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Final Regulatory Impact Analysis

Phase 2 Final Rule: Emission Standards for New Nonroad Handheld Spark-Ignition Engines At or Below 19 Kilowatts

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

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Chapter 1: Introduction

This Final Regulatory Impact Analysis ("Final RIA") contains the supporting information and analysis for the Phase 2 Final Rulemaking for handheld engines and for Class I-A and I-B nonhandheld engines. The information was gathered from number of sources including the Regulatory Negotiation (Reg/Neg) process between 1993 and 1996, industry meetings between 1993 and 2000, EPA contracts, comments to the January 1998 Notice of Proposed Rulemaking (NPRM) and the July 1999 Supplemental Notice of Proposed Rulemaking (SNPRM), and discussions with manufacturers and inventors. The Reg/Neg task groups provided information on test procedure, technologies, compliance programs, and costs. Industry provided data on the in-use deterioration characteristics of Phase 1 engines from their own test programs and on costs of technologies to the consumer. EPA contracts provided information on available technologies, costs of technology changes, and regulatory impacts for small entities. Comments to the January 1998 NPRM provided information on a number of issues including the timeframe for certain technologies, costs of technologies, costs of testing, the need for additional nonhandheld classes, etc. Discussions with manufacturers and inventors since the publication of the January 1998 NPRM and comments on the July 1999 SNPRM provided EPA with the latest information on emission reduction technologies and costs. All of this information is utilized in the chapters of this Final RIA as described.

Chapter 2 contains a summary of the work done by the Test Procedure Task Group of the Regulatory Negotiation Committee, as it relates to this rule. The work by the Task Group included an investigation into the differences in emission results when small engines[1] are tested on steady state and transient test cycles. The outcome for this rule is the use of the Phase 1 steady state test procedure with an adjustment in the weightings for the handheld test procedure changed from 90/10 to 85/15 for Mode 1 and Mode 2, respectively.

Chapter 3 presents the supporting rationale for the level of the Phase 2 standards being adopted including a comparison of cost estimates for various technologies. Research on technologies for handheld engines has focused on information obtained since Phase 1 was in the process of being finalized. Preliminary work was completed by several sources including the Technology Subgroup of the Regulatory Negotiation and an EPA work assignment with SwRI in 1996[2]. The Technology Subgroup of the Regulatory Negotiation investigated a number of engine

[1] The small engines were tested in Phase 1 and "future technology" configurations.

[2] The work assignment with SwRI focused on investigation of currently produced Phase 1 engines and identified the features of low and high emitting handheld and nonhandheld engines.

emission reducing technologies for the exhaust system and fuel system of Small SI engines. The results of the testing during these years revealed that some technologies required other engine improvements to be achieved prior to their use (such as catalysts), some technologies were currently too expensive compared to the price of the engine (such as traditional fuel injection on a handheld engine) and some were in the pre-prototype stages and required additional development before the prototype stage (such as an accelerator pump on a chainsaw engine). Standards being discussed were 30 percent below the respective Phase 1 standards for each class (210, 172,116 for Classes III, IV and V, respectively).

Most recent discussions with manufacturers, from 1998 to 2000, revealed potential technologies for meeting the California Air Resources Board (ARB) HC+NOx standard of 54 grams per horsepower-hour (g/hp-hr) (i.e., 72 grams per kilowatt-hour (g/kW-hr)) for small spark-ignition engines up to 65cc. Technologies include the compression wave technology, stratified scavenging with lean combustion, and mini four-stroke engines, as well as internal engine improvements with a catalyst. These technologies form the base of the technologies to meet EPA's final standards of 50 g/kW-hr for Classes III and IV and 72 g/kW-hr for Class V. For Classes III and IV, EPA expects manufacturers to use compression wave technology with and without a catalyst, stratified scavenging with lean combustion with a catalyst, and the mini four-stroke engine. For Class V, EPA expects manufacturers to use stratified scavenging with lean combustion and the compression wave technology.

Chapter 3 also includes information on technologies and related standards for Class I-A and Class I-B. Information was collected in discussions with manufacturers after the January 1998 NPRM was published, comments on the July 1999 SNPRM, and a comparison of the standards to the program adopted by the California ARB. In the California ARB program, engines under 65cc have a unique standard compared to those over 65cc. No distinction is made between handheld and nonhandheld engines in the ARB program as had been done in earlier standards. Given the market structure of the small engine industry, EPA is of the opinion that a harmonized approach, with Class I-A, as allowed in our rulemaking structure, would benefit all. Class I-B serves to allow the smaller Class I engines a higher standard due to the difficulty of smaller engines to meet the Phase 2 standard.

Chapter 4 contains the data and analysis behind the estimated costs for the technologies for this final rule. Cost information for handheld technologies was submitted to EPA by industry groups and individual companies and through a work assignment with ICF, Incorporated (Docket Item IV-A-01[3]).

The impact of technology changes to the Phase 1 engine families are based on review of

[3]Unless indicated otherwise, docket references in this document are to Docket A-96-55.

EPA's Phase 1 certification database and the regulatory programs for handheld engine manufacturers being adopted for Phase 2. The number of handheld engine families that are expected to be improved are estimated based on the use of ABT by the engine manufacturers[4] and the comparison of their deteriorated[5] Phase 1 emission rates to the Phase 2 standard with a 10 percent compliance margin[6]. Technology improvements for handheld engines include mini four-stroke, stratified scavenging with lean combustion and a catalyst, and compression wave with and without a catalyst. The estimated costs for each technology are also presented in this chapter. Costs for Class I-A standards are minimal as Class I-A allows handheld engines to be used in nonhandheld applications. Therefore the technology costs are attributed to the handheld rulemaking. Class I-B costs are minimal for the standard allows existing engines to meet the standards without modification. The only costs are those that are attributed to certification and other related applicable costs which are the same as those for other engine families.

Chapter 5 contains the details of the compliance program and outlines the estimated costs of the program. The compliance program includes certification and production line testing. One major assumption made here for the program is the useful lives that would be chosen by engine manufacturers for their engine families. This was done based on the market focus of the engine manufacturers from low cost consumer to medium quality to high use professional. Appendix C contains the spreadsheets for this analysis.

