U.S. Environmental Protection Agency

Sterndrive and Inboard Marine SI Engine Technologies and Costs

Preliminary Report

July 2006

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Final Report

July 2006

Prepared for
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1. Introduction

Adopted in 1996, the United States Environmental Protection Agency's (USEPA) final rule on spark-ignited (SI) marine engines did not contain emission limits for sterndrive-inboard SI engines. USEPA is considering new emission standards for sterndrive and inboard marine SI propulsion engines similar to those recently passed by the California Air Resources Board.

Updated technology will be required to reduce emissions from uncontrolled sterndrive and inboard marine SI engines to a level that will meet new standards. The purpose of this report is to provide details on incremental technology and estimated costs for sterndrive and inboard marine SI engines that could meet reduced emission standards. ICF International developed technology packages for sterndrive marine SI engines, which include electronically controlled fuel injection systems, three-way catalysts, and exhaust gas recirculation. These technology packages are representative of what might be used on inboard marine SI engines. The cost estimates include fixed and variable costs and rely on information obtained from 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. Particular attention is given to catalyst sizes, given the limited space between the engine exhaust port and the point at which the exhaust system is cooled with water. Early drafts of the technology package descriptions and cost estimates were submitted for review to industry contacts that provided initial information. Their comments were incorporated in the results presented in this report.

The following sections will discuss background information on sterndrive and inboard marine 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).

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2. Background

The marine engine manufacturing process consists in most cases of two phases: the first phase is performed by the engine block manufacturer and the second by the marinizer. Unlike marine diesel engines, it is rare for the engine block manufacturer to provide a completed engine. Engine block manufacturers are responsible for assembling the block, cylinder head, and occasionally the intake manifold. The block manufacturers also install fuel systems on a few of the engine models produced. This trend is projected to increase in the future. Block manufacturers also provide separately several of the parts that marinizers will later add to the engine.

Marinizers transform the engine blocks they receive from the manufacturers and add the features that permit optimal performance as marine engines. This process includes waterproofing, adding a fuel system, a sterndrive or an inboard gear package, a marine exhaust system, and a marine cooling system. Marinizers may also be water craft manufacturers and in that capacity install their completed engines in boats.

Sterndrive marine engines have unique cooling and exhaust systems as shown in Figure 2-1. Inboard marine engines are similar to sterndrive engines but have fewer design constraints. The cost estimates for sterndrive engines developed in this study can therefore be considered worst-case scenarios for inboard marine engines. Sterndrive marine SI engines are essentially all gasoline powered.

Figure 2-1. Volvo Sterndrive Gasoline Aquamatic Engine

Source: Volvo-Penta – Global at http://www.volvo.com/volvopenta/global/en-gb/marineengines/powerforleisureboats/gasoline_sterndrive/57sx/

According to the National Marine Manufacturers Association's (NMMA) estimates, which can be found in Table 2-1, the sales of sterndrive and inboard marine boats fluctuate slightly from year to year. Sterndrive and inboard boats account for about 18% and 5% respectively of the total mechanically propelled recreational boat sales in the United States in 2004, and have shown a slight decreasing trend in market share over the last several years.

Table 2-1. Sterndrive and Inboard Boat Sale Estimates (2000-2004) (NMMA)

Year	2000	2001	2002	2003	2004
Sterndrive Units Sold	78,400	72,000	69,300	69,200	71,100
Inboard Units Sold	23,900	21,900	22,300	19,200	20,200

Current trends in the sterndrive and inboard marine industry include the increased use of fuel injection over carburetion, especially among larger engines (4.3 L and above). Engine production is estimated to be mostly or completely fuel injected within the next five years. In addition, block manufacturers are starting to increase their production of more complete engines, which would include intake manifold and fuel system. This change is motivated by the block manufacturers' desire to simplify the manufacturing process and by the potential financial profit to be gained by selling to marinizers a more complete product at a higher price. This change shifts more of the emissions performance responsibility on the engine manufactures where production volumes are higher.

