UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ANN ARBOR, MI 48105

April 10, 2007

OFFICE OF
AIR AND RADIATION

MEMORANDUM

SUBJECT: Peer Review of ICF Draft Report for Small SI Engine Technologies and Costs

FROM: Cheryl Caffrey, Assessment and Standards Division

TO: Docket EPA-HQ-OAR-2004-0008

Under contract with EPA, ICF Consulting prepared a draft report which estimated costs for emission control technology that could be used to reduce exhaust emissions from small Spark Ignition (SI) engines ≤19kW. The report provides a description of the technologies under consideration and presents a detailed set of estimated costs. The analysis includes variable costs, fixed costs, overhead, and operating costs. This report was prepared consistent with EPA's quality guidelines, which require us to maintain a high degree of transparency regarding the source of data and information, and regarding the assumptions and analytical methods used to reach our results and conclusions.

To identify any potential errors or misjudgments that may have been made in this work or methodology, we underwent a peer review process. Two individuals with experience in engine technology and costs were chosen by EPA to review the draft report. In particular, they were directed to focus their review on the descriptions of the available emission-control technologies and the estimated costs. The directions to the peer reviews may be found in Attachment 1 to this memo. Note that the public will have an opportunity to review and comment on the cost report during the notice and comment period for the proposed rulemaking for new Small SI Engine emission standards.

The two peer reviewers were Steve Griffin, Carnot Emission Services, and John Anderson, an independent consultant. Mr. Griffin's comments are hand-written on the draft cost report and included as Attachment 2. Mr. Anderson's comments are included as Attachment 3. We directed ICF to address these peer review comments in a new version of the cost report. This updated cost report is available in the docket.[1] The rest of this memo gives an overview of the comments and the updates made to the ICF cost report with specific comment responses to some technical and cost comments in Tables 1 and 2, respectively.

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[1] "ICF Small SI Engine Technologies and Costs, August 2006" ICF Consulting, prepared for the U.S. Environmental Protection Agency, August 2006, Docket Identification EPA-HQ-OAR-2004-0008-0506.

Summary and Analysis of Comments

Mr. Anderson's comments were primarily based on the presentation and format of the report as well as on the technical content and documentation of cost resources used in the report. The technologies for analysis were provided to ICF by EPA. A detailed discussion of the engine types, emission control technologies, and technological feasibility is provided in the draft Regulatory Impact Analysis for the proposed exhaust emission standards for small SI engines.

Mr. Griffin provided additional information to help clarify costs for design, research and development and testing small SI engines. This information was generally incorporated into the report. Mr. Griffin also provided some technical comment of which some was incorporated and some was not based on EPA's experience with emission testing and aging of such engines.

In summary, Mr. Griffin provided comments that the design, research and development, and testing costs were too low and need to consider costs of prototype engines used in durability testing. The cost of design, research, development, and testing costs were increased significantly in the updated report to address Mr. Griffin's suggestions. The prototype engine was also included in the durability testing. Mr. Griffin also commented on the some of the hardware cost estimates. No changes were incorporated for no alternative suggestions were offered and ICF stood behind their cost estimates.

Mr. Griffin commented that the markups used in the cost report for labor, overhead, and warranty were too low. Mr. Anderson commented that the basis for these rates was not documented adequately. The basis for these markups is presented in the draft RIA and is consistent practice in the cost analysis for similar rules. The variable cost markups are based on an analysis that was performed on markup of costs of goods sold as presented in engine manufacturer annual reports.[2]

Mr. Griffin commented that the test fuel price used to calculate certification and durability testing costs were too low and a suggestion of $5 per gallon was made. The test fuel price was increased as requested due to Mr. Griffin's knowledge of the topic. Mr. Griffin also commented that the cost of gasoline used to calculate fuel savings was too low. As a result, the cost of gasoline was increased based on average retail gasoline prices (without taxes) reported by the Energy Information Administration for 2005. The usage estimates are based on the NONROAD model and were not modified. The gasoline price was updated as described above and cites were provided for this and the factors used to project engine operation. Anticipated impacts on fuel consumption are consistent with the NONROAD model and are described in the docket.[3]

A number of editorial comments were included with the exception of Mr. Griffin's comment on including Class IA and IB as engine certification categories. The Phase 3 rulemaking generally treats Class IA engines as handheld and Class IB engines

[2] "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, Docket Identification EPA-HQ-OAR-2004-0008-0204.

[3] "Phase 3 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Nonhandheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model," Memorandum from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Ann Arbor, March 8, 2007. Docket Identification EPA-HQ-OAR-2004-0008-0546.

as nonhandheld. Additional comments and EPA responses are included in Table 1: Cost Comments and Responses and Table 2: Technical Comments and Responses.

Table 1: Technical Comments and Responses

	Page	Comment	EPA Response
1	3-2	Mr. Anderson: Eight common combinations of valve configuration/useful life/displacement/power were used for costing purposes (Table 3-1). The derivation of these combinations is important. If they were assigned by EPA, then a reference to an EPA analysis should be included.	The combinations are based on current Phase 2 useful life certification categories. Specific SV/OHV breakout in Class I 125 hours useful life is for technology differences only. These specifics are described further in the Draft RIA. The cost report was completed prior to the Draft RIA.
2	3-4	Mr. Griffin: Cylinder liners may consume 10-20% of engine power to do correctly? What is meant by better cooling fluid flow at the top of the cylinder lining? Air or liquid?	EPA believes the use of a cylinder liner will not decrease available power. Small SI engines are air and water cooled. Improved fan design can provide more cooling air.
3	3-5	Mr. Griffin: Does not agree the carburetor is set rich to account for air leaks over time.	This phenomenon has been noted in EPA's experience of engine aging and emission testing in 2002-2006.
4	3-6	Mr. Anderson: Looking at 3-way catalyst, why not look at a simple oxidation catalyst configuration?	EPA provided the technology list to ICF for costing. The specific catalyst technology was chosen based on EPA's experience with testing of small SI engines and catalysts. The reason for using the particular catalyst technology is explained in the Draft RIA.
5	--	Mr. Anderson: The baseline engines should be defined with precision.	"Table 3-1 Engine Parameters Used for Costing" lists the baseline engines in general (valve configuration, useful life (hours), engine power (hp) and average units per Year per Engine Family). The description states "nearly all baseline engines are air-cooled, carbureted, lack any exhaust after-treatment and have either one or two cylinders." The variety of quality in engine design and production in this industry varies from the "high quality high durablility" engines to the consumer use mower quality. The percentage of each technology contained in the ICF report that is used in the cost analysis is contained in EPA's spreadsheets for the cost analysis.
6	5-11	Mr. Anderson: Include some background on the assumptions used for the catalyst specifics such as catalyst volume to engine displacement ratio, precious metal loadings, etc.	This information was determined from work done for EPA's Safety Study[1]. EPA provided the technology list to ICF for costing. Further discussion is found in the Draft RIA.

[1]EPA Technical Study on the Safety of Emissioon Controls for Nonroad Spark-Ignition Engines <50 Horsepower, EPA420-R-06-006, March 2006.

Table 2: Cost Comments and Responses

#	Page	Comment	EPA Response
1	4-1	Mr. Anderson: does not like that the fact that 4.1 Hardware Costs states hardware costs are low for EFI because they need to be low.	The marketplace has produced different EFI designs for different applications including simpler designs for low cost equipment (see Draft RIA), such as systems for scooters versus automobiles. The low cost of consumer equipment with small SI engines depends on low cost technologies.
2	4-2	Mr. Griffin doesn't agree with the 60% fringe rate for labor and 29% hardware markup.	ICF modified the 60% fringe rate for labor to 45% fringe and 40% overhead markup based on research at www.salary.com of Wisconsin salaries and fringe. In Dec 2005, EPA investigated the annual reports for companies for their markup rates over three years (2002-2004) and verified the 29% estimate.
3	4-2	Mr. Griffin states that the 5% warranty markup should be 8-10%.	EPA is keeping warranty at 5% for the industry wide cost analysis. This is an estimate of the incremental change in warranty claims, not the total warranty burden. EPA believes this is an appropriate estimate.
4	4-3	Mr. Griffin suggested increasing the $100/test for dynamometer test time to $400/test.	EPA has increased the Cost/test for dynamometer test time to $250/test from $100/test. The overall cost estimate is within the suggested range of Mr. Griffin.
5	4-4	Mr. Griffin: Design costs/month for an engineer are way low	Costs were modified via www.salary.com. The rate for an engineer increased to $64.41. The amount for design costs per month is now $10,306. This will result in an increase in design costs for each technology.
6	4-4	Mr. Griffin: Development costs/month are too low – suggests 28,000/month.	Costs were updated via www.salary.com. The result was changed to $28,704/month including number of technicians, engineer and test related costs. This will result in an increase in development costs for each technology.
7	4-4	Mr. Griffin: Suggests $5/gallon test fuel cost	EPA investigated current estimates and updated the cost estimate to that suggested. This will result in an increase in certification and durability costs for each engine family.
8	4-4	Mr. Griffin: Certification test costs: where are costs for facility capital, idle time, down time and retests?	EPA updated the cost estimate to reflect the amount charged by Mr. Griffin in recent emission test work. Engine manufacturers have test facility expenses that are similar to independent laboratories.
9	4-4	Mr. Griffin: Durability testing: do not agree that one technician can watch four dynamometers running engine aging cycles.	Changed to one technician per engine oversight.

#	Page	Comment	EPA Response
10	4-5	Mr. Griffin: What about emission test at near zero (<12 hrs), mid-pt and useful life?	Page 4-5 describes Engine Dynamometer Durability Testing Costs. Certification costs including emission testing are pulled together in the cost chapter of the Draft RIA.
11	4-5	Mr. Griffin: Bring costs in line with current practice. Add cost for prototypes, double scheduled maintenance, add extra run time for engine warmup, etc. Add in dynamometer test costs.	Agreed to changes. Costs increased for Class I also due to items 1-6 in this Table.
12	4-6	Mr. Griffin: "Absolutely no way" regarding Class II engine dynamometer durability testing costs.	EPA updated costs in accordance with changes made for Class I.
13	4-7	Mr. Griffin: Field durability cost estimates questioned.	Field durability cost also increased due to labor rate increase, fuel cost increase, etc. added hours for realistic run of field test. Added technician hours where there were none.
14	4-9	Mr. Griffin and Mr. Anderson: Operating Costs: estimates for per gallon fuel costs too low, load factors and annual activity rates and discount rates are unexplained.	Costs per gallon changed with comment from Mr. Griffin. Annual activity rates and load factors from EPA NONROAD model
15	4-9	Mr. Anderson: Benefits other than fuel economy improvements should be outlined and estimated.	EPA believes the fuel economy benefits are the best estimate for operating cost savings from this proposed rulemaking. Other things such as improved durability and precision resulting on lower maintenance/repairs on these equipment types is subject to the piece of equipment and user maintenance, etc.
16	4-10	Mr. Griffin: 46%-47% load factor should be used in estimating fuel savings	EPA used 37% and 50% to represent the most used application of a lawnmower and garden tractor. These figures are consistent with EPA's emissions model, which takes in use operation into account.
17	5-1	Mr. Griffin: 2000 hr Class II engine still has way to go to meet 50% reduction HC+NOx.	EPA has removed the 2000 hour useful life option from the proposal.
18	5-1	Mr. Griffin: Says most engines have oil pressure switches in Class II	EPA does not agree based on work with consumer Class II equipment.
19	5-2	Mr. Griffin says there should be some distinction between high and low volume sales families with respect to R&D.	EPA estimates apply to the whole industry, so we provide a single estimate that weighs the high and low sales families.
20	5-2	Mr. Griffin: $834 filing fee with EPA	The filing fee is an existing cost for the industry. The cost analysis accounts for new costs due to the Phase 3 rulemaking.