Chapter 6 contains a description of the methodology used to calculate anticipated emission reductions and fuel savings as a result of this rulemaking. Appendix F contains related data used in EPA's NONROAD Model for estimating the inventory reductions and fuel consumption.

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[4] The ABT calculation is performed for each engine manufacturer and it is based on information in the Phase 1 certification database (engine families, emission data and production estimates.

[5] Deterioration rates and functions are obtained from industry supplied data for both nonhandheld and handheld industries.

[6] This analysis projects that manufacturers will claim FELs that are 10 percent below the standard. This assumption is made based on the conclusion that, as manufacturers develop and implement low emitting technologies, manufacturers will want to take advantage of credits to be gained by achieving FELs slightly below the standard in order to offset credit needs by smaller engine families. A larger percentage is not used due to the stringency of the standard in relation to available technologies to meet emission levels much below the standard.

Chapter 7 contains the aggregate cost analysis for this rulemaking and Appendix E contains the corresponding spreadsheets. The cost estimates presented in Chapters 4 and 5 were used to calculate these costs which include uniform annualized costs for variable and fixed costs per class, average cost per engine per class and overall cost-effectiveness. The cost-effectiveness with fuel savings is also presented.

Chapter 8 outlines the analysis of impacts on small entities for this final rulemaking. The work for this analysis was completed through a work assignment with ICF, Incorporated in 1997 and additional work by EPA in 1999. Through this work, EPA analyzed the expected impact on small production volume engine and equipment manufacturers based on the standards and programmatic content of this final rulemaking[7]. Based on the stringency of the standards, phase-in, ABT and a number of compliance flexibilities, it is anticipated that the impact on small-volume manufacturers and small-volume models will be minimal.

Chapter 9 contains the background information and analysis on certification useful lives and regulatory flexibility parameters. The standards in this final rulemaking would be met by engines based on the emissions at the end of the certification useful life of the engine. Three choices of certification useful lives for handheld (50, 125 and 300) are included in this rulemaking. These options were based on useful life information by PPEMA and EPA's own analysis. The options for Class I-A are the same as that for handheld engines. The options for Class I-B are the same as nonhandheld engines which are 125, 250, 500 hours. The production volume cutoffs for the various flexibilities for this rulemaking were based on the information available in the 1996 PSR OELINK database and EPA's Phase 1 certification database as of September 1998. Chapter 9 contains the rationale behind the decisions for each flexibility cutoff.

[7] This includes certification and production line testing.

Chapter 2: Exhaust Emission Test Cycle and Test Procedures

2.1 Introduction

For EPA to successfully regulate exhaust emissions from small nonroad engines, the Agency strives to establish test procedures and cycles that ensure technologies used by manufacturers not only meet the emission standards when tested over the required test procedures, but also result in a predictable emission reduction in actual use. Test procedures are specified to a level of detail necessary to produce accurate, repeatable results. The following discussion is for those engine families using the handheld cycle (handheld engines and Class I-A). Discussion on the test cycle for Class I-B (nonhandheld cycles) can be found in the Phase 1 Final RIA (Ref. 1).

2.2 Phase 1 test procedures and test cycle

The Phase 1 test procedure is described in 40 CFR Part 90, Subparts D and E. The Phase 1 test procedure is based upon well established and accepted on-highway exhaust emission methods and equipment, with some modification to take into account the unique nature of Small SI engines. The procedures are designed to accurately measure engine emission performance. A description of the Phase 1 test cycle and procedure can be found in the Final RIA for the Phase 1 rule.(Ref. 1) The Phase 1 test cycle is comprised of a series of steady state 'modes'. A mode is a specified engine speed and load condition, during which the engine is stabilized and emissions are sampled. The emission results for all of the modes are combined using 'weighting factors' into a single number for each pollutant.

One distinct cycle (set of modes) is used for small handheld engines. The test cycle for handheld applications consists of two modes, one full load condition at rated speed and one no-load condition at idle speed.

The Agency determined during the Phase 1 rulemaking, based on the information available at the time, that for the range of technologies expected to be used to meet the Phase 1 standards, that the Phase 1 test cycle and weighting factors were appropriate.

2.3 Agency review of the Handheld Engine Test Cycle

Prior to proposing Phase 2 emission standards for small nonroad engines, the Agency first undertook, with the cooperation of the engine industry and members of the Negotiated Rulemaking Committee, a test program to determine if the Phase 2 rule should contain a change in the test cycle. The Agency has found for other mobile source categories that steady-state test cycles often do not result in real in-use emission reductions and that 'transient' test cycles which more closely mimic real world operating conditions are necessary. A transient cycle means a combination of speed and/or load conditions which vary with time, such as the on-highway Federal Test Procedure for light-duty vehicles or heavy-duty engines.

Chapter 2: Test Cycle and Tests Procedures

During the Reg/Neg process the Agency expressed concerns regarding the ability of the Phase 1 steady-state test cycles to adequately predict in-use emission reductions for a Phase 2 rule which would result in different engine technologies being employed. The Reg/Neg committee established a Test Procedure Task Group to examine the existing Phase 1 test cycle and procedure and make recommendations to the committee regarding any appropriate changes. (Ref. 2)

The Test Procedure Task Group established by the Reg/Neg committee examined the Phase 1 handheld test cycle and its viability as a Phase 2 test cycle. The work performed by the Handheld Subgroup is well documented in their final report. (Ref. 3)

The Handheld Subgroup chose a Class IV chain saw as the test engine used to evaluate the effect of transient operation on a future technology engine. The chain saw was picked because chain saws have the highest amount of throttle activations from idle to wide open throttle (WOT) (see Ref. 4 to this Chapter), e.g., chain saw use is considered to be the most transient of handheld engine applications. The Class IV chainsaw was tested in a baseline configuration and with a modified carburetor which included a leaner calibration and an accelerator pump to simulate a ‘future technology’ engine. The Handheld Subgroup used in-field engine operating data to determine the appropriate weighting between wide-open throttle (WOT, e.g., maximum load) and idle conditions. For chain saws, use was 70 percent WOT, and 30 percent idle. The Handheld Subgroup chose as a representative set of transient test cycles for chain saw operation three cycles. Of the three transient cycles, the Handheld Subgroup determined the “20-second” cycle to be the most appropriate for chain saw applications. The 20-second cycle fluctuated between WOT and idle at a rate of 14 seconds WOT followed by 6 seconds of idle which was repeated for a total cycle time of 360 seconds, or 18 repetitions of the WOT/idle change. The steady-state comparison cycle was a two mode test identical to the Phase 1 handheld engine test cycle, but with weighting factors adjusted to match the specific operating conditions of chain saws, 0.7 for the maximum power mode, and 0.3 for the idle mode. Table 2-01 contains a summary of the relevant emission test results collected by the Handheld Subgroup.