3. Technology Description

The subsections to follow will describe baseline uncontrolled sterndrive marine SI engines and the technologies likely to be implemented to meet possible future emissions standards to meet reduced HC+NOx and CO emissions. This study focuses on four representative sterndrive marine SI engines sizes: a 3.0 L in-line 4 cylinder engine, a 4.3 L V-6 engine, a 5.7 L V-8 engine, and an 8.1 L V-8 engine. Other engine models of similar sizes will have similar changes and costs. Table 3-1 lists the advance advanced technology packages for all four chosen engine sizes.

3.1. Baseline Technologies

The baseline technologies on the four sterndrive marine SI engine models consist of a mixture of carbureted and fuel injected systems that are not calibrated for low emissions. The smaller 4-cylinder engines' production tend to have a higher percentage of carbureted models whereas fuel injection is already becoming the most common fuel system for V-6 and V-8 engines. V-6 engines and V-8 engines are typically port fuel injected (PFI). The industry has been moving towards incorporating more fuel injected engines in their product lines, but still maintain their carbureted models to provide a low-cost, entry-level marine engine for their clients.

3.2. Advanced Technologies

The advanced technology changes projected to comply with lower emission standards consist of feedback-controlled fuel injection replacing all the remaining carbureted and all the uncontrolled fuel-injected engines. It is envisioned that three-way catalysts will be added to most engines; however, exhaust gas recirculation (EGR) might be used on some engines to gain partial reductions in emissions. The three-way catalysts may be inserted into each exhaust manifold bank. PFI provides advantages in both controlling emissions and in performance because it provides manufacturers with the ability to control the fuel-air ratio for each individual cylinder.

Technologies investigated in this report include fuel system technologies, exhaust gas recirculation, oxygen sensors, electronic control modules, and catalysts.

3.2.1. Fuel System Technologies

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 oxygen sensor for each exhaust bank, a high pressure fuel pump, a throttle assembly, a throttle position sensor, and a magnetic crankshaft pickup for engine speed. On V-6 and V-8 engines, the fuel rails are connected into one assembly and one pressure regulator is used.

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.

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. In addition, feed-back controlled fuel injected systems can maintain stoichiometry for better catalyst efficiency.

3.2.2. Exhaust Gas Recirculation

The exhaust gas recirculation (EGR) valve permits a portion of the exhaust gas to recirculate into the intake manifold. This dilutes the air/fuel mixture and lowers the combustion temperature, which in turn reduces the formation of oxides of nitrogen (NO_x). EGR systems have typically not been used in marine engines because they weren't judged necessary in the absence of emission standards. Certain manufacturers believed that EGR systems may cause higher exhaust temperatures, although with a water cooled exhaust system this is unlikely to be a safety problem.

EGR systems are comprised of a short tube section between the intake and exhaust manifold and a valve which is usually mounted on the intake manifold. Most EGR valves used today are electronically controlled for more accurate control at all engine conditions.

3.2.3. Oxygen Sensors

Oxygen sensors are added before the catalyst for closed-loop control purposes. A sterndrive marine engine will require one sensor per exhaust bank. This practice will minimize the occurrence of maldistribution between cylinders in V-6 and V-8 engines. Oxygen sensors also help hold the air/fuel mixture at stoichiometry for better combustion and catalyst efficiency.

Oxygen sensors are generally not used in uncontrolled systems. Controlled systems will most probably use non-heated sensors, since cold-starting emissions on these engines are not regulated. While there is some concern about oxygen sensor life in marine engines, placing the oxygen sensor before the catalyst in the exhaust riser should prevent water contact. Initial durability tests at Southwest Research Institute show reasonable oxygen sensor life using heated marine-grade oxygen sensors.

3.2.4. Electronic Control Modules

Electronic control modules (ECM) control fuel injection and ignition timing in uncontrolled and controlled 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 part of fixed costs.