#	Page	Comment	EPA Response
21	5-4	Mr. Griffin: expressed concern over the price parts estimates for the pressurized oil system components. Expects tooling costs would be more.	No quantitative suggestions offered by Mr. Griffin. EPA did double the modified crankshaft, etc. for 125UL Class I SV engine category.
22	5-7	Mr. Anderson: Cost estimate may be too high if two injectors are costed for a throttle body fuel injection in a two cylinder engine. Mr. Griffin: states that the oxygen sensors and wiring harnesses are too low.	The cost analysis assumes that only 33% of Class II engines use two fuel injectors. A single throttle body injector for a twin-cylinder engine would likely cost less than two separate injectors, so it is true that the estimated costs would be slightly too high for this scenario. After reviewing the figures, we continue to believe the estimated costs for oxygen sensors and wiring harnesses are appropriate.
23	5-7	Mr. Griffin: How does fixed R&D cost of closed loop become less than open loop? The more variables, the higher the cost.	In the case of electronic fuel injection, closed loop systems give design engineers a powerful tool for controlling emissions. As a result, overall R&D is smaller.
24	5-9	Mr. Griffin: Cast iron cylinder liners – requires complete redesign for Class I engines.	We believe the R&D allotted for adding cylinder liners.
25	5-10	Mr. Griffin: Three way catalyst for single cylinder small SI engine - Design and Development will need more than 7 months. No recommendation.	EPA staff designed and developed catalyst systems in such time for the proposal. The total time to design and develop a system will likely decrease overall once a protocol is established. The EPA Safety Study provides a number of design ideas for the engine manufacturer to develop a feasible catalyst muffler system.
26	Back Page	Mr. Griffin: What is the additional cost to consumers? Baseline = 0?, Bells and Whistles = $xxx.xx	The work of the cost chapter in the Draft RIA is to utilize the cost estimates from the ICF report into a cost estimate for engine/ equipment manufacturers to meet the Phase 3 proposed standard.

Attachment 1

Dear Reviewer:

We appreciate your agreement to participate in peer review for this study.

EPA is pursuing a proposal that would set new, more stringent emission standards for nonroad spark-ignition (SI) engines. We have prepared a set of reports by contract to estimate the cost of introducing a variety of emission-control technologies. The attached reports estimate costs separately for Small SI engines, sterndrive/inboard Marine SI engines, and outboard/personal-watercraft Marine SI engines. Each report provides a description of the technologies under consideration and presents a detailed set of estimated costs. The analysis includes variable costs, fixed costs, overhead, and operating costs. We prepared these reports consistent with EPA's quality guidelines, which require us to maintain a high degree of transparency regarding the source of data and information, and regarding the assumptions and analytical methods used to reach our results and conclusions (see http://www.epa.gov/quality/informationguidelines/).

Our goal for this peer review is to identify any errors or misjudgments that we may have made in this work or methodology. In particular, we would like your review to focus on the descriptions of the available emission-control technologies and the estimated costs. Note that the scope of the report does not include an assessment of the degree to which the individual technologies will control emissions, so it is not necessary to comment on the appropriateness of applying the control technologies to reach a certain emission level. Note also that we are separately evaluating the safety implications of the emission-control technologies under consideration, so this is also outside the scope of this peer-review effort.

No independent data analysis is required for this review, nor is it required that you duplicate or verify the results.

Your comments should be provided in separate reports that include your name, the name and address of your organization, what material was reviewed, a summary of your expertise and qualifications, and a statement of any real or perceived conflicts of interest. Your comments should include a summary describing the nature of your review and your findings and conclusions. Please also send an electronic file with your comments, either via e-mail or on a diskette. We will include your reports in the rulemaking docket that we have established for this rulemaking. We intend to compile all the peer-review materials into a collection of files for each of the cost reports, so you should send us three separate peer-review reports for the different engine categories represented by the cost studies. The comments should be sent to me via e-mail at stout.alan@epa.gov, or by mail to:

Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

Although EPA will eventually release this report along with your comments, we would appreciate your cooperation in not sharing the cost reports or your comments with anyone until we make them public.

We would appreciate receiving the results of this review within three weeks.

If it is acceptable, you will be paid a flat fee of $1,000 for your review of these cost reports. In your cover letter, please indicate the number of hours actually spent on the review; spending fewer or more hours than our estimate will not affect the fee paid for this work, but will help us improve our future estimates. A purchase order form is also included showing payment information. You may expect to receive payment in full within forty-five days of submitting your reports and a copy of the invoice to us. Please send your invoice directly to:

RTP Finance
Mail Drop MC-D143-02
109 T.W. Alexander Drive
Research Triangle Park, NC 27711

Thank you for your time and consideration. If you have any questions about the scope or process of this review, please contact me by phone at 734-214-4805 or e-mail at stout.alan@epa.gov.

Sincerely,

Alan Stout
Assessment and Standards Division
Office of Transportation and Air Quality

Enclosure

Attachment 2

Holly Schmidt <hgschmidt@sore-aces.com>
Sent by: Holly Schmidt <hgschmidt@sore-aces.com>

Received Date: 06/08/2006 05:11 PM
Transmission Date: 06/08/2006 05:11:30 PM

To: Alan Stout/AA/USEPA/US@EPA
cc:
bcc:
Subject: Peer Review

Mr. Stout.

Steve Griffin was contracted to provide three separate peer-review reports for the different engine categories represented by the cost studies. He provided these reviews in hand when he was in Ann Arbor. Attached are Steve's credentials and an overview of the Carnot Emission Services, the company he owns and operates.

Holly Schmidt
Office Manager
Carnot Emission Services
616 Perrin, KellyUSA
San Antonio, TX 78226
(210)928-2230

2006 Equipment List and Experience.pdf

January 31, 2006

Engines

- Research
  - Combustion
  - Emissions
  - Heat Rejection
  - Friction
  - Analysis
- Development
  - Testing
  - Durability
  - Mapping
  - Emissions

Emissions

- Research
- Development
  - Deterioration Factors
- Certification
- Audit
- Compliance

Services

- Support
- Consulting

To Whom It May Concern

Subject: "Facility and Equipment Description"

Carnot Emission Services is a multi-million dollar engine R&D lab that was established to conduct emission research, development, testing, and emission certification for on-highway motorcycles and nonroad engines ranging from 0.75 hp to 500 hp. CES is located on a privatized military base, and due to our extensive government infrastructure for compressed air, cooling capacity, and electrical power, our testing is accomplished on AC regenerative dynamometers only.

Hardware

Speed Control is easily maintained within ± 0.2 rpm of point. Torque Control is less than 2% of point with calibrations that are better than 0.1% FS. Torque is measured with Lebow© in-line torque meters having maximum loads ranging from 4.3 ft-lb to 1750 ft-lb.

Emission sampling is accomplished by either an 8" or an 18" full-flow dilution tunnel, CVS-PDP system, or in rare cases, raw sampling. Emission capabilities include:

HC R1 = 60 ppm, R2 = 400 ppm, R3 = 2500 ppm
NOx R1 = 60 ppm, R2 = 400 ppm, R3 = 2550 ppm
CO R1 = 100 ppm, R2 = 600 ppm, R3 = .5%
R4 = 10%, R5 = 12%
CO2 R1 = 2.8%, R2 = 12%
O2 R1 = 4.08, R2 = 19.96%
ICO2 R1 = 0.5%, R2 = 3.98%

With exception to the R5 12% CO cylinder, all bottles are EPA Protocol/RATA class blends provided by Scott Specialty Gases and Air Liquide. The emission analyzers are Emerson Rosemount with the bench system provided by Richmond Instruments. During raw emission sampling on small engines (i.e. power under 25 hp), fuel flow is measured gravimetrically using a Transuder Techniques 10 lb scale. Instrumentation is recorded electronically and calibrated regularly. For larger engines, MicroMotions are used.

All temperatures are measured with Type K thermocouples except during heat rejection on liquid cooled engines. In this case, only 4-wire RTDs are used. Barometric pressure is measured with a 26"Hg to 32"Hg Sensotec pressure transducer, and all other pressure transducers are manufactured by Validyne. For your reference, we are currently looking at changing from Validyne and Sensotec to GE Druck for our future pressure transducer needs. Electronic calibrations are performed using an Ectron 1120 Thermocouple and voltage calibrator for temperature and data acquisition, and a Heise calibrator for pressures.

Control Software

Temperature control is completed with Watlow temperature controllers.

PDP Speeds are controlled with a variable frequency drive with base flow calibrations at 15 Hz, 25 Hz, 35 Hz, 45 Hz, and 55 Hz.

Dynamometer control is completed with Carnot Emission Services proprietary software and hardware.

Throttle Controllers are provided by Jordan Controls

For particulate sampling and weighing, we use Pallflex 47 mm filters, and a Sotorius SC2 scale having a 2.1 g max., and a 0.1 microgram resolution that meets current EPA 2007 emission sampling requirements.

Dilution tunnel calibrations were performed with a Meriam Instruments LFE for both the primary and secondary dilution tunnels. Periodic propane recovery checks are also performed on the dilution tunnels using a Horiba single CFO. Smoke opacity measurements are conducted with a CalTest smoke meter.

Each dynamometer and engine installation is mounted on either a 4x6, 4x8, 4x9, or 5x12 engine bed plate that has been anchored and pressure grouted for reduced vibration and ease of installation and alignment. All test cells are equipped with test cell and intake air temperature and humidity control allowing us to regularly produce F factors of 1 ± 0.01, if desired. Humidity and Dewpoint temperature are monitored and electronically recorded from a Vaisala instrument.

Fuel blends are available for CA PII, EPA Indolene, Diesel 2-D low sulfur, and a multitude of pump grade fuels. Numerous other electronic, stainless valves, fittings, hardware, software, and equipment are used to support this lab along with a complete machine shop for rapid fabrication of engine mounts, fly wheel adapter plates, and other equipment.

If you have any questions regarding the emission certification testing, equipment, or provisions, please contact me at (210) 928-2230, or via FAX at (210) 928-1233, or via email sgriffin@sore-aces.com.

Sincerely,

Steve Griffin

Steven E. Griffin
President and CEO
Carnot Emission Services

STEVEN E. GRIFFIN
President and CEO

B.S. Mechanical Engineering, The University of Texas/San Antonio, 1992
M.S. Mechanical Engineering, The University of Texas/San Antonio, 1993

Mr. Griffin began working for Southwest Research Institute (SwRI) as a student engineer in May of 1991 where he supported the Engine and Vehicle Research Division on various projects. Upon graduation from the University of Texas at San Antonio (UTSA) in 1992, Mr. Griffin enrolled in graduate school and participated in two consecutive summer, graduate research internships at Air Force Phillips Laboratory, Kirtland AFB, New Mexico. The summer research resulted in an Air Force Office of Scientific Research subcontract to continue computer modeling of latent energy storage canisters for space power thermal management systems. As a UTSA principal investigator, he focused on developing numerical procedures to successfully evaluate the overall performance of phase change canisters using a fully implicit, piece-wise linear, finite-difference approximation that eliminates the nonlinear phase-front constraint.

Mr. Griffin briefly worked in SwRI's Center for Nuclear Waste and Regulatory Analysis Division in an ongoing effort by the Department of Energy to successfully develop the first high-level waste repository in the Yucca, Nevada site. His participation focused on storage containment and ion-induced corrosion. Since completing his master's degree in 1993, Mr. Griffin has been an adjunct professor and instructor of thermal science courses for UTSA and ASHRAE.

Mr. Griffin rejoined SwRI in the Spark-Ignition (SI) Engine Development group in the Department of Engine Research. Although his work focused primarily on SI gasoline engines, Mr. Griffin has undertaken various projects related to gasoline, diesel, liquified petroleum gas, and natural gas engines as well as component evaluations. Some of the component testing included a natural gas injector study aimed at establishing performance characteristics of prototype and conventional injectors. Mr. Griffin has also worked to improve engine performance through modifications to chamber head and port geometry by enhancing in-cylinder swirl and tumble. Other component projects included spark plug research to determine the effects from carbon and metallic-oxide accumulation along the insulator, mass flow gas sensor characterization as a function of temperature and pressure, and engine test cell instrumentation and controls. Mr. Griffin has conducted intake valve deposit studies to investigate several mechanisms of carbon deposits on valves and has also performed several diesel emission model estimates for steady state and transient hybrid bus applications.

Mr. Griffin's engine experience ranges from small engines like 33 cc gasoline generators and single cylinder 0.3L IDI spark-assisted, commercial aviation diesels to large diesels like 64L 16 cylinder emergency power units for submarines and 110 L 16 cylinder locomotives. Mr. Griffin has conducted quick-look research to determine the effect of spark plug rim-fire on engine performance and emissions. Mr. Griffin managed and engineered SwRI's efforts to conduct world-class benchmarking of vehicles and engines to provide supplemental vehicle and engine testing for General Motors' Contemporary Engine Evaluation program and competitive analysis. Through this program, Mr. Griffin has further developed extensive laboratory, computer, and technical skills required for stringent vehicle and engine test criteria. Mr. Griffin was awarded an internal research project to test a NASCAR Winston Cup engine for combustion and air/fuel ratio distribution. He has completed model-based EGR evaluations for comparison to benchmark data, presented two SAE technical papers and other topics. Mr. Griffin was awarded a 1998 Engine and Vehicle Research plaque for "outstanding and dedicated service".