Table 2-01
Summary of Results from Handheld Transient/Steady State Cycle Program

Test Engine	Cycle	Avg. HC (g/kW-hr)	Avg. NOx (g/kW-hr)	Avg. CO (g/kW-hr)
Class IV Chain Saw w/ Accelerator Pump	Steady-State	113	2.35	99
Class IV Chain Saw w/ Accelerator Pump	20 -Second Transient	113	1.96	109
Class IV Chain Saw w/ No Accelerator Pump	Steady-State	111	2.20	109
Class IV Chain Saw w/ No Accelerator Pump	20-Second Transient	120	2.20	89

Table 2-01 indicates that, if manufacturers choose to adopt a technology similar to that of a lean carburetor calibration, or with lean carburetor calibrations combined with an accelerator pump[8], a transient test cycle is not necessary to predict emission results at this level of control. Anticipated technologies for meeting Phase 2 emission standards (50 g/kW-hr) include a mini-four stroke engine (similar to nonhandheld engine designs which also concluded the steady state test cycle was acceptable) or reduced scavenged engine (through internal redesigns) with a catalyst. These technologies will likely not incorporate an accelerator pump as tested above and therefore the test engine comparison may be considered worst case. Therefore, the Agency is retaining use of the Phase 1 two-mode steady state test procedure for Phase 2 handheld engines.

In addition to examining the possible need for a transient test cycle for a Phase 2 program, the Test Procedure Task Group also examined the appropriateness of weighting factors for the two-mode steady state cycle. The Phase 1 test procedure specifies a weighting factor of 0.90 for Mode 1 (maximum power mode) and 0.10 for Mode 2 (idle mode). The analysis and recommendation of the industry group which studied the weighting factor issue is well documented in their final report.(Ref. 4) A group of handheld engine manufacturers collected field cycle data on several handheld applications: 12 trimmers/brush cutter, 4 chain saws, and 6 blowers. The industry group proposed a methodology to determine the appropriate handheld test cycle weighting factors which determined the average WOT/idle time percentages for each

8 The emission results for this experimental test engine are above the Phase 2 Class IV HC+NOx standard of 50 g/kW-hr. This is due to the fact that this was the best technology option at the time to evaluate emission results from transient/steady state tests cycles.

application (trimmers/brush cutters, chain saws, and blowers), and weighted these by the HC emissions inventory impact from each application. The HC emissions inventory impact of each application was determined by the following formula:

$$\textit{Emissions Inventory Impact} = (TU \times HU \times LF \times HP \times EM) \div TE$$

where,

TU = total units sold per year per application
HU = annual hours of use per application
LF = load factor per application
HP = average rated horsepower per application
EM = engine emission factor (g/hp-hr) per application
TE = total emissions per year for all applications.

The results of the analysis performed by members of the handheld engine industry indicate that the appropriate weighting factors for handheld engines is 0.85 for Mode 1 and 0.15 for Mode 2. For the Phase 2 handheld engine final rule, the Agency is modifying the weighting factors for Phase 2 engines to reflect the results of the analysis performed by industry. Though these new weighting factors are only slightly different from the 0.90/0.10 values used for Phase 1, the Agency believes the Phase 2 program is an appropriate time to make this minor change. This is based on the fact that the EPA Phase 1 certification database shows that the majority of handheld engine families in Phase 1 already meet the Phase 1 standards with some cushion and therefore the calculation change to 0.85/0.15 would not cause a significant change in the overall emission results, as related to the standard, and therefore additional technologies would not be required to comply with Phase 1. The Phase 2 handheld engine standards are much more stringent and the change to the 0.85/0.15 weightings would be more influential on standard calculations.

Chapter 2 References

1. "Regulatory Support Document, Control of Air Pollution, Emission Standards for New Nonroad Spark-Ignition Engines at or Below 19 kiloWatts" US EPA, May 1995, Docket A-93-25, Item V-B-03.

2. Handouts and Notes from all Meetings of the Test Procedure Task Group held during the Phase 2 Regulatory Negotiation are available in EPA Air Docket A-93-92.

3. "Final Report - Handheld Subgroup of the Test Procedure Task Group", Docket A-93-29, Item II-M-40.

4. "Hand Held Composite Duty Cycle", Dec. 30, 1994, Docket Item II-D-18.

Chapter 3: Technologies and Standards

3.1 Introduction

Section 213(a)(3) of the Clean Air Act presents statutory criteria that EPA must evaluate in determining standards for nonroad engines and vehicles. The standards must "achieve the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the engines or vehicles to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology." This chapter presents the technical analyses and information that form the basis of EPA's belief that the finalized emission standards are technically achievable accounting for all the above factors. Specific areas of discussion include a basic description of the technologies examined, current status of the technology in the existing market, new and in-use emission performance of each technology, costs of each technology, impact of the engine technology on equipment design and use, and impact of the technology on noise, safety, and energy. Finally, this chapter concludes with a discussion of the finalized standards (handheld, Class I-A and Class I-B) and how these standards meet the statutory criteria.

3.2 Technologies

Section 3.2 contains descriptions of technologies for handheld engines which include compression wave technology (with and without catalysts), stratified scavenged with lean combustion (with and without catalysts), four-stroke, improved two-stroke with a catalyst, and a spark-ignition technology. Class I-A engines use the same technologies as handheld engines. Class I-B engines use technologies similar to nonhandheld engines and are discussed at the end of this section. At the time of this final rule, handheld engine manufacturers have begun to certify to the California ARB standards for 2000. The current certification database, as of the time of this rulemaking, is contained in Appendix D.