3.2.5. Catalysts

Three-way catalysts are an essential component of the emission reduction systems of controlled engines. The catalyst envisioned for sterndrive marine engines will be a small "brick" (0.75 to 1.5 L) which will be located inside the exhaust riser. Southwest Research Institute has tested both metal and ceramic catalysts in this position in inboard engines and found that adequate emission reductions can be realized with reasonable catalyst life.

Table 3-2 summarizes the characteristics of three-way marine catalysts costed in this analysis. Platinum/Rhodium precious metal catalysts will most likely be used. Precious metal loading of around 1.0 grams per liter of catalyst size is expected to be used.

V-6 and V-8 engines will require two bricks, one in each exhaust bank. According to catalyst manufacturers, a ceramic substrate will be sufficiently strong to withstand the vibration and temperature variations marine systems are subjected to. Advances over the past few decades in the matting used to package the catalysts have led to very durable ceramic catalysts. To avoid underestimating costs, we calculated costs for the ceramic substrate mounted in the exhaust riser with a steel shell. In practice, the substrate can be mounted with or without a shell.

Table 3-1. Three Way Catalyst Characteristics

Engine Size	3.0 L I-4	4.3 L V-6	5.7 L V-8	8.1 L V-8
Number of Catalysts	1	2	2	2
Catalyst Size	1.00 L	0.75 L	1.00 L	1.40 L
Total Volume	1.00 L	1.50 L	2.00 L	2.80 L
Substrate	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
Precious Metals	Pt/Rh 4/1 Loading 1.0 g/liter	Pt/Rh 4/1 Loading 1.0 g/liter	Pt/Rh 4/1 Loading 1.0 g/liter	Pt/Rh 4/1 Loading 1.0 g/liter

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 four engine sizes 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 for engines to meet the proposed emission standards.

4.1. Hardware Costs

The main components of the hardware cost to the manufacturers are the fuel system and the catalyst or exhaust gas recirculation. Manufacturer prices of components were estimated from various sources including confidential information from engine manufacturers, marinizers, 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 marinizers.

Catalyst component information was obtained directly from catalyst manufacturers. Although there are presently no three-way catalysts for marine SI engines available on the market, a recent program at Southwest Research Institute tested catalysts on inboard marine engines which provided size and catalyst formulations used for this analysis. Catalyst manufacturers verified our estimates on precious metal and washcoat loadings as well as catalyst volumes and overall prices for the units. The prices of precious metal per troy oz. 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 three quarters of an hour per unit, which includes the time necessary to install the catalyst in the exhaust manifold. To minimize costs, marinizers 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 new parts. This is a lower rate than what would be typically used because of the long history of 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. Reflecting the two stages in manufacturing a marine SI engine, the fixed costs are listed separately for the engine block manufacturer and the marinizer. Because advanced fuel system technology needed to reduce emissions is already in part present in a considerable share of many current product lines, research and development for this technology is not considered in the fixed costs. Most of the fixed cost represents the research and development needed to develop and test controlled engines with EGR, oxygen sensors, and three-way catalysts. Much of this development work will be done by marinizers.

The number of units per year and the number of years to recover are used to determine the fixed cost per unit in 2005 dollars. Sales production in units per year for the four engine sizes are shown in Table 4-1. These numbers are estimates derived from confidential information received from the certification database. The numbers reflect the variation in average production between large and small businesses that share the market.

Table 4-1. Production Levels (units per year)

Engine Size	3.0 L I-4	4.3 L V-6	5.7 L V-8	8.1 L V-8
Manufacturer	15,000	15,000	15,000	15,000
Marinizer	2,000	2,000	2,000	1,000

[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.

Fixed costs include research and development engineers, technicians, mechanics and drivers with a 45% fringe and 40% overhead mark-up. The dynamometer test cost of $200 per hour includes the amortized capital costs for the test cells over a 10 year period and allocated costs for calibration gases and maintenance on the equipment.

Five years represents a typical length of time used in the industry to recover an investment in new technology.

