costs for 4-stroke MPI Outboard Marine Engines

4 stroke MPI Catalysts	9.9 hp		40 hp		75 hp		125 hp		225 hp	
	No Cat	Cat	No Cat	Cat	No Cat	Cat	No Cat	Cat	No Cat	Cat
Catalyst		$33		$45		$62		$67		$92
Manifold Modifications		$15		$17		$20		$25		$30
Oxygen Sensor		$25		$25		$25		$25		$25
Labor @ $28 per hour		$1		$1		$1		$1		$1
Labor overhead @ 40%		$1		$1		$1		$1		$1
OEM markup @ 29%		$22		$26		$32		$34		$43
Warranty Markup @ 5%		$2		$2		$3		$3		$5
Total Component Costs	**$0**	**$99**	**$0**	**$116**	**$0**	**$144**	**$0**	**$156**	**$0**	**$197**
Fixed Cost to Manufacturer										
R&D Costs	$0	$342,788	$0	$352,938	$0	$362,068	$0	$372,980	$0	$388,643
Tooling Costs	$0	$75,000	$0	$75,000	$0	$75,000	$0	$75,000	$0	$75,000
Units/yr.	5,000	5,000	5,600	5,600	6,400	6,400	5,900	5,900	4,700	4,700
Years to recover	5	5	5	5	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$23**	**$0**	**$21**	**$0**	**$19**	**$0**	**$21**	**$0**	**$27**
Total Costs ($)	**$0**	**$122**	**$0**	**$137**	**$0**	**$163**	**$0**	**$177**	**$0**	**$224**
Incremental Total Cost ($)		**$122**		**$137**		**$163**		**$177**		**$224**

R&D Costs	**No Cat**	**Cat**	**No Cat**	**Cat**	**No Cat**	**Cat**	**No Cat**	**Cat**	**No Cat**	**Cat**
R&D Costs	$0	$237,305	$0	$237,305	$0	$237,305	$0	$237,305	$0	$237,305
Durability Testing	$0	$105,483	$0	$115,633	$0	$124,763	$0	$135,675	$0	$151,338
Total R&D per Engine Line	**$0**	**$342,788**	**$0**	**$352,938**	**$0**	**$362,068**	**$0**	**$372,980**	**$0**	**$388,643**

Table 5-6 2-Stroke Direct Fuel Injected Personal Watercraft Marine Gasoline Engines

Carb - > DFI Costs	85 hp, 2 cyl		130 hp, 3 cyl		175 hp, 4 cyl	
	Carb	DFI	Carb	DFI	Carb	DFI
Carburetor	$38	N/A	$55	N/A	$80	N/A
Number Required	3		3		3	
Nozzle/Accumulator (each)		$22		$24		$26
Number Required		2		3		4
Air Compressor		$120		$140		$165
Air Regulator		$17		$20		$22
Throttle Body/Position Sensor		$35		$40		$50
Intake Manifold	$11	$20	$15	$25	$15	$30
Fuel Transfer Pump	$15	$10	$16	$10	$18	$10
ECM		$95		$100		$105
Air Intake Temperature Sensor		$5		$5		$5
Manifold Air Pressure Sensor		$11		$11		$11
Injection Timing Sensor/Timing Wheel		$9		$10		$10
Wiring/Related Hardware		$20		$30		$40
Hardware Cost to Manufacturer	**$140**	**$386**	**$196**	**$453**	**$273**	**$552**
Labor @ $28 per hour	$2	$21	$2	$24	$2	$24
Labor overhead @ 40%	$1	$8	$1	$10	$1	$10
OEM markup @ 29%	$41	$120	$58	$144	$80	$170
Warranty Markup @ 5%		$12		$13		$14
Total Component Costs	**$184**	**$548**	**$257**	**$654**	**$356**	**$769**
Fixed Cost to Manufacturer						
R&D Costs	$0	$705,255	$0	$714,728	$0	$725,996
Tooling Costs	$0	$150,000	$0	$150,000	$0	$150,000
Units/yr.	1,700	1,700	5,300	5,300	1,000	1,000
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$139**	**$0**	**$45**	**$0**	**$242**
Total Costs ($)	**$184**	**$687**	**$257**	**$699**	**$356**	**$1,011**
Incremental Total Cost ($)		**$503**		**$442**		**$655**