3.2.1 Compression Wave Technology (With and Without Catalyst)

3.2.1.1 Description of Technology -- The compression wave technology is a technology that has been presented to EPA by John Deere and is referred to herein as the LE Technology. As stated in information provided by John Deere (see Docket Item IV-G-30), "(t)he LE technology relates to a compressed air assisted fuel injection system for internal combustion engines, specifically two-stroke engines. Its primary characteristic is in its low emission performance, namely through almost total elimination of an unburned fuel charge during the scavenging process of the exhaust portion of the two-stroke cycle."

Docket Item IV-G-30 also states that the two-stroke engine containing the LE Technology "retains a conventional piston, crankshaft and crankcase from a standard two-stroke engine."

The fuel metering system needs to be designed to perform with the engine's needs, but does not need to provide a high precision timing or spray quality. "The fuel injection system is a compressed air assisted system. The injection system comprises an accumulator. The accumulator...has an inlet connectable to pressure within the crankcase and has an exit at the injection port. The accumulator functions as a collector and temporary storage area for compressed air. In this configuration, the source of the compressed air is air scavenged from the crankcase. The piston compresses the air in the crankcase on the piston's downward stroke.... the two apertures are both provided in the cylinder, one above the air inlet and one below the air inlet. Both apertures are piston ported. In other words, the piston head is sized and shaped to open and close access through the apertures as the piston head reciprocates up and down the cylinder. The accumulator... is a simple channel between the two apertures. The channel could be partially machined into an exterior surface of the cylinder with a cap then being attached to the cylinder to form and enclose the channel with only the two apertures. Alternatively, the accumulator could be provided in a separate member attached to the cylinder. An exit form the fuel metering system is located in the channel proximate the injection port.... The injection system has minimal moving parts.... the fuel injection system uses the piston head to open and close its ports. Timing of the opening and closing of the ports will be dependent upon location of the ports along the length of the cylinder."

A detailed description of the working of the technology can also be found in Docket Item IV-G-30. The main thrust behind the technology is a compression wave, which is essentially an acoustic wave, and thus the wave travels at the speed of sound. "As the reflected compression wave exits the inlet (of the accumulator), it causes the fuel and air in the cylinder to be greatly disturbed, in effect functioning as a shock wave. This helps to atomize the fuel and distribute the fuel better in the air. In addition, the reflected compression wave assists in removing fuel droplets that might be adhering to tips or edges of the inlet by surface adhesion or surface tension. The compression wave shocks the fuel off of the surface and into the cylinder."

3.2.1.2 Current State of Technology Development -- John Deere has been developing the technology on a Class IV trimmer into the 2000 calendar year. The latest California ARB certification list (see Appendix D) for the 2000 model year includes the 25cc engine by John Deere with this technology. In regards to other classes and applications, John Deere completed preliminary development of the technology (in the summer of 1999) to a 70cc (Class V) Stihl chainsaw and the latest emission levels are included in their comments to the Phase 2 SNPRM (Docket Item IV-D-48). In addition, John Deere has submitted more recent information on two Class IV trimmer engines and one Class V chainsaw engine equipped with the compression wave technology (Docket Item VI-E-09).

Class V engine manufacturers have raised a number of concerns about the technology through comments to the docket (Docket Items VI-D-08, VI-D-18, VI-E-26). The basis for the comments by manufacturers concern the applicability of early designs (as it was developed in winter 1999) of the John Deere LE technology to Class V engines. Concerns by the industry focused on the feasibility of the technology and included lubrication at engine operation other than idle, smooth transitions between all engine operating modes, details of the fuel system being unavailable and sensitivity of the fuel system to atmospheric temperature and pressure. EPA tested the John Deere engine in its development stage as of the summer of 1999. Advancements in the technology had been made and some address the issues raised by the Class V manufacturers. Advancements included lubrication of the engine through limited fuel-oil-air mixture that is brought into the crankcase during regular operation of the engine (the wider the throttle, the more fuel-oil-air mixture)[9]. With respect to smooth operation, the fuel system setup had been updated from the winter 1999 prototype, however, EPA testing revealed that further attention to the carburetor, including protection from heat, was required. The sensitivity of emission levels to atmospheric temperature and pressure was tested on two occasions. First, on March 1,1999, EPA observed operation of the engine prototype on the dynamometer in John Deere's emission test cell and requested that the operator change the CO range from 1.5 to 3.5 percent CO. The HC analyzer showed a minimal change in HC emissions (ppm basis).[10] Secondly, EPA tested the John Deere engine in its summer 1999 small engine test program and gathered emissions with engine settings varying from mid-range to rich air-fuel ratios (Ref. 7). While the CO concentration was not measurable due to test equipment problems, the HC+NOx emission levels changed from 51.9 g/kW-hr to 55.3 g/kW-hr The engine was also tested in its lean and rich conditions when it was fit with a catalyst and, in this configuration, CO was measured. The only difference seen in the emission results were the resultant CO emissions which were approximately 40 g/kW-hr in the lean setting and approximately 90 g/kW-hr in its rich setting. This testing revealed that the technology was relatively consistent over a range of air-fuel ratios.

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9 The amount of fuel-oil-air mixture that is brought into the engine crankcase can be application specific and is easily adjustable. For example, in a trimmer application, 15 percent of the fuel needed for engine operation can be brought in this manner and 85 percent of the fuel can be put into the accumulator tube. A chainsaw which runs for longer times at heavy load is able to monitor a higher amount of fuel-oil-air with some emission penalty. However, professional chainsaws have other internal designs that allow them to meet lower emissions without this technology. Therefore this technology does not need to achieve the same emission reduction (on a g/kW-hr basis) as it does with Class IV engines. If more is needed, then a low conversion efficiency catalyst may also be used assuming there is sufficient cooling available.

10 The overall g/kW-hr is likely less affected for the power increased as the engine ran richer and the power decreased as the engine ran leaner. These changes coincided with increases and decreases in measured engine-out emission levels, respectively.