4.3. Operating Costs

Fuel injection systems typically reduce fuel consumption by about 10% over carbureted versions due to better cylinder to cylinder fuel distribution, better air/fuel mixing, and better control of transients. Fuel cost savings for use of fuel injection over carburetion have been analyzed using an average gasoline price of $1.92 per gallon[2]. A load factor of 0.21 has been used along with an activity of 47.6 hours per year and an average life of 19.7 years to calculate total fuel savings.[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.

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

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5. Results

Preliminary cost estimates for engines and catalysts were submitted for review to the industry contacts that provided the initial cost information. Their comments were incorporated in the final version of the cost estimates which are presented in the tables at the end of this document.

Tables 5-1 to 5-4 show a detailed development of cost estimates for each of the technology packages for each engine.

Electronic control unit costs include hardware and software costs. The hardware costs are shown under the hardware costs to the manufacturer in Tables 5-1 through 5-4. Software costs are included in the fixed costs to the manufacturer and marinizer as the software is developed during the design and development process and refined during the prototype testing process.

The catalysts prices presented in Table 5-5 are the prices per unit. The total catalyst price depends on the number of units used for each engine. Prices per units vary between $89 and $127 and total prices between $103 and $254.

Tables 5-6 to 5-9 describe in detail the composition of the research and development costs and the tooling costs for both engine manufacturers (Table 5-6 and 5-7) and marinizers (Table 5-8 and 5-9). The research and development costs for engine manufacturers (Table 5-6) and marinizers (Table 5-8) consist of the engineering design costs, the product development costs, and the prototype testing costs. The design and development costs are essentially engineer and technician hours. The bulk of these hours are incurred by the engine manufacturer. This may increase in the future as a result of new emission standards. Prototype testing costs consist of performing stationary tests as well as tests in water.

The tooling costs for engine manufacturers are summarized in Table 5-7. Marinizers' only tooling costs (Table 5-9) will consist of the costs of updating their assembly line with new tools.

The costs presented in Table 5-10 are the incremental cost of all the possible combinations of baseline and controlled technology scenarios. The results show that the most costly technology change is the upgrade from a baseline of uncontrolled carbureted engines to controlled fuel-injected systems with catalysts. The cost for these changes range between $925 and $1,366 per engine. Upgrading from a baseline of uncontrolled to controlled fuel injected systems with catalysts costs about $291 to $647.

Operating cost savings for conversion from carburetor to fuel injection are shown in Table 5-11. Fuel consumption differences for using EGR or three-way catalysts are negligible.

Table 5-1. Water Cooled Marine Gasoline Engine 3.0 liters In-line

	Uncontrolled Carburetor	Uncontrolled PFI	Controlled PFI w EGR	Controlled PFI w Catalyst
Hardware Cost to Manufacturer				
Carburetor	$140	N/A	N/A	N/A
Injectors (each)		$17	$17	$17
Number		4	4	4
Pressure Regulator		$15	$15	$15
Fuel filter	$3	$4	$4	$4
Intake Manifold	$101	$115	$120	$115
Fuel Rail		$80	$80	$80
Throttle Assembly (incl. position sensor)		$150	$150	$150
Cool Fuel System		$120	$120	$120
Fuel Pump	$21	Included in Cool Fuel System		
Fuel Line		$16	$16	$16
Oxygen Sensor (each)			$17	$17
Number			1	1
ECM	$30	$100	$100	$100
Air Intake Temperature Sensor		$5	$5	$5
Manifold Air Pressure Sensor		$14	$14	$14
Crank Position Sensor		$16	$16	$16
Wiring/ Related Hardware		$80	$80	$80
Exhaust Gas Recirculation			$25	
Fuel System with EGR cost (if applicable)	**$295**	**$783**	**$830**	**$800**
Catalyst				**$74**
Incremental exhaust manifold cost			$2	$10
Total Hardware Cost	**$295**	**$783**	**$832**	**$884**
Labor @ $28/hr	$1	$4	$5	$6
Labor Overhead @ 40%	$1	$2	$2	$2
Markup @ 29%	$86	$229	$243	$259
Warranty Markup at 5%			$27	$29
Total Component Cost	**$383**	**$1,018**	**$1,109**	**$1,180**
Fixed Cost to Engine Manufacturer				
R&D Costs	-	-	$137,673	$137,673
Tooling Costs	-	-	$30,000	$30,000
Units/yr.	15,000	15,000	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	**-**	**-**	**$5**	**$3**
Total Cost from Engine Manufacturer	**$383**	**$1,018**	**$1,112**	**$1,183**
Fixed Cost to Marinizer				
R&D Costs	**-**	-	$238,773	$238,773
Tooling Costs	**-**	-	$35,000	$35,000
Units/yr.	2,000	2,000	2,000	2,000
Years to recover	5	5	5	5
Fixed cost/unit	**-**	**-**	**$38**	**$38**
Total Cost from Marinizer	**$383**	**$1,018**	**$1,150**	**$1,221**
Incremental Cost from Uncontrolled Carburetor		**$635**	**$767**	**$838**
Incremental Cost from Uncontrolled PFI			**$132**	**$203**