R&D Costs	**Carb**	**DFI**	**Carb**	**DFI**	**Carb**	**DFI**
R&D Costs	$0	$474,611	$0	$474,611	$0	$474,611
Durability Testing	$0	$230,644	$0	$240,118	$0	$251,386
Total R&D per Engine Line	**$0**	**$705,255**	**$0**	**$714,728**	**$0**	**$725,996**

Table 5-7 2-Stroke Indirect Fuel Injected Personal Watercraft Marine Gasoline Engines

Carb - > IDI Costs	85 hp, 2 cyl		130 hp, 3 cyl		175 hp, 4 cyl	
	Carb	IDI	Carb	IDI	Carb	IDI
Carburetor	$38	N/A	$55	N/A	$80	N/A
Number Required	3		3		3	
Injectors (each)		$17		$17		$17
Number Required		2		3		4
Fuel Distributor		$15		$20		$25
Pressure Regulator		$20		$30		$35
Intake Manifold	$11	$17	$15	$35	$15	$35
Throttle Body/Position Sensor		$35		$40		$50
Fuel Pump	$15	$30	$16	$40	$18	$45
ECM		$95		$100		$105
Air Intake Temperature Sensor		$5		$5		$5
Manifold Air Pressure Sensor		$11		$11		$11
Injection Timing Sensor		$9		$10		$10
Wiring/Related Hardware		$20		$30		$40
Hardware Cost to Manufacturer	**$140**	**$291**	**$196**	**$372**	**$273**	**$429**
Labor @ $28 per hour	$2	$11	$2	$12	$2	$12
Labor overhead @ 40%	$1	$4	$1	$5	$1	$5
OEM markup @ 29%	$41	$89	$58	$113	$80	$129
Warranty Markup @ 5%		$8		$9		$8
Total Component Costs	**$184**	**$402**	**$257**	**$510**	**$356**	**$583**
Fixed Cost to Manufacturer						
R&D Costs	$0	$705,255	$0	$714,728	$0	$725,996
Tooling Costs	$0	$100,000	$0	$100,000	$0	$100,000
Units/yr.	1,700	1,700	5,300	5,300	1,000	1,000
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$131**	**$0**	**$43**	**$0**	**$229**
Total Costs ($)	**$184**	**$533**	**$257**	**$553**	**$356**	**$812**
Incremental Total Cost ($)		**$349**		**$296**		**$455**

R&D Costs	Carb	IDI	Carb	IDI	Carb	IDI
R&D Costs	$0	$474,611	$0	$474,611	$0	$474,611
Durability Testing	$0	$230,644	$0	$240,118	$0	$251,386
Total R&D per Engine Line	**$0**	**$705,255**	**$0**	**$714,728**	**$0**	**$725,996**

Table 5-8 4-Stroke Electronic Fuel Injected Personal Watercraft Marine Gasoline Engines

Carb -> EFI Costs	85 hp, 2 cyl			130 hp, 3 cyl			175 hp, 3 cyl		
	Carb	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**
Carburetor	$45	N/A	N/A	$55	N/A	N/A	$80	N/A	N/A
Number Required	3			3			3		
Injectors (each)		$21	$17		$21	$17		$21	$17
Number Required		1	2		2	3		2	4
Fuel Rail			$65			$70			$80
Pressure Regulator		$15	$20		$20	$30		$25	$35
Intake Manifold	$11	$17	$17	$15	$25	$25	$15	$30	$30
Throttle Body/Position Sensor		$35	$35		$40	$40		$50	$50
Fuel Pump	$15	$20	$25	$16	$25	$30	$18	$30	$35
ECM		$95	$105		$100	$110		$105	$115
Air Intake Temperature Sensor		$5	$5		$5	$5		$5	$5
Manifold Air Pressure Sensor		$11	$11		$11	$11		$11	$11
Injection Timing Sensor		$9	$9		$10	$10		$10	$10
Wiring/Related Hardware		$20	$20		$30	$30		$40	$40
Hardware Cost to Manufacturer	**$161**	**$248**	**$346**	**$196**	**$308**	**$412**	**$273**	**$348**	**$479**
Labor @ $28 per hour	$2	$4	$6	$2	$4	$6	$2	$4	$6
Labor overhead @ 40%	$1	$2	$3	$1	$2	$3	$1	$2	$3
Markup @ 29%	$47	$74	$103	$58	$91	$122	$80	$103	$141
Warranty Markup @ 5%		$4	$9		$6	$11		$4	$10
Total Component Costs	**$211**	**$332**	**$467**	**$257**	**$411**	**$554**	**$356**	**$460**	**$640**
Fixed Cost to Manufacturer									
R&D Costs	$0	$705,255	$705,255	$0	$714,728	$714,728	$0	$725,996	$725,996
Tooling Costs	$0	$100,000	$125,000	$0	$100,000	$125,000	$0	$100,000	$125,000
Units/yr.	1,700	1,700	1,700	5,300	5,300	5,300	1,000	1,000	1,000
Years to recover	5	5	5	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$131**	**$135**	**$0**	**$43**	**$44**	**$0**	**$229**	**$236**
Total Costs ($)	**$211**	**$463**	**$602**	**$257**	**$453**	**$598**	**$356**	**$689**	**$875**
Incremental Total Cost ($)		**$252**	**$391**		**$197**	**$341**		**$333**	**$519**