John Deere has indicated that one of the major benefits to this technology is that many of the existing engine designs can be utilized with few alterations. The items that will need to be modified include the heat barrier between the engine and the carburetor (the accumulator is mounted in the existing width), two holes in the engine cylinder for the accumulator, a "stuffer" in one of the holes, and minor modifications to the existing carburetor. Additional cooling will be needed by the engine and this can be achieved by adding more fins (which can be done by decreasing the thickness of the existing fins) and widening the fins. Designs for these fins are already available from existing commercial engine designs. Additional engine improvements may be necessary given specific engine designs and applications.

With respect to engine power, John Deere states, in Docket Item IV-G-30, that the engine power remains nearly the same as the Phase 1 engine without the technology. "The 25cc engine is rated and certified at 0.75 bhp for trimmer applications and 0.85 bhp for blower applications. Its power range is 0.60 bhp to 0.98 bhp for trimmers and 0.60 bhp to 1.18 bhp for blowers." The engine could be classified as either a 50-hour residential engine or a 125-hour engine.[11]

3.2.1.3 Exhaust Emissions Performance -- John Deere has submitted certification to California ARB's 2000 standards on its 25cc engine at 125 hours. The certification value for HC+NOx is 45.6 g/hp-hr (61.1 g/kW-hr) with a 1.105 deterioration factor. The certification value for CO is 202 g/hp-hr with a 1.341 deterioration factor for CO. In its current form, the engine will require a catalyst to comply with the finalized emission standards for Classes III and IV. The catalyst efficiency can be estimated using the parameters of the in-use emission level, deterioration factor and power rating in the California ARB certification database (0.95hp/0.71kW), assuming a 20 percent compliance margin (therefore using a goal of approximately 40 g/kW-hr as one to reach in prototype development), and a catalyst deterioration of 30 percent. The new engine catalyst efficiency required on the engine is calculated to be 55 percent or 30 g/kW-hr or 18 g/hr (g/kW-hr × power × 85 percent (weighting of the test power for calculation of g/kW-hr)). However, it is possible further development of the LE system might obviate the need for a catalyst in at least some Class IV applications. Further, EPA believes the need for catalysts will decrease with increasing engine displacements. This is supported through John Deere's preliminary prototype of the technology on a 70cc Stihl chainsaw engine, (John Deere, however, has not redesigned their own engine in Class V). In Docket Item IV-D-48, emission results for the 70cc engine[12] were 50.0 g/kW-hr HC+NOx and 190.5 g/kW-hr CO. These levels fall below the standards being finalized for Class V engines.

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[11] John Deere produces the 25cc engine for use in string trimmers and blowers under the Homelite brand.

[12] Note that the engine design was not optimized for performance; however, it was used to cut wood.

3.2.1.4 Technology Cost -- Cost of the technology is detailed in EPA Air Docket Item IV-G-30. John Deere states that "(D)evelopment time for these changes is short, while both capital and added part costs are low." The cost of the technology includes (1) alteration to the cylinder block consisting of the addition of two holes at the carburetor position, (2) addition of a "stuffer" into one of the holes, (3) carburetor placer replacement which includes the tube and attachment, and a (4) slightly modified carburetor.[13] The variable costs estimated by John Deere were $4.50 to $8.00 and included the incremental cost of the hardware (i.e., the accumulator, modified fuel delivery system, modified cylinder and components) and the incremental cost of labor (estimated to be $0.50 of the costs). John Deere states that fixed costs are estimated to range from $75,000 to $300,000 for an engine model (these are amortized in the total cost) and a manufacturer should approach the low end of fixed R&D costs for subsequent engines. The licensing fee of the technology was proposed by John Deere ranging from $7.50 minimum to 5 percent of the cost of an engine over $300 in volumes of 10,000 (e.g., $20 for a model that costs $400 and is produced in 10,000 units/yr).[14] We have adjusted some of these cost estimates to reflect development work completed to meet California requirements; these adjustments are detailed in Chapter 4.

For Class III, a catalyst is estimated to be used with the John Deere technology, resulting in an extra cost for adding a catalyst to the engine. As mentioned above, catalysts may not be required for all Class IV engine applications using the LE technology. John Deere has estimated that with averaging available, approximately 50% of their Class IV applications can be certified without using a catalyst. We would expect manufacturers to attempt to not install catalysts on applications where catalyst usage would present the more difficult design challenge, specifically chainsaws or similar pieces of equipment. For the cost analysis performed for this rulemaking, we have analyzed two scenarios. The first, a "high-cost" scenario, anticipates that 50% of John Deere's Class IV equipment will not require catalysts but, conservatively, the rest of the industry's equipment will require catalysts. The second, a "mid-cost" scenario, anticipates that the rest of the industry, as well as John Deere, will also be able to certify half of their Class IV engines without relying on a catalyst. This assumption is supported by the high degree of cost competitiveness claimed by the industry especially within Class IV, suggesting that if one manufacturer can save catalyst costs in at least some applications, others will similarly try to do so to remain cost and price competitive. For Class III engines, the adverse surface-to-volume ratio of the engines makes it more difficult to meet the 50 g/kW-hr HC+NOx standard without a catalyst. Therefore, all Class III 2-stroke engines are assumed to require a catalyst even if using John Deere's compression wave technology.

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[13] Additional work on developing the technology has revealed that there may need to be some transport redesign and cooling improvements (fins, etc.).

[14] However, John Deere has stated they are open to other less costly licensing offers.

Therefore the overall variable costs for each engine class in this rulemaking is estimated using (1) the catalyst costs (as presented in section 3.2.2.4.) based on the estimated split of residential and commercial equipment (in Classes III and IV), (2) the range catalyst installation rates (noted above), (3) the range of costs provided by John Deere (adjusted by EPA as discussed in Chapter 4) including the full cost of licensing fees as initially proposed by John Deere, and (4) the percentage of engine families in the high and low volume categories as determined (based on a cutoff of 400,000 production for John Deere cost range) as determined from the EPA Phase 1 certification database. The total cost will vary due to the variation in the John Deere licensing fee based upon equipment price and engine family production volumes.

The licensing fees are of concern to several in the industry who have stated the licensing fees are above the profit margin for some consumer-marketed equipment. This is of special concern to competitors with John Deere, who claim they will be disadvantaged because John Deere will not have to pay the full royalty. Professional equipment manufacturers have commented about concerns that the price will impose a high added cost on professional equipment. While John Deere has indicated it expects a lower licensing fee, we do not have any way of estimating how much lower and therefore have used the originally offered fee schedule; this will result in an overestimation of costs if indeed the actual licensing fees are lower as anticipated by John Deere. We also expect lower licencing fees if the cost of the fee causes the cost of the John Deere technology to be higher than competing technology options.