Table 5-2. Water Cooled Marine Gasoline Engine 4.3 liters V-6

	Uncontrolled Carburetor	Uncontrolled PFI	Controlled PFI w EGR	Controlled PFI w Catalyst
Hardware Cost to Manufacturer				
Carburetor	$145	N/A	N/A	N/A
Injectors (each)		$17	$17	$17
Number		6	6	6
Pressure Regulator		$15	$15	$15
Fuel filter	$3	$4	$4	$4
Intake Manifold	$90	$115	$120	$115
Fuel Rail Assembly		$110	$110	$110
Throttle Assembly (incl. position sensor)		$150	$150	$150
Cool Fuel System		$120	$120	$120
Fuel Pump	$35	Included in cool fuel system		
Fuel Lines		$35	$35	$35
Oxygen Sensor (each)			$17	$17
Number			2	2
ECM	$35	$100	$100	$100
Air Intake Temperature Sensor		$5	$5	$5
Manifold Air Pressure Sensor		$14	$14	$14
Crank Position Sensor		$16	$16	$16
Wiring/ Related Hardware		$80	$80	$80
Exhaust Gas Recirculation			$25	
Fuel System with EGR cost	**$308**	**$866**	**$930**	**$900**
Catalyst (2 units)				**$119**
Incremental exhaust manifold cost			$5	$20
Total Hardware Cost	**$308**	**$866**	**$935**	**$1,039**
Labor @ $28/hr	$1	$5	$6	$6
Labor Overhead @ 40%	$1	$2	$2	$3
Markup @ 29%	$90	$253	$273	$304
Warranty Markup at 5%			$3	$9
Total Component Cost	**$400**	**$1,126**	**$1,220**	**$1,360**
Fixed Cost to Engine Manufacturer				
R&D Costs	-	-	$140,348	$140,348
Tooling Costs	-	-	$35,000	$35,000
Units/yr.	15,000	15,000	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	-	-	**$3**	**$3**
Total Cost from Engine Manufacturer	**$400**	**$1,126**	**$1,223**	**$1,363**
Fixed Cost to Marinizer				
R&D Costs	-	-	$245,773	$245,773
Tooling Costs	-	-	$45,000	$45,000
Units/yr.	2,000	2,000	2,000	2,000
Years to recover	5	5	5	5
Fixed cost/unit	-	-	**$40**	**$40**
Total Cost from Marinizer	**$400**	**$1,126**	**$1,263**	**$1,403**
Incremental Cost from Uncontrolled Carburetor		**$726**	**$863**	**$1,003**
Incremental Cost from Uncontrolled PFI			**$137**	**$277**