R&D Costs	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**	**Carb**	**TBI**	**PFI**
R&D Costs	$0	$474,611	$474,611	$0	$474,611	$474,611	$0	$474,611	$474,611
Durability Testing	$0	$230,644	$230,644	$0	$240,118	$240,118	$0	$251,386	$251,386
Total R&D per Engine Line	**$0**	**$705,255**	**$705,255**	**$0**	**$714,728**	**$714,728**	**$0**	**$725,996**	**$725,996**

Table 5-9 Migration Costs from 2-stroke to 4-stroke Personal Watercraft Marine Engines

Conversion to 4 Stroke Costs	85 hp Carb->EFI		130 hp, DFI->EFI		175 hp, DFI->EFI	
	2 stroke	4 stroke	2 stroke	4 stroke	2 stroke	4 stroke
Engine	$3,319	$4,350	$4,578	$5,587	$5,862	$7,207
Markup @ 29%	$963	$1,262	$1,328	$1,620	$1,700	$2,090
Total Costs ($)	**$4,282**	**$5,612**	**$5,906**	**$7,207**	**$7,562**	**$9,297**
Incremental Total Cost ($)		**$1,330**		**$1,302**		**$1,735**

Table 5-10 Three-way Catalyst costs for 4-stroke MPI Personal Watercraft Marine Engines

4 stroke MPI Catalysts	85 hp		130 hp		175 hp	
	No Cat	Cat	No Cat	Cat	No Cat	Cat
Catalyst		$64		$68		$82
Manifold Modifications		$35		$40		$45
Oxygen Sensor		$25		$25		$25
Labor @ $28 per hour		$1		$1		$1
Labor overhead @ 40%		$1		$1		$1
OEM markup @ 29%		$36		$39		$45
Warranty Markup @ 5%		$3		$3		$4
Total Component Costs	**$0**	**$165**	**$0**	**$177**	**$0**	**$202**
Fixed Cost to Manufacturer						
R&D Costs	$0	$363,502	$0	$371,332	$0	$381,016
Tooling Costs	$0	$75,000	$0	$75,000	$0	$75,000
Units/yr.	1,700	1,700	5,300	5,300	1,000	1,000
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$71**	**$0**	**$23**	**$0**	**$126**
Total Costs ($)	**$0**	**$236**	**$0**	**$200**	**$0**	**$328**
Incremental Total Cost ($)		**$236**		**$200**		**$328**

R&D Costs	**No Cat**	**Cat**	**No Cat**	**Cat**	**No Cat**	**Cat**
R&D Costs	$0	$237,305	$0	$237,305	$0	$237,305
Durability Testing	$0	$126,197	$0	$134,026	$0	$143,710
Total R&D per Engine Line	**$0**	**$363,502**	**$0**	**$371,332**	**$0**	**$381,016**

Table 5-11 Three-way Marine Catalysts Cost Estimates

Table 5-11a Catalyst Parameters

Washcoat Loading	g/L	160
% ceria	*by wt.*	*75*
% alumina	*by wt.*	*25*
Precious Metal Loading	g/L	1.0
% Platinum	*by wt.*	*80.0*
% Palladium	*by wt.*	*0.0*
% Rhodium	*by wt.*	*20.0*
Labor Cost	$/hr	$28.00