The cost of the licensing fee with respect to the licensing fees of other engine technologies, such as the Ryobi or Honda four-stroke, is unknown and therefore EPA has no knowledge of the comparison of the costs being requested by John Deere. The cost analysis for this rule assumes the John Deere technology costs, including licensing fees, for all engines (including John Deere) unless we know a manufacturer plans to rely on an alternative technology (e.g., Ryobi four-stroke) in which case the cost of that alternative technology is used. For the cost analysis of the second catalyst use scenario noted earlier (i.e., where only 50 % of Class IV engines using the John Deere technology employ catalysts), EPA has also assumed that John Deere will not pay any licensing fee itself.

3.2.1.5 Impact on Equipment Design -- In regards to impact on equipment design, in Docket Item IV-G-30, John Deere states that “no modifications are required to the standard piston, crankcase and crankshaft: only small adaptations are needed for the cylinder and fuel metering system (carburetor) and the only additional component is an accumulator, which can be in the form of a simple channel or tube. The LE Technology can thereby be readily applied to existing engines without substantial change to the molds and tooling of existing engine components or housings.”

However, based on discussions of other engine designs with several Class V equipment manufacturers, it is clear that the impact on equipment design depends on the manufacturer’s current product. Manufacturers that tightly house the engine, or make the shroud as an integral part of the engine may not have available room for the accumulator tube and therefore there may be minimal changes to the plastic shrouding surrounding an engine. Additional cooling may also be an issue. Any technology will likely run leaner and use less fuel/oil for cooling, so these issues will likely need to be addressed regardless of which low emitting technology is utilized.

Installation of a catalyst may well require some redesign, in particular of the engine shrouding to improve cooling flow past the catalyst and to provide extra shielding of the catalyst for safety. More discussion of this is contained in section 3.2.4. of this document.

3.2.1.6 Technology Impact on Noise, Safety and Energy -- In Docket Item IV-G-30, John Deere stated that "No measurements have been made to determine the impact of the LE Technology on the sound characteristics or performance of the two-stroke engine. Observation of the LE engines, without quantification, suggests that there is no appreciable difference in sound levels between the engines and standard engines." John Deere also states that "during the testing of the prototypes, the fuel consumption of both the 25cc and 70.7cc LE engines was measured. A reduction of approximately 30 percent as compared to conventional or standard engines was demonstrated." Regarding safety, a particular concern is the higher exhaust temperatures of an engine equipped with a catalyst. More discussion on this is contained in section 3.2.4. of this document.

3.2.2 Stratified Scavenging with Lean Combustion (With and Without Catalyst)

3.2.2.1 Description of Stratified Scavenging with Lean Combustion-- The December 1998 edition of Power Equipment Trade stated that the problem with emissions from a two-stroke is that it "use(s) the incoming fuel charge to scavenge, or expel, exhaust gases from the previous combustion event. Unfortunately, about 30 percent of the intake charge goes out the exhaust port with the exhaust.... Reducing these scavenging losses is the key to meeting emissions regulations."

Stratified scavenged engines means that the scavenging is done with something other than the fuel/oil/air charge. The stratified scavenged engine design by Komatsu-Zenoah uses air as the scavenging component. Potential downsides of this approach include lower power. Advantages of this approach include lower fuel consumption and lower engine out emissions.

3.2.2.2 Current State of Technology Development -- Komatsu Zenoah has certified several engines to the California ARB standards for 2000 using stratified scavenging with lean combustion. The December 1998 issue of Power Equipment Trade contains an in-depth description of the Komatsu-Zenoah "Air Head" technology. The engine is an industrial engine[15]

[15] The crankcase is forged in three pieces is supported by a pair of ball bearings. The forged rod has caged needles on both ends. The top end is scalloped to encourage lubrication of piston pin and bearing.

which has undergone major changes to the crankcase, cylinder and carburetor. Description of the engine technology is as follows (quotes are taken from the December 1998 Power Equipment Trade article):

Reduced scavenging is used to keep the air/fuel mixture from short-circuiting out the exhaust port. Komatsu Zenoah developed a simple way to stratify the incoming fuel charge with a layer of fresh air. This "air head" creates a barrier between the fuel charge and the exhaust port, and it leans out the air/fuel mixture in the combustion chamber.

1. The engine uses a unique two-barrel carburetor by Walbro (special Walbro rotary valve carburetor - key part which resembles standard WY-type carburetors). One meters fuel and air in the usual way and the other the stratification air. Outlet pipes on the back of the insulator block connect to pre-formed tubes (on the cylinder). Tubes carry stratification air to transfer ports.

2. "To prevent scavenging losses, the carburetor's upper barrel sends pure air directly to the transfer ports. Each port sports an alloy cover plate equipped with a nipple for the air hose, a reed valve, and a valve stop."
   -Pure air volume is controlled by the carburetor. "At idle the upper barrel is completely closed. To ensure proper idle stability and acceleration, the upper barrel doesn't open until the throttle barrel is about 5 to 7 degrees off idle. At wide open throttle, both barrels are wide open."
   -"The transfer ports are a closed port design. The air/fuel charge enters the transfer channel through rectangular ports in the cylinder mounting surface. The reed valve assembly does not affect air/fuel transfer from crankcase to cylinder."
   -"The reed valves open in (toward the cylinder). As the piston travels up, negative crankcase pressure draws the reeds open via the transfer ports. A column of pure air fills up the port (at this point the port's cylinder opening is sealed by the piston skirt)."
   -"As the piston comes down, the air/fuel mix is compressed and squished into the air-rich transfer ports. Just before bottom dead center, the exhaust and transfer ports open, the air stratified fuel charge enters the cylinder, and exhaust gases are pushed out. Compared to standard two-stroke engines, the transfer openings are quite small. They are aimed back, away from the exhaust port, to assure that exhaust gas, not the transfer charge, is first out the exhaust port."
   -"Since the air/fuel mix is preceded by a cushion of pure air, very little fuel is lost out of the exhaust port. RedMax engineers report that Air Head scavenging losses are 9 percent— a 38 percent reduction compared to conventional (Schnurle) scavenging. "
   -"Not all of the air goes out the exhaust port. Much of it remains in the combustion chamber where it leans out the air/fuel mixture. To ensure the mixture is rich enough to support combustion, the carb is set richer than usual."