Mr. Griffin transferred to the Certification, Audit, and Compliance Section of the Emission Research Department (ERD) in October 1999. His responsibilities included heavy-duty, on-highway and nonroad, gasoline and diesel engine and emission testing for utility, industrial, commercial, and recreational type applications. Mr. Griffin's participation in the ERD expanded services to include EPA and CARB certification application support, marine engine development, LP and CNG forklift development, small offroad engine (SORE) research and emission certification, and the department's use of LabVIEW and other data acquisition hardware. Mr. Griffin's work has been recognized and cited by the EPA and CARB for heavy-duty on-highway gasoline, large spark-ignited nonroad (forklift), marine, and small offroad (SORE), and nonroad (diesel) emission testing. Mr. Griffin has helped manufactures achieve EPA/CARB engine certification.

Mr. Griffin resigned from SwRI in September, 2002 to establish Carnot Emission Services (♠CES) as a premier emission services laboratory dedicated to engine manufacturers and importers of small offroad engine (SI) and nonroad engines producing power below 37 kW (50 hp). Higher power (up to 200 hp at 7000 rpm) ratings are also available. ♠CES provides engine research, development, and testing to establish emission certification for EPA and CARB compliance, customer audits, and other emission support.

Mr. Griffin's extracurricular activities have included several years on the local SAE board, mentoring and tutoring local area high school students, chairing a quality council research-in-progress team for improving laboratory facilities, and teaching technical sessions for SwRI staff. Mr. Griffin is actively involved in his church as the property chair, and community through road pickup and neighborhood watch. His most enjoyable activities include raising three daughters while meeting his wife's loving wishes.

PROFESSIONAL CHRONOLOGY: Air Force Phillips Laboratory, graduate student, Summer 1992 and 1993; University of Texas, (research associate, 1992-93; teaching associate, Spring 1994-97, Summer 1997); Southwest Research Institute 1991-(student engineer, 1991-1992, engineer, 1994-96, research engineer, 1996-2002, senior research engineer, 2002); Carnot Emission Services, Inc. President and CEO, 2002-present.

ICF
CONSULTING

SD
3/15/06

U.S. Environmental Protection Agency

Small SI Engine Technologies and Costs

Draft Final Report

June 2005

I don't feel like legacy cost (warranty) are nearly high enough for some of the engines. families. Warranty has literally put multi-million dollar companies out of business.

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powered by perspective

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U.S. Environmental Protection Agency

Small SI Engine Technologies and Costs

Draft Final Report

June 2005

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

Prepared by:
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San Francisco, CA 94111
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1. Introduction

The United States Environmental Protection Agency (EPA) began regulating emissions from small, nonroad spark-ignited (SI) engines with Phase 1 standards beginning in 1997. Small SI engines are designated as those less than 19 kilowatts (kW) (25 horsepower [hp]) and are broken into Class I and II also 1A & 1B for non-handheld engines and Classes III through V for handheld engines, depending on the intended use and engine displacement. In March 1999, EPA finalized new, more stringent Phase 2 regulations for small, non-handheld SI engines, and in March 2000, EPA finalized Phase 2 regulations for small, handheld SI engines. EPA is now considering new exhaust emissions standards for small, non-handheld SI engines that will likely be met by the combined use of advanced technology, engine redesign, and exhaust after-treatment.

The updated technology expected to be implemented to reduce emissions from small, non-handheld SI engines includes improved engine design, fuel injection technology, or low-cost electronic engine management systems. Engine redesigns could include improved machining tolerances and gaskets, better oil control, migrating from side valve (SV) to overhead valve (OHV) combustion chamber design, modified cylinder liners, and/or use of a pressurized oil system. Exhaust after-treatment could be addressed by the use of catalysts in the muffler. The purpose of this report is to provide details on incremental technology and estimated costs for small, non-handheld SI engines that could be used to meet reduced emission levels. ICF Consulting priced technology packages including all the technologies mentioned above. Because the technology mix needed to comply with any lower emission standards for small SI engines is not known and is likely achievable through a variety of technologies and engines, the array of technology packages discussed in this report is likely to encompass what will be available from manufacturers to meet any new standards. All technology packages considered for small, non-handheld SI engines are available today in some form.

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. Table 1-1 provides definitions of Class I and II small non-handheld engines.

Table 1-1 Small Non-Handheld SI Engine Classes

Also Class 1A + 1B.

Engine Class	I	II
Displacement	≥100 and < 225 cubic centimeters (cc)	≥ 225 cc
Examples	Walk behind mowers, Pressure washers, Air pumps, generators	Riding mowers, Commercial turf equipment, ~~Some~~ generators

Source: EPA Phase 2 Standards for Small SI Engines

The following sections discuss background information on small, non-handheld 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

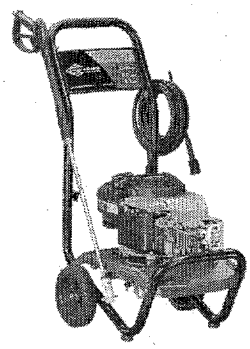
Small SI engine manufacturers may purchase components from other manufacturers, but typically produce and assemble the engine system themselves. Engine manufacturers will be largely responsible for additional costs associated with advanced technologies for exhaust emissions mitigation in the United States.

Small, non-handheld SI engines in the U.S. are generally only available in a four-stroke configuration. (Some two-stroke engines are still available for snow throwers.) Fuel delivery is typically carburetion, although a few systems employ fuel injection. Although many use overhead valve (OHV) induction technology, side valve (SV) induction is still common, especially in Class I engines. Most small SI engines are carbureted, and most do not have after-treatment of exhaust gases from the engine. Generally, the Phase 2 standards required manufacturers to reduce exhaust emission levels from new engines and to ~~mitigate~~ okay. deterioration throughout their useful life through improved engine design. ~~encourage emission reduction through useful life~~

Figure 2-1 shows some current examples of Class I small, non-handheld SI engine applications. The first example is a 6.5 hp Briggs and Stratton residential-grade power washer. It has a retail price of about $400. The second piece of equipment is a 5.5 hp Honda residential-grade walk behind mower with OHV configuration. It retails for around $340. The third example is a 10 hp, commercial-grade generator from Yamaha. It offers OHV configuration, cast iron cylinder lining, and refined combustion chamber design and retails for about $667.

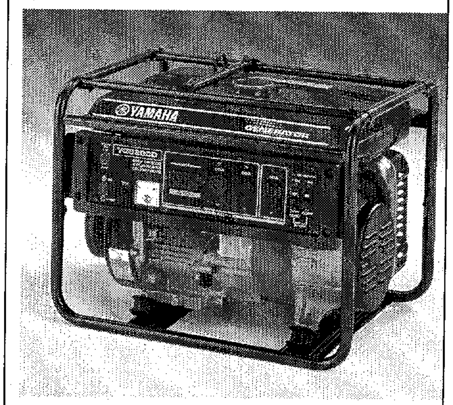
Figure 2-2 shows some current examples of Class II small, non-handheld SI engine applications. The first piece of equipment is a Toro riding lawnmower with a 17 hp OHV Briggs and Stratton Vanguard engine. It has a retail price of around $2,850. The second example is a 5 kW Kohler marine generator with a 16 hp Kawasaki liquid-cooled 2-cylinder engine. It retails for $3,394.

Figure 2-1 Examples of Class I Non-Handheld Small SI Engine Uses



Pressure Washer

Walk Behind Mower

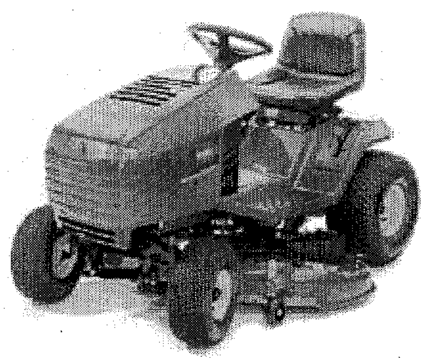


Gen Set

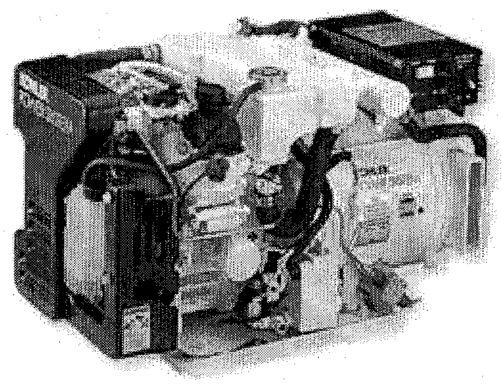
Sources:

1. http://www.briggsandstratton.com/
2. http://www.hondapowerequipment.com/
3. http://www.yamaha-motor.com/

Figure 2-2 Examples of Class II Non-Handheld Small SI Engine Uses



Lawn Tractor



Marine Generator Set

Sources:

1. http://shop.briggsandstratton.com/
2. http://www.kohlerpowersystems.com

3. Technology Description

Because engine manufacturers are expected to use a mix of technologies to meet future, more stringent emission standards, this study focuses on a range of technologies and develops incremental costs in migrating between these technologies. The range of technologies that could be employed varies significantly, from refined engine designs, to improved fuel delivery, to exhaust after-treatment. In general, the baseline package consists of a Phase 2 compliant carbureted four-stroke engine without any exhaust after-treatment.

Advanced technology packages considered in this analysis include all of the following. For fuel induction, we considered migrating from traditionally carbureted fuel induction to both open and closed loop electronic fuel injection, open loop electronically controlled carburetors with electronic governors, and mechanical fuel injection systems. For improved engine design, we considered improved casting and machining processes, improved combustion chamber designs, reduced crevice volumes, improved oil control, improved cooling, calibration changes, better gaskets and fuel filtering, and larger induction coils. Other engine improvements considered separately are migration from SV to OHV configurations, migration to a pressurized oil system, and the addition of cast iron cylinder liners. For exhaust after-treatment, we considered the addition of three-way catalysts in the exhaust muffler for both SV and OHV engines.

Note: Most important

Common sizes, power ratings, and useful lives of small SI engines were used for costing purposes. These metrics are shown in Table 3-1 and are based upon information provided to EPA by engine manufacturers as part of the certification process for small SI non-handheld engines. Other engine models of similar sizes will have similar changes and costs. Note that not all manufacturers produce engines in the configurations shown in Table 3-1, and not all configurations are available for all sizes today from all manufacturers. Where not available, estimates were made based on similar sized engines and comparable technology.

Table 3-1 Engine Parameters Used for Costing

Class	Valve Configuration	Useful Life (hours)	Displacement (cc)	Engine Power (hp)
Class I	SV	125	173	3.2
	OHV	125	163	5.1
	OHV	250	188	5.9
	OHV	500	170	4.8
Class II	OHV	250	378	10.2
	OHV	500	436	12.7
	OHV	1000	581	16.2
	OHV	2000	657	19.7

Note: 196 cc Honda is significant in sales since it is also replicated in huge #s by Chinese.

3.1. Baseline Technologies

As discussed above, the baseline technology package considered varies with the advanced technology to which it is compared. However, all baseline engines are typically air-cooled, carbureted, and lack any exhaust after-treatment.

3.2. Advanced Technologies

A mix of advanced technologies is likely to be applied to the suite of new engines produced to comply with any new emission standards. As discussed above, likely candidates to be employed include engine modifications, improved fuel delivery, and exhaust after-treatment. These technologies could be marketed individually or in combination. The technologies are discussed below.

3.2.1. Engine Improvements

Improved engine design and construction enhances engine performance and durability, improves fuel economy, and reduces emissions. Engine improvements can include several different processes and components. We focused on the following improvements:

- Casting and machining tolerances
- Combustion chamber modifications
- Reduced crevice volumes
- Improved oil control

- Improved cooling
- Better gaskets and fuel filtering
- Larger/better induction coil

Improvements in casting and machining tolerances generally allow engines to meet more restrictive emissions levels over a longer lifetime, reduce variance between engines, and further ensure quality in engines produced. However, additional costs can be incurred through redesign and possibly from slowing down the manufacturing process and the requirement of additional tools. Improvements in combustion chamber design focus on improved combustion chamber geometry to produce a more uniform charge distribution, more complete charge burning, and better efficiency. Modifying the chamber design generally does not require additional parts. Reducing the crevice volume between the compression ring and the top of the piston greatly reduces the amount of unburned fuel trapped in that region and helps minimize unburned fuel emissions.* Improved oil control reduces the amount of fugitive oil that leaks into the combustion chamber (which degrades the combustion and emissions characteristics over time) and limits catalyst poisoning. Improved cooling helps reduce nitrogen oxides (NOx) emissions and results in extended engine life.[1] Better gaskets reduce air leaks in the intake manifold and carburetor and minimize lean air/fuel ratio shifts as the engine ages. By placing a fuel screen at the inlet to the carburetor, large contaminants such as rust particles are captured before entering the carburetor, which reduces the possibility of clogging jets and needle valves. Larger induction coils would insure enough spark energy to ignite the air/fuel mixture in the cylinder on a more consistent basis.