Table 5-11b Material Costs

Material	$/troy oz	$/lb	$/g	Density (g/cc)
Alumina		$64.00	$0.141	3.9
Ceria		$22.00	$0.049	7.132
Platinum	$811		$26.08	
Palladium	$210		$6.76	
Rhodium	$1,121		$36.04	
Stainless Steel		$0.85	$0.003	7.817

Table 5-11c Catalyst Unit Price

Engine Type	**Outboards**					**PWC**		
Engine Power	**9.9 hp**	**40 hp**	**75 hp**	**125 hp**	**225 hp**	**85 hp**	**130 hp**	**175 hp**
Engine Displacement (L)	**0.25**	**0.76**	**1.60**	**1.80**	**3.00**	**1.65**	**1.85**	**2.50**
Catalyst Volume (L)	0.09	0.27	0.56	0.63	1.05	0.38	0.43	0.58
Substrate Diameter(cm)	4.50	6.00	8.50	9.00	11.00	9.00	9.00	10.00
Substrate	$2.48	$3.56	$5.35	$5.77	$8.32	$5.45	$5.88	$7.26
Ceria/Alumina	$1.00	$3.05	$6.42	$7.23	$12.04	$6.62	$7.43	$10.03.
Pt/Pd/Rd	$2.46	$7.47	$15.72	$17.69	$29.48	$16.21	$18.18	$24.57
Can (18 gauge 304 SS)	$0.39	$0.82	$1.31	$1.42	$1.98	$1.34	$1.44	$1.76
Substrate Diameter (cm)	4.50	6.00	8.50	9.00	11.00	9.00	9.00	10.00
Substrate Length (cm)	5.5	9.4	9.9	9.9	11.0	9.1	10.2	11.1
Working Length (cm)	8.3	12.2	12.7	12.7	13.8	11.9	13.0	13.9
Thick. of Steel (cm)	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Shell Volume (cm3)	10	22	32	34	47	31	35	43
Steel End Cap Volume (cm3)	4	8	15	17	25	17	17	21
Vol. of Steel (cm^3) w/ 20% scrap	17	35	57	61	86	58	63	76
Wt. of Steel (g)	132	277	445	481	673	454	489	597
TOTAL MAT. COST	**$6.33**	**$14.90**	**$28.80**	**$32.10**	**$51.82**	**$29.63**	**$32.92**	**$43.62**
LABOR	**$14.00**	**$14.00**	**$14.00**	**$14.00**	**$14.00**	**$14.00**	**$14.00**	**$14.00**
Labor Overhead @ 40%	$5.60	$5.60	$5.60	$5.60	$5.60	$5.60	$5.60	$5.60
Supplier Markup @ 29%	$7.52	$10.00	$14.04	$14.99	$20.71	$14.28	$15.23	$18.33
Manufacturer Price	**$33.45**	**$44.50**	**$62.44**	**$66.69**	**$92.13**	**$63.50**	**$67.76**	**$81.55**

and operator salaries are taken as $42,900 per year[4] plus 45 percent fringe and 40 percent overhead mark-up. Prototype testing costs shown in the table consist of performing stationary tests as well as tests in water. These are estimated at $1,250 per day for test time plus $500 per day for test engine costs for 20 days per month. Durability testing labor costs per month are shown in Table 5-13, with 3 and 6 month durability testing costs shown in Table 5-14 for outboards and Table 5-15 for personal watercraft.

Table 5-12 Research, Development and Prototype Testing Costs per Month

Cost Item	No	Cost per Month	Amount
Engineers	2	$5,500	$11,000
Techs/Operators	3	$3,575	$10,725
Total Salaries			$21,725
Fringe		45%	$9,776
Overhead		40%	$12,601
Prototype Testing			$35,000
Total Cost per Month			**$79,102**

Table 5-13 Durability Testing Labor Costs per Month

Cost Item	No	Cost per Month	Amount
Engineers	0.75	$5,500	$4,125
Techs/Operators	2	$3,575	$7,150
Total Salaries			$11,275
Fringe		45%	$5,074
Overhead		40%	$6,540
Testing Costs			$10,000
Total Cost per Month			**$32,888**