Table 5-3. Water Cooled Marine Gasoline Engine 5.7 liters V-8

	Uncontrolled Carburetor	Uncontrolled PFI	Controlled PFI w EGR	Controlled PFI w Catalyst
Hardware Cost to Manufacturer				
Carburetor	$145	N/A	N/A	N/A
Injectors (each)		$17	$17	$17
Number		8	8	8
Pressure Regulator		$15	$15	$15
Fuel filter	$3	$4	$4	$4
Intake Manifold	$95	$125	$135	$125
Fuel Rail Assembly		$115	$115	$115
Throttle Assembly (incl. position sensor)		$150	$150	$150
Cool Fuel System		$120	$120	$120
Fuel Pump	$35	Included in cool fuel system		
Fuel Line		$35	$35	$35
Oxygen Sensor (each)			$17	$17
Number			2	2
ECM	$35	$100	$100	$100
Air Intake Temperature Sensor		$5	$5	$5
Manifold Air Pressure Sensor		$14	$14	$14
Crank Position Sensor		$16	$16	$16
Wiring/ Related Hardware		$80	$80	$80
Exhaust Gas Recirculation			$25	
Fuel System with EGR cost	**$313**	**$915**	**$984**	**$949**
Catalyst (2 units)				**$148**
Incremental exhaust manifold cost			$5	$25
Total Hardware Cost	**$313**	**$915**	**$989**	**$1,122**
Labor @ $28/hr	$1	$6	$6	$7
Labor Overhead @ 40%	$1	$2	$3	$3
Markup @ 29%	$91	$268	$289	$328
Warranty Markup at 5%			$4	$10
Total Component Cost	**$406**	**$1,190**	**$1,291**	**$1,470**
Fixed Cost to Engine Manufacturer				
R&D Costs	-	-	$142,798	$142,798
Tooling Costs	-	-	$40,000	$40,000
Units/yr.	15,000	15,000	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	-	-	**$3**	**$3**
Total Cost from Engine Manufacturer	**$406**	**$1,190**	**$1,294**	**$1,474**
Fixed Cost to Marinizer				
R&D Costs	-	-	$254,273	$254,273
Tooling Costs	-	-	$55,000	$55,000
Units/yr.	2,000	2,000	2,000	2,000
Years to recover	5	5	5	5
Fixed cost/unit	-	-	**$43**	**$43**
Total Cost from Marinizer	**$406**	**$1,190**	**$1,337**	**$1,516**
Incremental Cost from Uncontrolled Carburetor		**$784**	**$931**	**$1,110**
Incremental Cost from Uncontrolled PFI			**$147**	**$326**

Table 5-4. Water Cooled Marine Gasoline Engine 8.1 liters V-8

	Uncontrolled Carburetor	Uncontrolled PFI	Controlled PFI w EGR	Controlled PFI w Catalyst
Hardware Cost to Manufacturer				
Carburetor	$145	N/A	N/A	N/A
Injectors (each)		$20	$20	$20
Number		8	8	8
Pressure Regulator		$15	$15	$15
Fuel filter	$3	$4	$4	$4
Intake Manifold	$100	$140	$150	$140
Fuel Rail Assembly		$125	$125	$125
Throttle Assembly (incl. position sensor)		$60	$60	$60
Cool Fuel System		$120	$120	$120
Fuel Pump	$35	Included in	cool fuel system	
Fuel Line		$35	$35	$35
Oxygen Sensor (each)			$17	$17
Number			2	2
ECM	$40	$100	$100	$100
Air Intake Temperature Sensor		$5	$5	$5
Manifold Air Pressure Sensor		$14	$14	$14
Crank Position Sensor		$16	$16	$16
Wiring/ Related Hardware		$80	$80	$80
Exhaust Gas Recirculation			$25	
Fuel System with EGR cost	**$323**	**$874**	**$943**	**$908**
Catalyst (2 units)				**$195**
Incremental exhaust manifold cost			$5	$30
Total Hardware Cost	**$323**	**$829**	**$948**	**$1,133**
Labor @ $28/hr	$1	$6	$6	$7
Labor Overhead @ 40%	$1	$2	$3	$3
Markup @ 29%	$94	$256	$277	$331
Warranty Markup at 5%			$4	$13
Total Component Cost	**$419**	**$1,138**	**$1,238**	**$1,487**
Fixed Cost to Engine Manufacturer				
R&D Costs	-	-	$147,848	$147,848
Tooling Costs	-	-	$45,000	$45,000
Units/yr.	15,000	15,000	15,000	15,000
Years to recover	5	5	5	5
Fixed cost/unit	**-**	**-**	**$4**	**$4**
Total Cost from Engine Manufacturer	**$419**	**$1,138**	**$1,242**	**$1,491**
Fixed Cost to Marinizer				
R&D Costs	-	-	$262,773	$262,773
Tooling Costs	-	-	$55,000	$55,000
Units/yr.	1,000	1,000	1,000	1,000
Years to recover	5	5	5	5
Fixed cost/unit	**-**	**-**	**$88**	**$88**
Total Cost from Marinizer	**$419**	**$1,138**	**$1,329**	**$1,579**
Incremental Cost from Uncontrolled Carburetor		**$718**	**$910**	**$1,159**
Incremental Cost from Uncontrolled PFI			**$192**	**$441**