3.2.2. *Overhead Valve Configurations*

SV four-stroke engines are mechanically simpler and cheaper to manufacture than OHV four-stroke engines; although, SV design dictates that cylinder cooling is much less efficient than in OHV configurations. Because of this, SV engines have to run rich, and the cylinders tend to distort, resulting in higher hydrocarbon (HC) emissions. Also, the larger surface-to-volume ratio in SV engines provides more surface area for flame quenching and has poorer mixing and combustion than in OHV engines, both of which lead to greater emissions. Although traditionally most small SI engines have used SV technology for its reduced cost and weight,

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[1] Improved cooling also allows operation at leaner air-fuel ratios and reduces cylinder bore distortion, both of which reduce HC emissions.

* Oil consumption primarily stems from crankcase venting back into the intake air filter or assembly.
Early Reed valve failure is common place causing HC to more than double @ useful life.

OHV engines are becoming more common as emissions ~~mitigations~~ become more important. Most Class II engines are OHV engines.

3.2.3. Pressurized Oil Systems

Pressurized oil systems are superior to non-pressurized because they provide positive oil delivery to the internal components. Instead of just splashing oil onto the bearings, lubrication is delivered as a light mist to the bearings, thus increasing bearing life, decreasing temperature, and reducing maintenance. This improved lubrication system will result in enhanced performance and decreased emissions; although, increased costs are associated with the increased complexity of the system. Several engines use a pressurized oil system with an oil pump and filter, but do not have passageways to bearings and valve guides. The pressurized oil systems proposed in this document include channels that transfer oil to the bearings and valve train. - increases cost of repair if and when engine failure happens.

3.2.4. Cylinder Liners

May consume 10-20% of engine power to do correctly.

Some engines use cast-iron or other cylinder liners to better regulate temperature and shape of the cylinder bore during operation. Cast iron cylinder liners are used to create equal cylinder wall thickness and provide a better finished surface than the aluminum of the block itself. The better shaped and harder cylinder liners resist distortion and vibration, reducing the risk of cavitation. The reduced vibration and cavitation allow piston rings to follow liner surfaces smoothly, resulting in ~~very low~~ lower oil consumption. A smoother engine cylinder has the benefit of increased reliability, low wear characteristics, and reduced emissions from oil in the combustion chamber. Some engines incorporate better cooling fluid flow at the top of the cylinder lining to better dissipate heat, improving cylinder liner sealing, reducing engine temperature, and further decreasing NOx emissions. Like many engine improvements, cylinder liners increase engine cost. ~~One of the most cost effective [illegible] to address both HC, NOx and [illegible] to oil consumption.~~

? what is meant here: air or liquid cooling.

3.2.5. Electrically-Controlled Carburetion

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, thus directly enhancing control over the air-fuel mixture. Traditionally, carburetion provides fuel to multiple cylinders unevenly; has less control of air/fuel ratio, particularly during transients; and may requires the user to operate a choke, all of which tend to

(A significant number of these engines are single cylinder.

I don't believe this.

make carburetion less attractive than advanced fuel delivery systems. Also typically carburetors need to be set fairly rich to compensate for air leaks over time. However, carbureted systems are less expensive and mechanically and electrically simpler than advanced systems, such as fuel injection.

An electronic carburetor usually includes an air valve placed ahead of the carburetor that controls air flow through the carburetor. Air flow is controlled through the use of a simplified electronic control module (ECM) which uses a manifold air pressure (MAP) sensor and a crankshaft speed sensor for input. The crankshaft speed is usually derived from the inductive ignition coil ~~used for ignition~~, so no additional sensor is needed. The additional regulation of fuel provides a more sensitive response of the carburetor to dynamic engine loads and can help ~~to~~ compensate for ~~mitigate~~ any default overly rich setting of the carburetor, provide fuel shut off during periods of engine deceleration, and allow electronic governing through air flow control.

Not without running the cat.

difficult to use with a TWC effectively.

3.2.6. *Mechanical Fuel Injection*

As discussed above, carburetion is less ideal than fuel injection for delivering an appropriately mixed charge to the cylinder(s) for combustion. Particularly in response to sudden increases in load, carbureted systems on small SI engines are susceptible to stalling due to inefficient management of the air/fuel mixture. For larger engines, electronic fuel injection has been employed successfully to mitigate the problems associated with carburetion. However, electronic fuel injection systems tend to require a battery and alternator not present on most Class I engines. One possible solution for delivering a more precise, metered amount of fuel evenly to the cylinder~~s~~ without needed excess electronics and significant cost and weight increases is mechanical fuel injection (MFI).

mostly because they barely have power to cut a blade of grass.

do a word search and eliminate 1/2.

A MFI system works by employing a mechanical fuel pump to pressurize and deliver fuel to a fuel injector that then sprays a precise amount of fuel into the mixing chamber, based on air flow rate and speed. Fuel metering is determined through an air bellows, which moves a rack based upon air pressure and flow. The fuel pump is operated by the mechanical energy of the engine, typically through the use of the cams. MFI was commercially developed for automobile use in the 1950s, but later replaced by electronic fuel injection. For small SI engines, MFI offers the promise of more controlled fuel delivery than carburetion, but with lower cost and weight than electronic fuel injection. YES also used by HD engines in the past but not with TWC

3.2.7. *Electronic Fuel Injection*

The performance advantages of fuel injection over carburetion are discussed above. Electronic fuel injection (EFI) offers superior performance over MFI because it allows the ability to change more instantaneously and create more precise metering of fuel charge for given loads. For single cylinders engine, mass air flow sensors or manifold air pressure measurements are extremely difficult.

For small SI engines, EFI systems will most likely use a throttle body with the ECM and MAP sensor built in to reduce space requirements and costs. Because these engines usually operate at steady state, a throttle position sensor could be eliminated. Instead, the air flow rate could be interpreted from the speed and MAP sensors. The speed signal can be obtained from the inductive ignition coil ~~usually used for ignition~~. I say air flow rate can be inferred from Spd and TPS.

unlikely. We have been working on this and found that TPS is more important than MAP. I would eliminate MAP before throttle position sensor.

The injector can be mounted in the throttle body or the intake manifold. For two-cylinder engines, two injectors are used. Based upon certification information provided to EPA by engine manufacturers, approximately one-third of Class II engines are two-cylinder engines. A pressure regulator and ~~higher~~ pressure fuel pump are also required. For closed loop systems, an oxygen sensor also is required. These systems are now becoming available on small motorcycles and scooters, and the technology is being considered in the small SI engine arena. For Class I engines, a battery and alternator also are required, as these are not standard equipment on most Class I engines; although, at least one system has been developed that runs off the existing engine magneto and thereby, requires no battery. EFI systems also provide better fuel economy than carbureted engines. ~~[illegible]~~

It depends on targeted A/F.

3.2.8. *Catalysts*

Three-way catalysts are likely to be incorporated on some small engine models as an additional control mechanism for emissions reduction. The catalyst expected to be used in these applications could be purchased by engine manufacturers as small substrates from catalyst manufacturers and added into the exhaust muffler or could be purchased as a complete catalyst/muffler that would be added into the exhaust stream. The catalyst volume would range from about 25% of the total engine displacement for the smallest engines with the shortest useful lives to about 75% of the total engine displacement for the largest commercial-grade engines with long useful lives. Catalysts for small, non-handheld SI engine applications were discussed for the Phase 2 rulemaking, but were not used as the basis for the Phase 2 standard. Since that time, catalysts for both small, handheld and small, non-handheld SI engines have begun to be commercially available from companies such as Engelhard, Delphi, Umicore, Johnson Matthey and others.

Table 3-2 describes the three-way catalysts envisioned for small SI engines. Platinum/Rhodium (Pt/Rh) precious metal catalysts will most likely be used for Class I engines due to concern with oil sulfur content, while Palladium/Rhodium (Pd/Rh) catalysts will be used for Class II engines. Precious metal loadings of between 40 and 60 grams per cubic foot (g/cu ft) of catalyst size are expected, depending upon useful life. Washcoat material is expected to be a 30%/70% mixture of cerium and alumina oxide, respectively. Passive secondary air injection is also envisioned. HC + NOx conversion efficiencies of 35% to 50% for Class I and 50% to 75% for Class II are expected over the regulatory useful life of these catalysts.

low compared to auto stnd 90%

Metallic substrates provide better resistance to vibration and temperature and are more desirable where the muffler/catalyst is mounted directly on the engine block, as is usually the case with Class I engines. In addition, metallic substrates can be built using lower cell densities, which reduces back pressure. On the other hand, ceramic substrates are significantly less expensive and can be used in Class I and Class II applications where engine vibration is not a problem. In both Class I and Class II engines, one catalyst is envisioned per engine, but ~~may consist~~ of more than one substrate. Catalysts in Class I engines are envisioned as one or more substrates placed in the muffler. Class II engine catalysts are envisioned to be canned with a second layer air ejector construction to aid in cooling.

depends on muffler used and wall thickness

While not all Class I applications require additional catalyst durability and some Class II applications will require additional durability, catalyst costs are estimated with the assumption that 50% of the production of each engine type having metallic substrate catalysts with a cell density of 200 cells per inch and 50% of the production having ceramic substrate catalysts with a cell density of 400 cells per inch. The total cost of adding a catalyst includes the catalyst, catalyst housing, retooling the exhaust manifold, labor, mark-up, and warranty costs. Substrate costs are calculated based on standard sizes being used for a variety of applications beyond small SI engines.

very durable and still used in the auto industry

Can be very large when catalyst are damaged from shock or from thermal effects.

Table 3-2 Catalyst Characteristics for Small SI Engines

Engine	Class	I				II			
	Useful life (hrs)	125	125	250	500	250	500	1000	2000
	Valving	SV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
	Power	3.2 hp	5.1 hp	5.9 hp	4.8 hp	10.2 hp	12.7 hp	16.2 hp	19.7 hp
	Displacement	173 cc	163 cc	188 cc	170 cc	378 cc	436 cc	581 cc	657 cc
Catalyst	Volume	43 cc	41 cc	62 cc	85 cc	125 cc	218 cc	436 cc	493 cc
	Washcoat	500 g/cu ft	500 g/cu ft	500 g/cu ft	500 g/cu ft	1100 g/cu ft	1100 g/cu ft	1100 g/cu ft	1100 g/cu ft
	Precious Metals	5:1 Pt/Rh	5:1 Pt/Rh	5:1 Pt/Rh	5:1 Pt/Rh	5:1 Pd/Rh	5:1 Pd/Rh	5:1 Pd/Rh	5:1 Pd/Rh
		40 g/cu ft	40 g/cu ft	50 g/cu ft	50 g/cu ft	50 g/cu ft	50 g/cu ft	60 g/cu ft	60 g/cu ft

4. Cost Methodology

As discussed above, costs were determined for advanced technologies relative to a baseline that could differ for each technology type. 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 Class I and four Class II small SI engines were determined, as described earlier. In some cases, different technology improvements are expected to be applied together. In these cases, costs were distributed among technologies wherever possible. Also, it is expected that, in several cases, development costs will be spread over a number of manufacturer's engine families. This was considered in the development costs of each technology. 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, therefore, may 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 2004 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 with the emission technology packages considered. Generally, as engines and fuel delivery systems become more complicated, the largest incremental costs come from the addition of sensors and electronic controls (e.g., ECMs). Other components, such as pressure regulators and injectors also add significant costs to the enhanced technology packages. However, manufacturer component costs are still estimated to be below about $75 for all systems considered. This low price emanates from the need to maintain costs associated with these engines low, particularly for smaller, introductory models. Manufacturer prices of all components were estimated from various sources, including confidential information from engine manufacturers and previous work performed by ICF Consulting 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 and fuel system manufacturers.

Three-way catalyst component information was obtained directly from catalyst manufacturers and current ICF work with three-way catalyst technology and costs for other applications. The prices of precious metal per troy ounce represent average prices over the last five years. Washcoat and steel prices represent current estimates. The labor cost is based on small-scale production of catalysts of similar sizes and includes the retooling costs associated with modifying the muffler design, the costs associated with additional heat shielding, and the costs of the catalyst itself. To minimize costs, all manufacturers with similar-sized engines will most likely use a similar catalyst. Labor rates used are estimated at $17.50 per hour plus a 60% fringe rate for a total labor cost of $28 per hour.

These numbers couldn't be more wrong.

Please see notes from other reviews

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.[2] This mark-up includes manufacturer overhead, manufacturer profit, dealer overhead, and dealer profit. A separate supplier mark-up of 40% also is applied to items, such as fuel injection systems and catalysts, typically purchased from a supplier. The 5% warranty mark-up is added to the hardware cost to represent an overhead charge covering warranty claims associated with new parts.

→ I used to think this was enough, but for small SI it probably needs to be closer to 8-10%.