Table 5-14 Outboard Durability Testing Costs

	3 Months Testing				6 Months Testing			
Engine	**Labor**	**Engine**	**Fuel**	**Total**	**Labor**	**Engine**	**Fuel**	**Total**
9.9 hp, 2 cyl	$98,665	$5,620	$1,198	$105,483	$197,330	$5,620	$2,396	$205,346
40 hp, 3 cyl	$98,665	$13,165	$3,803	$115,633	$197,330	$13,165	$7,607	$218,101
75 hp, 3 cyl	$98,665	$19,305	$6,793	$124,763	$197,330	$19,305	$13,587	$230,221
125 hp, 4 cyl	$98,665	$27,520	$9,490	$135,675	$197,330	$27,520	$18,980	$243,829
225 hp, 6 cyl	$98,665	$38,805	$13,868	$151,338	$197,330	$38,805	$27,737	$263,871

[4] Midwest engineer and technician salaries for 2005 from www.salary.com.

Table 5-15 Personal Watercraft Durability Testing Costs

Engine	3 Months Testing				6 Months Testing			
	Labor	Engine	Fuel	Total	Labor	Engine	Fuel	Total
85 hp, 2 cyl	$98,665	$21,750	$5,782	$126,197	$197,330	$21,750	$11,565	$230,644
130 hp, 3 cyl	$98,665	$27,935	$7,427	$134,026	$197,330	$27,935	$14,853	$240,118
175 hp, 4 cyl	$98,665	$36,035	$9,011	$143,710	$197,330	$36,035	$18,021	$251,386

Operating cost savings for conversion from 2-stroke to 4-stroke for all outboard and PWC sizes considered are given in Tables 5-16 and 5-17, respectively.

The costs presented in Table 5-18 are the incremental costs of all the possible combinations of baseline and advanced technology scenarios for outboard engines. Table 5-19 lists incremental costs for personal watercraft. The results show that the most costly change in technology is upgrading the same size engine from carbureted 2-stroke to 4-stroke, particularly in the case where the 4-stroke engine is EFI. Without redesigning the entire engine, direct fuel injection is the most expensive upgrade for 2-stroke engines, with costs as high as about $500 for the 225 hp engine. For 4-stroke engines, the most expensive upgrade is migration to multipoint injection with an three-way catalyst, which has a price of about 98% that of the DFI 2-stroke upgrade.

Table 5-16 Annual Cost Savings by Converting from 2-Stroke to 4-Stroke for Marine Outboard Gasoline Engines

Engine Size	**9.9 hp**		**40 hp**		**75 hp**		**125 hp**		**225 hp**	
Stroke	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**
Horsepower	9.9	9.9	40	40	75	75	125	125	225	225
BSFC (gal/hp-hr)	0.24	0.15	0.19	0.14	0.18	0.13	0.15	0.11	0.12	0.10
Load Factor	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Hours/year	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8
Gallons per year	17.4	10.6	55.2	41.4	98.5	74.0	137.6	103.5	201.1	168.0
Gasoline cost/yr	$33.36	$20.41	$105.89	$79.52	$189.13	$142.04	$264.20	$198.80	$368.10	$322.53
2-st Oil Consump qts/yr	1.39		4.41		7.88		11.01		16.09	
2-st Oil Cost/yr	$4.11		$13.06		$23.33		$32.58		$47.62	
4-st Oil Sump, qt		1.1		2.1		4.5		4.5		6.1
4-st Oil change Freq, yr		1.0		1.0		1.0		1.0		1.0
Oil Cost per year		$2.54		$4.85		$10.40		$10.40		$14.09
4-st Filter Change Freq, yr		2.0		2.0		2.0		2.0		2.0
Filter Cost		$8.8		$8.8		$8.8		$8.8		$8.8
Filter Cost per year		$4.40		$4.40		$4.40		$4.40		$4.40
Total Costs per year	$37.47	$27.35	$118.95	$88.77	$212.45	$156.84	$296.78	$213.60	$433.72	$341.02
Life, yrs X load factor	5.49	5.49	4.25	4.25	3.62	3.62	3.10	3.10	2.79	2.79
Life, yrs	26.1	26.1	20.2	20.2	17.2	17.2	14.8	14.8	13.3	13.3
Total Cost discounted 7%	**$444**	**$324**	**$1,267**	**$946**	**$2,090**	**$1,543**	**$2,678**	**$1,927**	**$3,674**	**$2,889**
Cost Savings		**$120**		**$321**		**$547**		**$751**		**$785**

Table 5-17 Annual Cost Savings by Converting from 2-Stroke to 4-Stroke for Personal Watercraft Gasoline Engines