"The resulting air/fuel ratio is still very lean compared to conventional mixtures, and that tends to delay the ignition process and cause incomplete combustion." To counter this potential problem, Red Max did the following (information in parentheses is from SAE 980761)

1. The spark plug was moved to a straight up, dead-center location to maximize combustion dynamics.
2. Timing and spark energy have been altered (the ignition system is now a CDI with CPU rather than a transistor)
3. Higher compression was achieved by reducing crankcase volume
4. The combustion chamber geometry was changed. The piston is slightly domed to mate with hemispherical combustion chamber and is fitted with two compression rings.

Also, according to SAE 980761, a crankcase reed valve is used in place of a piston valve in the intake.

The stratified scavenged with lean combustion engine is estimated to require the use of a catalyst for Class III and IV engines in order to meet the Phase 2 standards. As is the case with the compression wave technology, there is a potential for at least some Class IV stratified scavenged engines to be certified without a catalyst for a manufacturer taking advantage of averaging. However, we have no manufacturer estimates of the portion of the Class IV engines using stratified scavenging that could be certified without a catalyst. Therefore, for this analysis, we are assuming all stratified scavenged engines use catalysts. EPA does not estimate that Class V engines employing stratified scavenging will require a catalyst due to the likelihood that application of the technology to larger engines results in lower emissions (as seen in Komatsu Zenoah engine certification data from the California ARB as presented in Appendix D) and the fact that the standard for Class V engines is higher than that for Classes III and IV.

3.2.2.3 Exhaust Emissions Performance -- Komatsu Zenoah has certified their 25.4cc and 33.6cc engines to the California ARB in-use standards. The 25.4cc engine is certified at 66 g/kW-hr for HC+NOx and 186 g/kW-hr CO at 300 hours and the 33.6cc engine is certified at 53 g/kW-hr HC+NOx and 75 g/kW-hr at 300 hours. The results show that emissions appear to decrease as engine displacement increases and that these engines will require a catalyst in order to comply with EPA Phase 2 standards unless further improvements to the engine are made. With regards to testing the technology with a catalyst, EPA's emission test data on Komatsu's 25cc stratified scavenged engine with one medium and one medium/high efficiency catalyst ranged from 39-28 g/kW-hr HC+NOx, respectively. Using the data associated with the catalyst that yielded 28 g/kW-hr, and assuming a 30 percent deterioration of the catalyst and 10 percent deterioration of the engine, the resultant emission level in-use is calculated to be 48 g/kW-hr. While these results show compliance with the standards in this rulemaking, there are several issues that need to be addressed for application of this technology in Class III and IV engines. The first is lower emissions to allow for a compliance margin with production engines and to decrease the needed catalyst conversion efficiency (a catalyst of 58 percent conversion efficiency (39 g/kW-hr) is used in the above example). While lower engine out emissions may be achievable in Class IV engines with further refinement of the engine design and the fuel delivery system, this is of special concern in Class III engines where the surface-to-volume ratio is the least favorable and further enleanment (than 14:1 as was used in the 34cc engine) may be prohibited due to engine stability concerns. Second is exhaust temperature compliance with the U.S. Forest Service temperature requirements. It should be noted however, that while EPA's testing of the prototype 25cc engine with a catalyst did reveal concerns of high exhaust temperatures, observation of the current muffler/housing arrangement revealed that the design was not optimized and there was room for improvement in its design when compared to Tanaka's current production version of an enleaned two-stroke engine equipped with a catalyst.

In regards to its application to Class V engines, EPA expects that the trend for decreasing emissions (on a g/kW-hr basis) in larger displacement engines will continue due to the favorable surface-to-volume ratios in larger engines. This is illustrated in the comparison of the new engine HC+NOx emissions of the two engines mentioned in the previous paragraph, in which the 25cc engine yielded 64-73 g/kW-hr in EPA testing (Ref. 7) and the 34cc engine was 47.3 g/kW-hr HC+NOx (SAE 980761). This is beneficial for application of this technology to Class V engines for the lower engine out emissions and the higher HC+NOx standard for Class V will likely require less of an engine enleanment and not require the use of catalysts, thereby removing any concerns for sufficient lubrication in high speed applications, such as chainsaws, and adding no cooling requirements for a catalyst.

The December 1998 article by Power Equipment Trade states that "Despite its closed ports and higher compression, the Air Head's extra-lean combustion makes it less potent than conventionally scavenged engines." Komatsu Zenoah states that the technology as currently developed results in a decrease in power of 7 percent.

3.2.2.4 Cost of Stratified Scavenging with Lean Combustion (With and Without Catalyst) – The December 1998 article by Power Equipment Trade states that "Red Max sets the price impact at about 3 percent." Discussion with a Red Max dealer in the Ann Arbor, MI area in January 2000 resulted in popular Class IV trimmer prices of $320 to $410 at the retail level. Using an average cost of $365, a three percent price impact results in an estimated increase of $10.95 at the retail level. Backing out retail markup (estimated to be 29 percent for this analysis) results in a manufacturer cost impact of $8.50. EPA expects engine families in Classes III and IV to require the use of a catalyst. The cost for a catalyst are estimated in Section 3.2.4.4. of this chapter. Equipment in Class V is typically more costly than those in Class IV and therefore, assuming the 3-percent cost impact applies, the cost will be slightly more than the $8.50 cost for Class IV noted above. EPA projects that catalysts will not be required for Class V engines.

Estimated costs for the stratified scavenged technology and improved two-stroke are included in the 1996 Cost Study for Phase 2 Small Engine Emission Regulations (Ref. 1.). However, a large number of components utilized in the Komatsu Zenoah design, particularly for lean combustion, are not included in the ICF cost estimate (the Komatsu Zenoah model was not available at the time of the cost study) and therefore the ICF costs are not used as the basis of this analysis.