Table 5-5. Three-way Marine Catalysts Cost Estimates

Table 5-5a. 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 5-5b. 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 5-5c. Catalyst Unit Price

Engine Size (L)	**3.0**	**4.3**	**5.7**	**8.1**
Catalyst Volume (L) (each)	**1.00**	**0.75**	**1.00**	**1.40**
Number of Catalysts	**1**	**2**	**2**	**2**
Substrate Diameter (cm)	9.5	8.3	9.5	11.0
Substrate	$7.67	$6.50	$7.67	$9.53
Ceria/Alumina	$11.47	$8.60	$11.47	$16.06
Pt/Pd/Rd	$28.07	$21.06	$28.07	$39.30
Can (18 gauge 409 SS)	$3.49	$3.15	$3.49	$4.06
Substrate Diameter (cm)	9.5	8.3	9.5	11.0
Substrate Length (cm)	14.1	13.9	14.1	14.7
Working Length (cm)	16.9	16.7	16.9	17.5
Thick. Of Steel (cm)	0.121	0.121	0.121	0.121
Shell Volume (cm3)	126	116	126	144
Steel End Cap Volume (cm3)	19	15	19	25
Vol. Of Steel (cm3)w/20% scrap	174	157	174	203
Wt. Of Steel (g)	1361	1228	1361	1584
TOTAL MAT. COST	**$50.70**	**$39.30**	**$50.70**	**$68.95**
LABOR	**$4.76**	**$4.76**	**$4.76**	**$4.76**
Labor Overhead @ 40%	$1.90	$1.90	$1.90	$1.90
Supplier Markup @ 29%	$16.63	$13.33	$16.63	$21.93
Manufacturer Price per unit	**$73.99**	**$59.30**	**$73.99**	**$97.54**

Table 5-6. Engine Manufacturer Research, Development and Prototype Costs

		3.0 L In-Line 4 135 hp			4.3 L V-6 205 hp			5.7 L V-8 285 hp			8.1 L V-8 400 hp		
		Hours	Rates	Cost	Hours	Rates	Cost	Hours	Rates	Cost	Hours	Rates	Cost
Design	Engineer	600	$64.41	$38,648	600	$64.41	$38,648	600	$64.41	$38,648	600	$64.41	$38,648
Development	Engineer	800	$64.41	$51,531	800	$64.41	$51,531	800	$64.41	$51,531	800	$64.41	$51,531
	Technician	1000	$41.87	$41,869	1000	$41.87	$41,869	1000	$41.87	$41,869	1000	$41.87	$41,869
Prototype	Engine			$3,625			$5,800			$7,750			$12,300
	Shipping			$2,000			$2,500			$3,000			$3,500
		Total Cost		**$137,673**	Total Cost		**$140,348**	Total Cost		**$142,798**	Total Cost		**$147,848**