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. All technologies needed to reduce emissions are already present in many current product lines; thus, significant new development needed is minimal.

[2] "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.

The number of units per year and the number of years to recover up-front costs are used to determine the fixed cost per unit in 2004 dollars. The present cost estimate uses the average engine sales shown in Table 4-1. The average numbers of units per year per engine family are estimates derived from confidential information received by EPA from manufacturers. The numbers reflect the variation in average production between large and small businesses that share the market. Five years is typical as the length of time to recover an investment in a new technology for the small SI engine industry.

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

Engine Class	Useful Life (hrs)	Valve Configuration	Average Units per Year per Engine Family
I	125	SV	540,000
	125	OHV	150,000
	250	OHV	70,000
	500	OHV	30,000
II	250	OHV	40,000
	500	OHV	70,000
	1000	OHV	40,000
	2000	OHV	4,000

Fixed costs can be broken into design and development, certification testing, durability testing, and tooling costs. Each category is described below.

4.2.1. *Design and Development*

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. Table 4-2 details the monthly design and development costs. Design is calculated in engineer months with a full time engineer at $65,000 per annum and a 60% fringe and overhead mark-up. Development is calculated as one engineer and one technician full time for a month. The technician is calculated at $35,000 per annum with a 60% fringe and overhead mark-up. Dynamometer test time (20 tests at $100 per test) for the month also is included in development.

way low
closer to $400/test if
cost of eqpmt is amortized.

Table 4-2 Design and Development Costs per month

Design Costs per month

	Hours	Rates	Cost
Engineer	160	$50	$8,000

(Is it a 1 engineer company? Way low) Design today requires a "team"

Development Costs per month

	Hours	Rates	Cost
Engineer	160	$50	$8,000
Technician	160	$27	$4,308
Dynamometer Test Time	20 tests	$100	$2,000
Total			$14,308

Site licenses for software alone is >$2000 month.

try $7000/wk × 4 = 28000/month w/ engineer + tech. You are short $14 600/mo.

4.2.2. Certification Testing

Certification testing is also required for new technologies. The cost of test fuel is taken as $3.25 per gallon (gal). A dynamometer testing cost of $500 per test is added. Calibration testing cost per test are shown in Table 4-3.

It ~~almost~~ over $5/gal.

Table 4-3 Certification Testing Costs

	Hours		Fuel Gals	Costs			TOTAL
	Techs	Engrs		Techs	Engrs	Fuel	
Test Set-up	8			$215	$0	$0	$215
Calibration	4			$108	$0	$0	$108
Dynamometer							$500
Perform Test	6	2	4	$162	$100	$13	$275
Prepare Report	4	6		$108	$300	$0	$408
TOTAL	22	11	4	$592	$550	$0	$1,655

Where are the costs for facilities capital; idle time, down time, retest?

4.2.3. Durability Testing

Durability testing is required on new technologies to ensure that the engine meets the emission standard over the useful life of the engine. Durability testing potentially could be done on a dynamometer or in the field, and costs have been developed for each approach. Dynamometer testing costs for Class I engines for the various useful lives are shown in Table 4-4 and for Class II engines in Table 4-5. A technician can watch four engines on dynamometers at the same time. In durability testing, the engine is run on the dynamometer over the useful life

wow. that's talent.

of the engine. For the 2000-hour case, the costs were estimated for the engine being run for half the useful life with the results extrapolated.

Estimated durability field testing costs for Class I engines are shown in Table 4-6 for various useful lives and in Table 4-7 for Class II engines. Field testing, in many cases, also requires an operator.

What about cost of engine? consumables?

What about emission test at near zero (<12 hrs) mid-pt, and useful life.

Table 4-4 Class I Engine Dynamometer Durability Testing Costs

125-hr useful life

* Hours are never 1 for 1. Assume 20 hrs/day avg

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	6	2		$162	$100	$0	$262
Operate equipment	31		31	$841	$0	$100	$941
Scheduled Maintenance	10			$258	$0	$0	$258
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	47	8	31	$1,261	$400	$100	$1,761 *

No less than $3125

* If I am operating "free" facilities or in China, I might be able to do this. But no less than $25/hr should be budgeted for durability if you want to stay in business[2]

250-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	6	2		$162	$100	$0	$262
Operate equipment	63		71	$1,683	$0	$231	$1,913
Scheduled Maintenance	20			$544	$0	$0	$544
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	89	8	71	$2,388	$400	$231	~~$3,019~~

Way under. — $6250 min.

500-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	6	2		$162	$100	$0	$262
Operate equipment	125		115	$3,365	$0	$375	$3,741
Scheduled Maintenance	24			$657	$0	$0	$657
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	155	8	115	$4,184	$400	$375	~~$4,959~~ $12500

Same comments $25/hr minimum

[2] Also down time on these little engines is brutal. Shutdown every 8-hrs to chk oil, performance chks, etc.

This is way under for durability cost. At 500-hrs on class 1, downtime is going to hurt. est 15-20% downtime.

Table 4-5 Class II Engine Dynamometer Durability Testing Costs

250-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	8	2		$215	$100	$0	$315
Operate equipment	63		157	$1,683	$0	$510	$2,192
Scheduled Maintenance	16			$429	$0	$0	$429
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	87	8	157	$2,328	$400	$510	$3,237

500-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	8	2		$215	$100	$0	$315
Operate equipment	125		391	$3,365	$0	$1,269	$4,635
Scheduled Maintenance	28			$758	$0	$0	$758
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	161	8	391	$4,339	$400	$1,269	$6,008

1000-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	6	2		$215	$100	$0	$315
Operate equipment	250		996	$6,731	$0	$3,238	$9,969
Scheduled Maintenance	49			$1,314	$0	$0	$1,314
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	305	8	996	$8,260	$400	$3,238	$11,898

2000-hr useful life

	Hours		Fuel	Costs			
	Techs	Engrs	Gals	Techs	Engrs	Fuel	TOTAL
Test Set-up	6	2		$215	$100	$0	$315
Operate equipment	250		1212	$6,731	$0	$3,938	$10,668
Scheduled Maintenance	44			$1,193	$0	$0	$1,193
Analyze data		2		$0	$100	$0	$100
Other		4		$0	$200	$0	$200
TOTAL	300	8	1212	$4,184	$400	$3,938	$12,476

Absolutely no way

Table 4-6 Class I Engine Field Durability Testing Costs

125-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$200
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	188			31	$2,400	$0	$0	$100	$2,500
Scheduled Maintenance		10			$0	$258	$0	$0	$258
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	188	16	8	31	$2,400	$420	$400	$107	$3,520

Realistic, but only because you aren't using facilities capital. Engineering hours are to low. Double for site visit.

250-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$500
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	375			71	$4,800	$0	$0	$231	$5,031
Scheduled Maintenance		20			$0	$544	$0	$0	$544
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	375	26	8	71	$4,800	$705	$400	$231	$6,636

Same comments.

500-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$1,000
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	520	~~100~~		115	$0	$2,692	$0	$375	$3,067
Scheduled Maintenance		24			$0	$657	$0	$0	$657
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	0	126	8	115	$0	$3,511	$400	$375	$5,286

should be at least x2

Durability in the field becomes expensive because its also due to climate (annual) and day-to-day weather chgs.

Table 4-7 Class II Engine Field Durability Testing Costs

250-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$1,000
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	313			157	$4,000	$0	$0	$510	$4,510
Scheduled Maintenance		16			$0	$429	$0	$0	$429
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	313	22	8	157	$4,000	$591	$400	$510	$6,501

500-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$2,000
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	625			391	$8,000	$0	$0	$1,269	$9,269
Scheduled Maintenance		28			$0	$758	$0	$0	$758
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	625	34	8	391	$8,000	$919	$400	$1,269	$12,589

1000-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$6,000
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	625 ~~500~~			498	$6,400	$0	$0	$1,619	$8,019
Scheduled Maintenance		49			$0	$1,314	$0	$0	$1,314
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	500	55	8	498	$6,400	$1,475	$400	$1,619	$15,894

No way you are getting 1 for 1 on hrs. Impossible.

Table 4-7 Class II Engine Field Durability Testing Costs (continued)

2000-hr useful life

	Labor Hours			Fuel	Costs				
	Opers	Techs	Engrs	Gals	Opers	Techs	Engrs	Fuel	TOTAL
Equipment Costs									$8,000
Test Set-up		4	2		$0	$108	$100	$0	$208
Perform Durability Test									
Operate equipment	1200 hrs	200		1212	$0	$5,385	$0	$3,938	$9,322
Scheduled Maintenance		44			$0	$1,193	$0	$0	$1,193
Unscheduled Maintenance		2			$0	$54	$0	$0	$54
Analyze data			2		$0	$0	$100	$0	$100
Other			4		$0	$0	$200	$0	$200
TOTAL	0	250	8	1212	$0	$6,739	$400	$3,938	$19,076

Is it robot controlled?

Operator salaries are taken as $16,640 per annum with a 60% fringe and overhead mark-up. For Class I engines with a 125- and 250-hour useful life, an operator uses the equipment for the full useful life. Because operating a lawnmower or pressure washer is tiring, for every 1 hour of operation, the operator rests for 30 minutes. Typically, Class I engines with 500-hour useful lives are used in applications that require no operator. A technician can watch 5 such engines running at the same time. For Class II engines with 250- and 500-hour useful lives, such as riding mowers, the operator rests 15 minutes for every hour of operation. For Class II engines with a 1000-hour useful life, the equipment is operated for half the useful life and the results are extrapolated. Class II engines with a 2000-hour useful life represent liquid-cooled engines, which are used primarily in applications which require no operator. These engines are run over half the useful life in the field, and the results are extrapolated. A technician can watch 5 such engines at the same time. Also with field testing, the engine manufacturer needs to purchase the equipment to test.

Huh?

Disagree. The only thing that doesn't require an operator is a genset. Then you don't need field work.

4.2.4. *Tooling Costs*

Tooling costs cover the cost of purchasing new tooling and the set-up of new tooling to manufacture a new technology.

4.3. Operating Costs

Migration to advanced engine technologies may lead to reduced fuel consumption, thus saving money in operating expenses. Fuel cost savings have been analyzed using a five year average gasoline price, excluding taxes, of $1.64 per gallon and a nominal volumetric brake-

This is funny since the 5yr est was made 2 yrs ago.

the load factor for an ISO 8178 E1 + E2 cycle is 46-47%. This is the A+B cycles.

specific fuel consumption (BSFC) reduction of 10% (measured in gallons per horsepower-hour [gal/hp-hr]). Actual operating expenses can be scaled up or down based upon actual percent reductions. A load factor of 0.37 was used for all Class I engines and 0.50 for all Class II engines. Additionally, an annual activity of 20% of the useful life of each engine was used, consistent with the 5-year average lifetime of the engine. These values ranged from 25 to 400 hours per year. A discount rate of 7% per annum over the life of the engine was used to calculate present values. The fuel cost savings that would be achieved by migrating to advanced technologies for Class I and Class II engines that result in a 10% reduction in fuel consumption are presented in Table 4-8 and Table 4-9, respectively.

Table 4-8 Fuel Savings for Class I Engines

Useful life (hr) Valving Engine Power (hp)	**125 SV 3.2**		**125 OHV 5.1**		**250 OHV 5.9**		**500 OHV 4.8**	
BSFC (gal/hp-hr)	0.154	0.139	0.130	0.117	0.130	0.117	0.130	0.117
Load Factor	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Life (yrs)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Hours/year	25	25	25	25	50	50	100	100
Gallons per year	4.6	4.1	6.1	5.5	14.2	12.8	23.1	20.8
Gasoline cost/yr	$7.48	$6.73	$10.06	$9.05	$23.27	$20.94	$37.86	$34.08
Total Cost discounted 7%	$31	$28	$41	$37	$95	$86	$155	$140
Cost Savings		$3		$4		$10		$16

Would ~~be~~ be more $ at a higher load factor.

Table 4-9 Fuel Savings for Class II Engines

Useful life (hr) Valving Engine Power (hp)	**250 OHV 10.2**		**500 OHV 12.7**		**1,000 OHV 16.2**		**2,000 OHV 19.7**	
BSFC (gal/hp-hr)	0.123	0.111	0.123	0.111	0.123	0.111	0.123	0.111
Load Factor	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Life (yrs)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Hours/year	50	50	100	100	200	200	400	400
Gallons per year	31.4	28.2	78.1	70.3	199.3	179.3	484.6	436.2
Gasoline cost/yr	$51.44	$46.29	$128.09	$115.28	$326.79	$294.11	$794.78	$715.30
Total Cost discounted 7%	$211	$190	$525	$473	$1,340	$1,206	$3,259	$2,933
Cost Savings		$21		$53		$134		$326

5. Results

Tables 5-1 to 5-8 show detailed development of cost estimates for each of the technology packages for each small SI engine category considered. Each of these tables has the cost summary in the uppermost portion, followed by a breakdown of the research and development and tooling costs for each engine category in the lower portions. The majority of these tables have engine categories broken into 3 lines describing engine Class, engine useful life (in hours), and valve configuration (SV or OHV).