Engine Size	**85 hp**		**130 hp**		**175 hp**	
Stroke	**2**	**4**	**2**	**4**	**2**	**4**
Horsepower	85	85	130	130	175	175
BSFC (gal/hp-hr)	0.18	0.13	0.15	0.11	0.12	0.10
Load Factor	0.21	0.21	0.21	0.21	0.21	0.21
Hours/year	77.3	77.3	77.3	77.3	77.3	77.3
Gallons per year	248.0	186.2	317.9	239.2	347.4	290.2
Gasoline cost/yr	$476.11	$357.58	$610.33	$459.26	$667.04	$557.22
2-st Oil Consump qts/yr	19.84		25.43		27.79	
2-st Oil Cost/yr	$58.72		$75.27		$82.27	
4-st Oil Sump, qt		4.5		4.5		4.5
4-st Oil change Freq, yr		1.0		1.0		1.0
Oil Cost per year		$10.40		$10.40		$10.40
4-st Filter Change Freq, yr		2.0		2.0		2.0
Filter Cost		$8.8		$8.8		$8.8
Filter Cost per year		$4.40		$4.40		$4.40
Total Costs per year	$534.83	$372.37	$685.61	$474.05	$749.31	$572.02
Life, yrs X load factor	2.07	2.07	2.07	2.07	2.07	2.07
Life, yrs	9.9	9.9	9.9	9.9	9.9	9.9
Total Cost discounted 7%	$3,719	$2,589	$4,767	$3,296	$5,210	$3,977
Cost Savings		$1,130		$1,471		$1,233

Table 5-18 Summary of Incremental Outboard Technology Costs

Engine Type	Engine	Fuel System	Incremental Cost	Change from Baseline
2-stroke OB	9.9 hp	Carb	$58	
		DFI	$483	$425
		IDI	$387	$329
		4stk Carb		$289
	40 hp	Carb	$176	
		DFI	$572	$396
		IDI	$438	$262
		4stk Carb		$686
	75 hp	Carb	$211	
		DFI	$627	$415
		IDI	$472	$260
		4stk Carb		$1,013
	125 hp	Carb	$257	
		DFI	$753	$496
		IDI	$585	$328
		4stk Carb		$1,689
	225 hp	Carb	$357	
		DFI	$925	$568
		IDI	$708	$351
		4stk Carb		$1,834
4-stroke OB	9.9 hp	Carb	$58	
		TBI	$335	$277
		PFI	$435	$377
		PFI + Cat	$557	$499
	40 hp	Carb	$176	
		TBI	$360	$185
		PFI	$506	$330
		PFI + Cat	$644	$468
	75 hp	Carb	$211	
		TBI	$380	$169
		PFI	$539	$328
		PFI + Cat	$702	$491
	125 hp	Carb	$257	
		TBI	$462	$206
		PFI	$629	$373
		PFI + Cat	$807	$550
	225 hp	Carb	$356	
		TBI	$537	$181
		PFI	$763	$407
		PFI + Cat	$987	$631

Carb = carbureted; DFI = direct fuel injected; IDI = indirect fuel injection
TBI = throttle-body fuel injection, PFI = multi-point fuel injection; Cat = three-way catalyst

Table 5-19 Summary of Incremental Personal Watercraft Technology Costs

Engine Type	Engine	Fuel System	Incremental Cost	Change from Baseline
2-stroke PWC	85 hp	Carb	$184	
		DFI	$687	$503
		IDI	$533	$349
		4stk Carb		$1,330
	130 hp	Carb	$257	
		DFI	$699	$442
		IDI	$553	$296
		4stk Carb		$1,302
	210 hp	Carb	$356	
		DFI	$1,011	$655
		IDI	$812	$455
		4stk Carb		$1,735
4-stroke PWC	85 hp	Carb	$211	
		TBI	$463	$252
		PFI	$602	$391
		PFI + Cat	$839	$628
	130 hp	Carb	$257	
		TBI	$453	$197
		PFI	$598	$341
		PFI + Cat	$798	$541
	210 hp	Carb	$356	
		TBI	$689	$333
		PFI	$875	$519
		PFI + Cat	$1,203	$848

Carb = carbureted; DFI = direct fuel injected; IDI = indirect fuel injection
TBI = throttle-body fuel injection, PFI = multi-point fuel injection; Cat = three-way catalyst