Table 5-7. Engine Manufacturer Tooling Costs

Engine Size	3.0 L	4.3 L	5.7 L	8.1 L
Fixture/Tools	**$30,000**	**$35,000**	**$40,000**	**$45,000**

Table 5-8. Marinizer Research, Development and Testing Costs

		3.0 L In-Line 4 135 hp			4.3 L V-6 205 hp			5.7 L V-8 285 hp			8.1 L V-8 400 hp		
		Hours	Rates	Cost	Hours	Rates	Cost	Hours	Rates	Cost	Hours	Rates	Cost
Design	**Engineer**	600	$64.41	$38,648	600	$64.41	$38,648	600	$64.41	$38,648	600	$64.41	$38,648
Development	**Engineer**	800	$64.41	$51,531	800	$64.41	$51,531	800	$64.41	$51,531	800	$64.41	$51,531
	Technician	800	$41.87	$33,495	800	$41.87	$33,495	800	$41.87	$33,495	800	$41.87	$33,495
Prototype Test	**Boat**			$10,000			$15,000			$20,000			$25,000
	Dyno	300	$250	$75,000	300	$250	$75,000	300	$250	$75,000	300	$250	$75,000
	Boat Testing Tech	200	$41.87	$8,374	200	$41.87	$8,374	200	$41.87	$8,374	200	$41.87	$8,374
	Boat Testing Mech	200	$41.87	$8,374	200	$41.87	$8,374	200	$41.87	$8,374	200	$41.87	$8,374
	Test Fuel ($5/gal)	300	3 gal/hr	$4,500	300	4 gal/hr	$6,000	300	6 gal/hr	$9,000	300	8 gal/hr	$12,000
	Shipping			$2,000			$2,500			$3,000			$3,500
	Driver	300	$22.84	$6,851	300	$22.84	$6,851	300	$22.84	$6,851	300	$22.84	$6,851
		Total Cost		**238,773**	**Total Cost**		**$245,773**	**Total Cost**		**$254,273**	**Total Cost**		**$262,773**

Table 5-9. Marinizer Tooling Costs

Engine Size	3.0 L	4.3 L	5.7 L	8.1 L
Pattern Work	$20,000	$25,000	$30,000	$30,000
Fixture/Tools	$15,000	$20,000	$25,000	$25,000
Total Cost	**$220,000**	**$265,000**	**$310,000**	**$355,000**

Table 5-10. Summary of Incremental Technology Costs

Engine Size	Technologies	Controlled PFI with EGR	Controlled PFI with TWC
3.0 liter I- 4	Uncontrolled Carburetor	$767	$838
	Uncontrolled PFI	$132	$203
4.3 liter V-6	Uncontrolled Carburetor	$863	$1,003
	Uncontrolled PFI	$137	$277
5.7 liter V-8	Uncontrolled Carburetor	$931	$1,110
	Uncontrolled PFI	$147	$326
8.1 liter V-8	Uncontrolled Carburetor	$910	$1,159
	Uncontrolled PFI	$192	$441

Table 5-11. Operating Cost Savings

Engine Size	3.0 L I-4		4.3 L V-6		5.7 L V-8		8.1 L V-8	
Fuel System	Carb	FI	Carb	FI	Carb	FI	Carb	FI
Horsepower	135	135	205	205	285	285	400	400
BSFC (lbs/hp-hr)	0.658	0.567	0.658	0.567	0.658	0.567	0.658	0.567
Load Factor	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Hours/year	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
Gallons per year	143.2	123.4	217.5	187.4	302.3	260.5	424.3	365.7
Cost per year	$275	$237	$418	$360	$581	$500	$815	$702
Life, yrs	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7
Total Cost	$4,046	$3,486	$6,144	$5,294	$8,541	$7,360	$11,987	$10,330
Cost Savings		$560		$850		$1,181		$1,658