Table 5-1 shows the cost of engine modifications for the various classes and useful lives of small SI engines. Potential engine modifications include improved machining and casting tolerances, improved combustion chamber configuration, reduced crevice volumes, better cooling, improved carburetion and gaskets, improved fuel filtering, and larger induction coils. For the 2000-hr useful life Class II engines, most of these modifications have already been made, so variable, design, development, and tooling costs have been set to zero.

Not true. Class II engines still have a way to go for R&D to meet 50% reduction in HC+NOx

Table 5-2 shows the cost for converting a Class I SV engine to an OHV configuration. Because changing the valving configuration of an engine will require major modifications to the engine block and head, an additional cost of upgrading the factory is added and amortized over ten years of production.

Table 5-3 shows the costs for converting to a pressurized oil system. This includes the addition of an oil pump, an oil pump screen, an oil pressure switch, an oil filter adapter, and oil filter, as well as various hoses and other hardware. For the 500-hour Class I and 1000- and 2000-hour Class II engines, an oil cooler also is added to improve cooling. In addition, tooling includes modifying the crankshaft and oil sump, plus providing additional oil passageways in the cylinder block.

most engines already have.

Table 5-4 shows the cost of converting to electronic carburetion. Costs are shown for open loop carburetion with an electronic governor for Class I and Class II engines. A battery and alternator/regulator are added to Class I engines, as they typically do not have these items. Class II engines usually do have batteries and alternators, so both items have been left out of the incremental cost considerations. Because calibrations normally will be completed with the engine modifications, no design, development, or testing costs have been added.

Mfrs spend the same amt on a family that has 150,000 units compared to 30,000 units?

Table 5-1 Costs for Engine Modifications for Small SI Engines

Engine Class	I				II			
Useful life (hrs)	125	125	250	500	250	500	1000	2000
Valving	SV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
Hardware Cost to Manufacturer								
Improved Intake Gaskets	$0.03	$0.03	$0.03	$0.04	$0.05	$0.05	$0.05	$0.00
Fuel Filter Screen	$0.02	$0.02	$0.02	--	--	--	--	--
Larger Induction Coil	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10	$0.00
OEM Mark-up @ 29%	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.00
Warranty Mark-up @ 5%	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.00
Component Costs	**$0.20**	**$0.20**	**$0.20**	**$0.19**	**$0.20**	**$0.20**	**$0.20**	**$0.00**
Fixed Cost to Manufacturer								
R&D Costs	$126,228	$126,228	$127,486	$129,426	$127,705	$130,475	$136,365	$19,098
Tooling Costs	$243,000	$243,000	$243,000	$243,000	$160,000	$160,000	$160,000	$0
Units/Yr	540,000	150,000	70,000	30,000	40,000	70,000	40,000	4,000
Years to Recover	5	5	5	5	5	5	5	5
Fixed Cost/Unit	**$0.18**	**$0.66**	**$1.42**	**$3.32**	**$1.94**	**$1.12**	**$2.00**	**$1.34**
Total Costs ($)	**$0.38**	**$0.86**	**$1.62**	**$3.51**	**$2.14**	**$1.32**	**$2.20**	**$1.34**
R&D Costs								
* Design	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000	$0
Months	4	4	4	4	4	4	4	-
Development	$85,846	$85,846	$85,846	$85,846	$85,846	$85,846	$85,846	$0
Months	6	6	6	6	6	6	6	-
Certification Testing	$6,621	$6,621	$6,621	$6,621	$6,621	$6,621	$6,621	$6,621
Number of Tests	4	4	4	4	4	4	4	4
Durability Testing	$1,761	$1,761	$3,019	$4,959	$3,237	$6,008	$11,898	$12,476
R&D Costs per Engine Line	**$126,228**	**$126,228**	**$127,486**	**$129,426**	**$127,705**	**$130,475**	**$136,365**	**$19,098**
Tooling Costs								
Cylinder head	$25,000	$25,000	$25,000	$25,000	$15,000	$15,000	$15,000	
Piston	$25,000	$25,000	$25,000	$25,000	$15,000	$15,000	$15,000	
Connecting Rod	$15,000	$15,000	$15,000	$15,000	$10,000	$10,000	$10,000	
Camshaft	$8,000	$8,000	$8,000	$8,000	$5,000	$5,000	$5,000	
Carburetor	$60,000	$60,000	$60,000	$60,000	$35,000	$35,000	$35,000	
Flywheel	$35,000	$35,000	$35,000	$35,000	$20,000	$20,000	$20,000	
Setup Changes	$75,000	$75,000	$75,000	$75,000	$60,000	$60,000	$60,000	
Tooling Cost per Engine Line	**$243,000**	**$243,000**	**$243,000**	**$243,000**	**$160,000**	**$160,000**	**$160,000**	**$0**

No way

* Someone isn't reporting real cost. The design cost of $32k for four months is ludicrous. Certification cost & Durability cost are way under. There is even an $834/yr EPA filing fee.

Table 5-2 Costs for Converting Side to Overhead Valve Configurations for Class I Engines

Side Valve to Overhead Valve	SV	OHV
Hardware Cost to Manufacturer		
Rocker Arms and Assembly		$3.60
Push Rods		$1.20
Push Rod Guides		$0.50
Valve Cover		$1.50
Miscellaneous Hardware		$0.50
OEM Mark-up @ 29%	$0.00	$2.12
Warranty Mark-up @ 5%	$0.00	$0.37
Component Costs	**$0.00**	**$9.78**
Fixed Cost to Manufacturer		
R&D Costs		$937,151
Tooling Costs		$335,000
Units/Yr		540,000
Years to Recover		5
Upgrading Factory		$15,000,000
Years to Recover		10
Fixed Cost/Unit	**$0.00**	**$4.60**
Total Costs ($)	**$0.00**	**$14.38**
R&D Costs		
Design		$192,000
Months		24
Development		$686,769
Months		48
Training/Technical Support		$50,000
Certification Testing		$6,621
Number of Tests		4
Durability Testing		$1,761
Useful Life (hrs)		125
R&D Costs per Engine Line	**$0**	**$937,151**
Tooling Costs		
Cylinder Head	$0	$60,000
Cylinder/Crankcase	$0	$40,000
Connecting Rod	$0	$15,000
Piston	$0	$25,000
Crankshaft	$0	$25,000
Rocker Arm	$0	$30,000
Rocker Cover	$0	$50,000
Push Rod Guide	$0	$10,000
Setup Changes	$0	$80,000
Tooling Costs per Engine Line	**$0**	**$335,000**

how.

I'm not sure about these items.

If the parts price estimates are anything like the other tech reviews, then we're in trouble.

Table 5-3 Costs for Converting to a Pressurized Oil System

Engine Class	I				II			
Useful life (hrs)	**125**	**125**	**250**	**500**	**250**	**500**	**1000**	**2000**
Valving	**SV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**
Hardware Cost to Manufacturer								
Oil Pump	$4.25	$4.25	$4.25	$4.25	$4.50	$4.50	$4.75	$4.75
Pump Screen	$1.15	$1.15	$1.15	$1.15	$1.20	$1.20	$1.25	$1.25
Oil Cooler & Bracket				$8.90			$9.50	$9.50
Oil Pressure Switch	$0.75	$0.75	$0.75	$0.75	$0.80	$0.80	$0.90	$0.90
Oil Filter Adaptor	$3.00	$3.00	$3.00	$3.00	$3.25	$3.25	$3.40	$3.40
Oil Filter	$1.00	$1.00	$1.00	$1.25	$1.25	$1.25	$1.25	$1.25
Hoses/Hardware	$0.90	$0.90	$0.90	$0.90	$1.00	$1.00	$1.25	$1.25
OEM Mark-up @ 29%	$3.20	$3.20	$3.20	$5.86	$3.48	$3.48	$6.47	$6.47
Warranty Mark-up @ 5%	$0.55	$0.55	$0.55	$1.01	$0.60	$0.60	$1.12	$1.12
Component Costs	**$14.81**	**$14.81**	**$14.81**	**$27.07**	**$16.08**	**$16.08**	**$29.88**	**$29.88**
Fixed Cost to Manufacturer								
R&D Costs	$73,231	$73,231	$73,231	$73,231	$73,231	$73,231	$73,231	$73,231
Tooling Costs	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000
Units/Yr	540,000	150,000	70,000	30,000	40,000	70,000	40,000	4,000
Years to Recover	5	5	5	5	5	5	5	5
Fixed Cost/Unit	**$0.07**	**$0.27**	**$0.57**	**$1.34**	**$1.00**	**$0.57**	**$1.00**	**$10.01**
Total Costs ($)	**$14.88**	**$15.07**	**$15.38**	**$28.40**	**$17.08**	**$16.65**	**$30.88**	**$39.89**
R&D Costs								
Design	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Months	2	2	2	2	2	2	2	2
Development	$57,231	$57,231	$57,231	$57,231	$57,231	$57,231	$57,231	$57,231
Months	4	4	4	4	4	4	4	4
R&D Costs per Engine Line	**$73,231**	**$73,231**	**$73,231**	**$73,231**	**$73,231**	**$73,231**	**$73,231**	**$73,231**
Tooling Costs								
Modified Crankshaft	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Modified Engine Sump	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Modified Cylinder Block	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Tooling Costs per Engine Line	**$75,000**	**$75,000**	**$75,000**	**$75,000**	**$75,000**	**$75,000**	**$75,000**	**$75,000**

x2

I suspect it would be more. Even a cheap CNC is $100 K+

Table 5-4 Costs for Converting to Electronic Carburetors

Electronic Carburetor	Baseline Carburetor		Open Loop with Governor	
	Class I	Class II	Class I	Class II
Electronic Carb Air Valve			$0.40	$0.40
Electronic Fuel Shut-off Valve			$2.00	$2.00
Tubing			$0.05	$0.05
ECM/Map Sensor			$10.00	$12.50
Mechanical governor	$1.00	$2.16		
Electronic governor			$2.50	$2.50
Battery			$6.50	
Magneto	$3.15			
Alternator/Regulator			$6.00	
Wiring			$0.50	$0.50
Hardware Cost to Manufacturer	**$4.15**	**$2.16**	**$27.95**	**$17.95**
OEM Mark-up @ 29%	$1.20	$0.63	$8.11	$5.21
Warranty Mark-up @ 5%	$0.21	$0.11	$1.40	$0.90
Component Costs	**$5.56**	**$2.89**	**$37.45**	**$24.05**
Incremental costs			**$31.89**	**$21.16**

obviously the new evap fuel hoses haven't been prized.

Table 5-5 shows the costs of converting from carburetion to MFI. Design, development, testing, and tooling costs have been amortized over five years of production. Different production levels are given for the various engine classes and useful lives. In addition, injector costs for Class II engines are calculated based on 33% of the engines being two-cylinders and thus, requiring two injectors.

Table 5-5 Costs for Converting to Mechanical Fuel Injection

	Carburetor		Mechanical Fuel Injection	
Engine Class	**I**	**II**	**I**	**II**
Hardware Cost to Manufacturer				
Carburetor	$3.35	$6.45		
Injectors			$6.00	$8.00
Pressure Regulator			$3.75	$3.75
Throttle Body/Position Sensor			$3.50	$4.75
Fuel Pump		$3.35	$10.50	$10.50
Air flow bellows			$5.50	$5.50
Related Hardware			$5.00	$5.00
OEM Mark-up @ 29%	$0.97	$2.84	$9.93	$10.88
Warranty Mark-up @ 5% —low	$0.17	$0.49	$1.71	$1.88
Component Costs	**$4.49**	**$13.13**	**$45.90**	**$50.25**
Fixed Cost to Manufacturer				
R&D Costs	$0	$0	$146,462	$146,462
Tooling Costs	$0	$0	$0	$0
Years to Recover	5	5	5	5
Useful Life (hrs)	125		125	
Units/Yr	150,000		150,000	
Fixed Cost/Unit	$0.00		$0.27	
Total Cost per Unit	**$4.49**		**$46.48**	
Incremental Cost			**$41.68**	
Useful Life (hrs)	250	250	250	250
Units/Yr	70,000	40,000	70,000	40,000
Fixed Cost/Unit	$0.00	$0.00	$0.59	$1.02
Total Cost per Unit	**$4.49**	**$13.13**	**$46.48**	**$51.27**
Incremental Cost			**$41.99**	**$38.14**
Useful Life (hrs)	500	500	500	500
Units/Yr	30,000	70,000	30,000	70,000
Fixed Cost/Unit	$0.00	$0.00	$1.37	$0.59
Total Cost per Unit	**$4.49**	**$13.13**	**$47.26**	**$50.84**
Incremental Cost			**$42.77**	**$37.70**
Useful Life (hrs)		1,000		1,000
Units/Yr		40,000		40,000
Fixed Cost/Unit		$0.00		$1.02
Total Cost per Unit		**$13.13**		**$51.27**
Incremental Cost				**$38.14**
Useful Life (hrs)		2,000		2,000
Units/Yr		4,000		4,000
Fixed Cost/Unit		$0.00		$10.24
Total Cost per Unit		**$13.13**		**$60.49**
Incremental Cost				**$47.36**
R&D Costs				
Design			$32,000	$32,000
Months			4	4
Development			$114,462	$114,462
Months			8	8
R&D Costs per Engine Line	**$0**	**$0**	**$146,462**	**$146,462**

priced low — tubing?

all of this just seems low.

Table 5-6 shows the costs for converting to EFI. Fuel injection systems normally come from a supplier, so a supplier mark-up is also added for the injectors, pressure regulator, throttle body, ECM/MAP sensor, fuel pump, air temperature sensor, and oxygen sensor. For Class II engines, injector costs have been calculated based on 33% of the Class II engines being two-cylinders and, therefore, requiring two injectors. For the 2000-hour Class II carbureted engine, the fixed costs are set to zero because most of the modifications have already been completed on current liquid-cooled engines in this category. Also, minimal R&D is needed for Class II closed loop EFI engines as closed loop makes calibration significantly simpler.

where is the supplier markup

Table 5-6 Costs for Converting to Electronic Fuel Injection

Fuel Delivery System	Carburetor		Open Loop EFI		Closed Loop EFI	
Engine Class	**I**	**II**	**I**	**II**	**I**	**II**
Hardware Cost to Manufacturer						
Carburetor	$3.35	$6.45				
Injectors			$6.00	$8.00	$6.00	$8.00
Pressure Regulator			$3.75	$3.75	$3.75	$3.75
ECM/MAP Sensor			$27.00	$27.00	$27.00	$27.00
Throttle Body			$2.75	$4.00	$2.75	$4.00
Air Temperature Sensor			$1.50	$1.50	$1.50	$1.50
Fuel Pump		$3.35	$10.50	$10.50	$10.50	$10.50
Oxygen Sensor — nope - to low.					$7.00	$7.00
Magneto	$3.15					
Battery			$6.50		$6.50	
Alternator/Regulator			$6.00		$6.00	
Wiring/Related Hardware — impossible			$2.00	$2.00	$2.00	$2.00
OEM Mark-up @ 29%	$1.89	$2.84	$19.14	$16.46	$21.17	$18.49
Warranty Mark-up @ 5%	$0.33	$0.49	$2.98	$2.35	$3.33	$2.70
Component Costs	**$8.71**	**$13.13**	**$88.12**	**$75.56**	**$97.50**	**$84.94**
Fixed Cost to Manufacturer				#①	②	
R&D Costs	$0	$0	$146,462	$146,462	$117,846	$44,615
Tooling Costs	$60,000	$35,000	$0	$0	$25,000	$25,000
Years to recover	5	5	5	5	5	5
Useful Life, hrs	125		125		125	
Units/yr.	150,000		150,000		150,000	
Fixed cost/unit	$0.10		$0.27		$0.26	
Total Cost per Unit	**$8.81**		**$88.39**		**$97.76**	
Incremental Cost			**$79.57**		**$88.94**	
Useful Life (hrs)	250	250	250	250	250	250
Units/Yr	70,000	40,000	70,000	40,000	70,000	40,000
Fixed Cost/Unit	$0.22	$0.23	$0.59	$1.02	$0.56	$0.48
Total Cost per Unit	**$8.93**	**$13.36**	**$88.70**	**$76.58**	**$98.06**	**$85.41**
Incremental Cost			**$79.77**	**$63.22**	**$89.13**	**$72.05**

① how does Fixed R+D cost of closed loop become less than open loop. The more variables the higher the cost.

Table 5-6 Costs for Converting to Electronic Fuel Injection (continued)

Fuel Delivery System	Carburetor		Open Loop EFI		Closed Loop EFI	
Engine Class	**I**	**II**	**I**	**II**	**I**	**II**
Fixed Cost to Manufacturer						
Useful Life(hrs)	500	500	500	500	500	500
Units/Yr	30,000	70,000	30,000	70,000	30,000	70,000
Fixed Cost/Unit	$0.52	$0.13	$1.37	$0.59	$1.32	$0.27
Total Cost per Unit	**$9.23**	**$13.26**	**$89.48**	**$76.14**	**$98.81**	**$85.21**
Incremental Cost			**$80.25**	**$62.88**	**$89.58**	**$71.94**
Useful Life (hrs)		1,000		1,000		1,000
Units/Yr		40,000		40,000		40,000
Fixed Cost/Unit		$0.23		$1.02		$0.48
Total Cost per Unit		**$13.36**		**$76.58**		**$85.41**
Incremental Cost				**$63.22**		**$72.05**
Useful Life (hrs)		2,000		2,000		2,000
Units/Yr		4,000		4,000		4,000
Fixed Cost/Unit		$0.00		$10.24		$4.75
Total Cost per Unit		**$13.13**		**$85.79**		**$89.69**
Incremental Cost				**$72.66**		**$76.55**
R&D Costs						
Design			$32,000	$32,000	$32,000	$16,000
Months			4	4	4	2
Development			$114,462	$114,462	$85,846	$28,615
Months			8	8	6	2
R&D Costs per Engine Line	**$0**	**$0**	**$146,462**	**$146,462**	**$117,846**	**$44,615**
Tooling Costs						
Modified Exhaust Manifold for O2 Sensor	$0	$0	$0	$0	$25,000	$25,000
Carburetor Modifications	$60,000	$35,000				
Tooling Costs per Engine Line	**$60,000**	**$35,000**	**$0**	**$0**	**$25,000**	**$25,000**

Table 5-7 shows the incremental costs of adding cast iron cylinder liners. Costs are provided for cylinder liners 6 millimeters (mm) thick. Incremental costs are shown only for Class I and Class II engines with 250- and 500-hour useful lives. Most engines with 1000- and 2000-hour useful lives already have cast iron cylinder liners.

Table 5-8 shows the incremental costs for adding a three-way catalyst. For Class I engines, the heat shield is placed over the muffler and the catalyst bricks are placed in the muffler. In Class II engines, the catalyst and muffler are canned together with a second layer of perforated steel, which acts as an air ejector. For the 2000-hour Class II engine, less development time is needed because those engines are more evolved than other small SI engines. – No So.

Table 5-7 Costs for Adding Cast iron Cylinder Liners

Engine Class	I	I	II
Displacement (cc)	**173**	**163**	**378**
Valving	**SV**	**OHV**	**OHV**
Hardware Cost to Manufacturer			
Cast Iron Sleeve	$4.47	$4.46	$4.91
OEM Mark-up @ 29%	$1.30	$1.29	$1.42
Warranty Mark-up @ 5%	$0.22	$0.22	$0.25
Component Costs	**$5.99**	**$5.97**	**$6.58**
Fixed Cost to Manufacturer			
R&D Costs	$109,846	$109,846	$109,846
Tooling Costs	$40,000	$40,000	$40,000
Years to Recover	5	5	5
Useful Life (hrs)	125	125	
Units/Yr	540,000	150,000	
Fixed Cost/Unit	**$0.08**	**$0.27**	
Total Cost per Unit	**$6.07**	**$6.27**	
Useful Life (hrs)		250	250
Units/Yr		70,000	40,000
Fixed Cost/Unit		**$0.59**	**$1.03**
Total Cost per Unit		**$6.58**	**$7.87**
Useful Life (hrs)		500	500
Units/Yr		30,000	65,000
Fixed Cost/Unit		**$1.37**	**$0.63**
Total Cost per Unit		**$7.36**	**$7.48**
R&D Costs			
Design	$24,000	$24,000	$24,000
Months	3	3	3
Development	$85,846	$85,846	$85,846
Months	6	6	6
R&D Costs per Engine Line	**$109,846**	**$109,846**	**$109,846**
Tooling Costs			
Modified Cylinder Block	$40,000	$40,000	$40,000
Tooling Costs per Engine Line	**$40,000**	**$40,000**	**$40,000**
Material Costs			
Bore (mm)	67	65	80
Stroke (mm)	50	50	75
Thickness (mm)	6	6	6
Weight (g)	11.04	10.71	19.77
Cost per gram	$0.05	$0.05	$0.05
Total Material Cost	**$0.55**	**$0.54**	**$0.99**
Labor	$2.80	$2.80	$2.80
Overhead	$1.12	$1.12	$1.12
Total liner cost	**$4.47**	**$4.46**	**$4.91**

requires a complete class I
redesign from where most
engines currently are

Table 5-8 Three-Way Catalyst Costs for Small SI Engines

Engine Class	**I**	**I**	**I**	**I**	**II**	**II**	**II**	**II**
Useful life (hrs)	**125**	**125**	**250**	**500**	**250**	**500**	**1000**	**2000**
Valving	**SV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**
Hardware Cost to Manufacturer								
Catalyst	$7.56	$7.31	$10.08	$12.49	$15.22	$23.62	$46.55	$52.00
Heat Shield	$0.37	$0.36	$0.38	$0.39	$2.60	$2.93	$3.63	$3.43
OEM Mark-up @ 29%	$2.30	$2.23	$3.03	$3.74	$5.17	$7.70	$14.55	$16.07
Warranty Mark-up @ 5%	$0.40	$0.38	$0.52	$0.64	$0.89	$1.33	$2.51	$2.77
Component Costs	**$10.62**	**$10.29**	**$14.01**	**$17.27**	**$23.87**	**$35.59**	**$67.24**	**$74.27**
Fixed Cost to Manufacturer								
R&D Costs	$87,538	$87,538	$87,538	$87,538	$87,538	$87,538	$87,538	$44,615
Tooling Costs	$105,000	$105,000	$105,000	$105,000	$120,000	$120,000	$120,000	$120,000
Units/Yr	540,000	150,000	70,000	30,000	40,000	70,000	40,000	4,000
Years to Recover	5	5	5	5	5	5	5	5
Fixed Cost/Unit	**$0.10**	**$0.35**	**$0.74**	**$1.73**	**$1.39**	**$0.80**	**$1.39**	**$10.95**
Total Costs ($)	**$10.72**	**$10.64**	**$14.75**	**$19.00**	**$25.27**	**$36.38**	**$68.63**	**$85.22**
R&D Costs								
Design	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Months	2	2	2	2	2	2	2	2
Development	$71,538	$71,538	$71,538	$71,538	$71,538	$71,538	$71,538	$28,615
Months	5	5	5	5	5	5	5	2
R&D Costs per Line	**$87,538**	**$87,538**	**$87,538**	**$87,538**	**$87,538**	**$87,538**	**$87,538**	**$44,615**
Tooling Costs								
Modified Muffler Stamping*	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000
Heat Shield Stamping	$30,000	$30,000	$30,000	$30,000	$45,000	$45,000	$45,000	$45,000
Setup Changes	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Tooling Costs per Line	**$105,000**	**$105,000**	**$105,000**	**$105,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**
Heat Shield Costs								
Length (centimeter [cm])	4.9	4.7	5.4	5.9	23.0	30.8	45.3	31.0
Width (cm)	12.5	12.5	14.0	15.5	31.5	36.0	42.0	54.0
Thickness (cm)	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Vol. of Steel (cc) w/ 20% scrap	8.97	8.46	11.04	13.23	105.42	161.21	276.20	242.92
Weight of Steel (g)	70.2	66.1	86.3	103.4	824.1	1260.2	2159.1	1898.9
TOTAL MAT. COST	**$0.05**	**$0.05**	**$0.07**	**$0.08**	**$0.64**	**$0.97**	**$1.67**	**$1.47**
Labor	$0.22	$0.22	$0.22	$0.22	$1.40	$1.40	$1.40	$1.40
Labor Overhead @ 40%	$0.09	$0.09	$0.09	$0.09	$0.56	$0.56	$0.56	$0.56
Total Heat Shield Costs	**$0.37**	**$0.36**	**$0.38**	**$0.39**	**$2.60**	**$2.93**	**$3.63**	**$3.43**

* includes secondary air

Believable -

Again, I'm struggling with the idea that 1 engineer is going to do all this work and that there is super duo (egr/tech) for the developments

Table 5-9 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. Catalyst costs are calculated based upon 50% of the production of each engine type will have metallic substrates and 50% will have ceramic substrates. Manufacturer prices vary between about $7 and about $52 for each catalyst unit.

Table 5-9 Three-way Catalysts Cost Estimates

Catalyst Material Costs

Material	$/troy oz	$/lb	$/g	Density (g/cc)
Alumina		$64.00	$0.14	3.9
Ceria		$22.00	$0.05	7.132
Platinum	$639		$20.53	
Palladium	$421		$13.52	
Rhodium	$1,172		$37.68	
Stamped Steel		$0.35	$0.00	7.817

Catalyst Unit Costs

Engine Class	I	I	I	I	II	II	II	II
Useful life (hrs)	**125**	**125**	**250**	**500**	**250**	**500**	**1000**	**2000**
Valving	**SV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**	**OHV**
Engine Power (hp)	**3.2**	**5.1**	**5.9**	**4.8**	**10.2**	**12.7**	**16.2**	**19.7**
Engine Displacement (cc)	**173**	**163**	**188**	**170**	**378**	**436**	**581**	**657**
Catalyst Volume (cc)	**43**	**41**	**62**	**85**	**125**	**218**	**436**	**493**
Substrate Diameter (cm)	3.50	3.50	4.00	4.50	5.25	6.00	7.00	9.00
Washcoat (g/cu ft)	500	500	500	500	1100	1100	1100	1100
ceria/alumina (%)	30/70	30/70	30/70	30/70	30/70	30/70	30/70	30/70
PM Loading (g/cu ft)	40	40	50	50	50	50	60	60
Pt/Pd/Rh	5/0/1	5/0/1	5/0/1	5/0/1	0/5/1	0/5/1	0/5/1	0/5/1
Hardware costs using 50% ceramic and 50% metallic substrates								
Metallic substrate cost	$1.87	$1.81	$2.26	$2.67	$3.28	$4.41	$6.38	$6.81
Ceramic substrate cost	$1.98	$1.87	$2.84	$3.89	$5.71	$9.98	$19.96	$22.57
Washcoat cost	$0.09	$0.08	$0.12	$0.17	$0.55	$0.96	$1.92	$2.17
Precious Metal cost	$1.43	$1.35	$2.56	$3.51	$3.87	$6.76	$16.20	$18.32
Substrate Diameter (cm)	3.50	3.50	4.00	4.50	5.25	6.00	7.00	9.00
Substrate Length (cm)	4.5	4.2	4.9	5.3	5.8	7.7	11.3	7.7
TOTAL MAT. COST	**$3.44**	**$3.26**	**$5.24**	**$6.96**	**$8.91**	**$14.19**	**$31.29**	**$35.18**
LABOR	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Labor Overhead @ 40%	$0.56	$0.56	$0.56	$0.56	$0.56	$0.56	$0.56	$0.56
Supplier Mark-up @ 40%	$2.16	$2.09	$2.88	$3.57	$4.35	$6.75	$13.30	$14.86
Manufacturer Price	**$7.56**	**$7.31**	**$10.08**	**$12.49**	**$15.22**	**$23.62**	**$46.55**	**$52.00**

So what is the ~~cst~~ additional cost to consumers.

Baseline is
$Ø

Bells & Whistles
$XXX.XX

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1250
5000

250
25
6250

125
25
625
2500
3125

Attachment 3

Peer Review Report

Small SI Engine Technologies and Costs
Draft Final Report of June 2005
by ICF Consulting

John F Anderson

March 8, 2006

John F Anderson
1274 Kuehnle Court, Ann Arbor MI 48103

Summary

As described in greater detail in the body of this peer review, I find the draft final report prepared by ICF to be weak in both editorial aspects of the presentation and in the technical details needed to fully understand the analyses presented. While the quality of the report is certainly sufficient for the proposal stage of a rulemaking, it should be revised prior to final action. Following are some key areas for improvement:

i. *Clear and precise identification of the baseline configurations used for each case.*
ii. *Derivation of the four valve configuration/ useful life/ displacement/power cases for each engine class.*
iii. *Clear referencing and justification for all key assumptions throughout the report. (One set of examples from the catalyst cost section: provide references for the assumptions driving catalyst cost - catalyst volume to engine volume ratios, precious metal loadings, class I engine use of a catalyst-in-muffler configuration with class II engines using an independently canned catalyst with an air ejector, the split between metallic and ceramic substrates. The draft final report contains no justification for any of the assumptions chosen.)*
iv. *Expansion of the operating cost analysis to consider improved engine durability resulting from some of the technology improvements analyzed, which could translate into reduced frequency of repairs and/or a longer useful life.*

Introduction

In this peer review report I look at the draft final report prepared by ICF Consultants from two distinct aspects. First will be a number of comments on presentation and format of the report. While not as important as the actual technical content, editorial weakness can serve to obscure a clear understanding of the material being presented.

My second focus will be on the technical content of the draft final report. This is, of course, the most critical aspect of the review. Unfortunately, as I will describe in greater detail below, this report is lacking a significant amount of the documentation needed to allow the reader to critically assess the cost analysis.

The analysis that follows will review the draft final report section by section, beginning with the introduction.

Analysis

Introduction

It is here in the introduction that significant editorial issues begin to present themselves. The end of the first paragraph uses the three terms "advanced technology," "engine redesign," and "exhaust aftertreatment" to categorize the types of changes contemplated for the new rule. The very next paragraph replaces advanced technology with "updated technology," and includes within that category something called "improved engine design" even while retaining the "engine redesign" category as a separate item for the next sentence.

These sorts of casual confusions appear regularly in the whole report, and can easily confuse the reader and/or lead one to think that the authors do not understand their material well. The final report should be reviewed carefully for editorial consistency and clarity.

Background

No comments on this section

Technology Description

The second paragraph of this section opens with another editorial misstep, which is also technically incorrect. It states that for "fuel induction" ICF considered electronic fuel injection electronic carburetors and mechanical fuel injection. Unfortunately, fuel <u>injection</u> is not fuel <u>induction</u>.

This section identifies only a three-way catalyst option for aftertreatment. It should explain why it is not also going to analyze a simple oxidation catalyst configuration.

It is in this section that the draft report identifies a set of 8 “common” combinations of valve configuration/useful life/displacement/power which were used for costing purposes (Table 3-1). Since these combinations are used throughout the cost analysis, their derivation is important. If they were assigned by EPA, then a reference to an EPA analysis should be included. If developed by ICF using EPA data, then the derivations should be provided.

Baseline Technologies

This one sentence section states that the baseline technology package considered varies with the advanced technology to which it is compared. On its face, this statement seems incorrect. That is, the baseline engine should be a fixed entity or set of entities, to which modifications are made as needed to adapt the required new technology. If the baseline varied, the cost comparisons would be confounded.

The sentence also references an earlier discussion of the topic of a varying baseline engine. I found no such discussion in my review. If it exists I missed it.

Finally, neither here nor in any other part of the report are the baseline engine(s) defined with any precision.

Advanced Technologies

In this section, the three categories of technology to be analyzed have morphed into “engine modifications, improved fuel delivery, and exhaust after-treatment.” In the subsequent sub-section, “engine modifications” changes again, into “engine improvements.” These are clearly a different grouping of the changes to be examined than the taxonomy used in the introduction of the report. I have no preference for how the various improvements are categorized, but the approach should be consistent throughout the draft report.

Engine Improvements

This section notes that improvements to engine design enhance both engine performance and durability. These factors should be given further consideration in the discussion of operating costs, since they would reduce maintenance and/or increase the useful life of the engine.

Overhead Valve Configurations

No comments on this section.

Pressurized Oil Systems

No comments on this section.

Cylinder Liners

No comments on this section.

Electrically-Controlled Carburetion

No comments on this section.

Mechanical Fuel Injection

No comment on this section.

Electronic Fuel Injection

This section describes one of the benefits of electronic fuel injection as "the ability to change more instantaneously…" The phrase "more instantaneously" is particularly poorly chosen.

The discussion points out that the injector can be mounted in the throttle body or the intake manifold, and states that for two-cylinder engines two injectors are used. This would be incorrect for TBI, which would still only need one injector. If this assumption is used in the cost analysis, it would lead to an estimate that is too high.

Catalysts

This section states that three-way catalysts "are likely to be incorporated on some small engines models…" Unless the emission standards are deliberately catalyst-forcing, this statement is in need of further justification.

It seems that there could also be an ox-cat based strategy used that should be included in the analysis. Even if NOx control is going to be required, the engine could be tuned for low NOx and an ox-cat used to clean up the HC and CO emissions. This would increase fuel consumption, but at least for the smallest engines fuel consumption is less of an issue than first cost. A simple ox-cat would be less expensive than a three-way system.

The discussion of catalysts includes a number of assumptions that effectively drive the cost. These assumptions are undocumented, and therefore cannot be critiqued. This is hardly appropriate for a "transparent" analysis. The assumptions are:

1. The catalyst volume to engine displacement ratio.
2. The precious metal loadings.
3. The washcoat composition.
4. The assumptions that Class I engine catalysts will be in the muffler while Class II engine catalysts will be separately canned and have air injection for cooling.
5. The assumption of a 50/50 split for metallic and ceramic substrates, as well as the cell density of each.
6. The assumption that substrate costs can be calculated based on standard sizes being used for a variety of applications beyond small SI engines.

Cost Methodology

This section begins with the repeat of earlier statements that costs were determined "relative to a baseline that could differ for each technology type." As I noted in my earlier comments, this appears to be an incorrect methodology. Additionally, there is no more definition of baselines in the report than this, with its vague "could differ."

In this section, the methodology discussion for moving from separate engine model based costs to the estimates of the report describes the process with this language: "representative averages of all costs collected were used for each technology." There is no further description of what this means or how it was carried out in practice.

Hardware Costs

The hardware costs section makes a rather inappropriate statement about hardware costs, which are estimated to be below about $75 for all systems considered. It seeks to explain this low cost by saying "This low price emanates from the need to maintain costs associated with these engines low,…" Besides the awkward use of the word "emanates," the sentence seems to be saying that the cost estimates are low because they need to be low, as if a low target were driving the analysis rather than the nature of the hardware itself.

Labor rates used for hardware costs are, as in nearly all of the assumptions in the draft report, given with no reference or justification to support the numbers. The hardware cost markup of 29% is referenced (perhaps the only source reference in the document), but the reference is a 1985 report by Jack Faucett Associates. It is hard to imagine that mark-up rates have not changed in over 20 years. Supplier mark-up and warranty mark-up are, once again, given with no reference or justification.

Fixed Costs

Here the statement is made that 5 years is "typical" for the time to recover investments for the small SI engine industry. There is no discussion or reference as to what this claim is based upon.

Design and Development

There are numerous assumed values in this section (e.g., annual cost and fringe rate for an engineer, technician salary and fringe rate, number of dyno tests per month and their unit cost) which are totally un-sourced.

Certification Testing

More numbers without basis are found in this section. Table 4-3 details the number of technician and engineer hours separately for five stages of certification testing, the amount of fuel needed for testing and costs for each, all in great detail. Unfortunately, without any explanation or reference for the source of all these numbers, it is impossible for me to evaluate any of them.

Durability Testing

This section has the same underlying flaws as the certification testing discussions. I will not repeat them again.

Tooling Costs

No comments on this section.

Operating Costs

This section uses unexplained per-gallon fuel costs, load factors, annual activity rates and discount rates in its calculations.

More importantly, it fails to discuss any impact on operating costs other than possible fuel economy improvements. An analysis should be made of the in-use impacts of the improved durability and precision expected from many of the included technology changes. Improved durability could translate into a longer useful life, or perhaps cost savings by the manufacturer at the current useful life. It could also translate into fewer repairs for the purchaser, although in some of the options this would need to be balanced against potential repair needs for more elaborate fuel systems.

Results

By the time one reaches this section, little is left other than to "turn the crank." New factors or assumptions appearing in the results section that have not been mentioned earlier are lacking in justification, just as those in earlier sections of the draft report.

Conclusions

This report is well organized and presents extensive tables showing its results in detail. However, it is significantly lacking in details justifying the underlying assumptions needed to make the analyses transparent; it is these assumptions that determine the outcome of the cost analysis. It is, in fact, not possible to verify the accuracy of the results without this information.

To correct this deficiency the report should be significantly revised for any final rulemaking action.

About the author

John Anderson is an independent consultant with extensive experience in engine technology and cost issues, having worked for EPA as a Senior Program Manager in the Office of Transportation and Air Quality, Assessment and Standards Division for over 25 years prior to his retirement in 2004. In that position he was responsible for technical oversight in the development of Regulatory Impact Analyses for a wide range of rulemakings affecting both gasoline-fueled and diesel engines, highway and nonroad, large and small. His responsibilities included, among others, the areas of cost analysis and economic impact assessment.