3.2.2.5 Impact on Equipment Design -- Given the slight power loss, the engine size may need to be increased, depending on the manufacturer's equipment designs and power requirements. Space will also have to be made for the larger dual barrel carburetor. The Air-Head's extra-lean combustion likely requires additional engine cooling than is provided by current two-stroke engine designs. This can be achieved through additional engine fins and optimally designed thinner and wider engine fins. All of these factors could result in the need for a redesigned engine shroud. These costs are reflected in the cost estimates of Chapter 4.

3.2.2.6 Technology Impact on Noise, Safety, and Energy -- There are no known impacts of this technology on the factors of noise or safety. EPA projects a 30-percent reduction in fuel consumption based on the discussion contained in Section 3.2.3.1. Issues related to the use of catalysts are contained in section 3.2.4. on catalysts. While some manufacturers commented that the potential need to increase engine displacement would add size and weight which could compromise safety**,** we note that existing equipment covers a wide range of sizes and weights which have been accommodate without compromising safe operation; we anticipate that the same would occur for handheld equipment using stratified scavenging. We currently are unaware of any equipment using this technology which has compromised safety due to the weight of size of the engine compared to equipment using conventional 2-stroke engines.

3.2.3 Conversion of Handheld Two-stroke Designs to Four-stroke Designs

3.2.3.1 Description of Two-stroke and Four-stroke Technology -- Spark-ignited two-stroke technology has seen widespread use in the small engine market, particularly in handheld equipment applications (approximately 16cc-141cc). Four stroke engines have typically been limited to ground supported applications, such as lawnmowers and garden tractors (approximately 84cc-1395cc). The basic operating principle of the charge scavenged two-stroke engine (traditional two-stroke) is well understood; in two strokes the engine performs the operations of intake, compression, expansion and exhaust, which the four-stroke engine requires four strokes to accomplish. Two-stroke engines have several advantages over traditional four-stroke engines for use in handheld equipment: high power-to-weight ratios; multi-positional operation; and lower manufacturing costs. Additional information on the basic operation of two-stroke and four-stroke engines is widely available in the literature, including the references listed at the end of this chapter.(Ref. 1), (Ref. 2), (Ref. 3)

3.2.3.2 Current State of Four-stroke Handheld Engine Technology Development -- In recent years, the four stroke designs have drawn the interest of some handheld manufacturers due to the four-stroke's lower HC exhaust emissions and better fuel economy than two-stroke designs. At least three handheld engine/equipment manufacturers, Ryobi, Honda and Robin America, have designed and are manufacturing, or plan to manufacture, Class IV (20cc-50cc) overhead valve four-stroke powered equipment in the U.S. The major equipment using Class IV four-stroke engines are trimmers/edgers/cutters, pumps, generator sets and tillers[16]. In 1998, EPA observed the operation of a four-stroke engine in a chainsaw and believes that this will come to the marketplace for consumer use equipment in the near future.

The manufacturers of mini four stroke engines have made improvements over the initial “scaling down” of the four stroke engine, by Ryobi in 1994, and have gained ground in the power-to-weight ratio, multi-positional use and manufacturing cost benefits of two-stroke engines. However, the four stroke technology has not yet been demonstrated as able to cover the smallest (<20cc) or the highest range of two-stroke engine sizes (100cc+). Particular challenges include improving and continued downsizing of the technology to improve power-to-weight ratios and improvements in acceleration performance. We are optimistic that miniaturization of four-stroke technology can proceed directly from the most recent work done to miniaturize the Class IV engine. Particularly interesting are the newer mini four-stroke engines which are lighter in weight than the initial Ryobi engine design and can handle high speeds as has been shown to EPA in a Class IV four-stroke chainsaw application. The concern of acceleration in the larger engines may be addressed in the future by engine manufacturers.

3.2.3.3 Exhaust Emission Performance of Four-stroke Technology -- Prior to the introduction of the Ryobi four-stroke handheld engine in 1994, no handheld four-stroke engines existed, therefore, no exhaust emission data on uncontrolled engines is available. Federal 1998 Phase 1 certification data (new engine emissions) for the Ryobi 26.2cc four-stroke engine shows the new engine HC+NOx emission rate is 37.6 g/kW-hr. The most recent California ARB certification list for their in-use emission standards reveals that Ryobi has certified three 26.2cc engines as low as 11.1 g/hp-hr HC+NOx (14.8 g/kW-hr) at 50 hours and 15.8 g/hp-hr HC+NOx (21 g/kW-hr) at 300 hours, both of which are well below EPA’s Phase 2 standards. Honda has certified three four-stroke engines (22cc, 31cc and 49cc) at 31, 34.1 and 15.7 g/kWh respectively to EPA’s Phase 1 standards for HC+NOx. The California ARB certification list shows that the 31.1cc engine in-use emission result is 30.5 g/hp-hr (40.9 g/kW-hr) and the 49.4cc engine in-use emission result is 19.0 g/hp-hr (25.4 g/kW-hr), which are both below EPA’s Phase 2 standard. Both of these engine families were certified to 300 hours. No information is yet available for the 22cc Honda engine. Lastly, Fuji Robin has certified a 24.5cc four-stroke engine to California ARB standards and it is certified at 12.7 g/hp-hr (17 g/kW-hr). The range of equipment indicated by the engine manufacturers includes brushcutters, trimmers, generators, pumps and tillers.

The HC+NOx deterioration rates for the four-stroke engine designs listed in the California ARB certification database are listed for some manufacturers. Fuji Robin lists the HC+NOx deterioration rate at 1.089 (at 125 hours). Honda lists the deterioration rate at 1.427

[16] As indicated by the manufacturers in the Phase 1 certification database as of September 1998.

for the 49.4cc engine and 1.64 for the 31.1cc engine (both certified at 300 hours). Using the EPA Phase 1 new engine certification information and the ARB in-use certification information, the deterioration rate for the Ryobi 26.2cc engine is calculate to be 1.24 (at 50 hours). The deterioration factors of the mini four-stroke engines fall within the expected deterioration rates based on larger OHV engines in Class I and II (1.4 for OHV in Classes I and II) which are certified at 125 hours. The increased mechanical friction in the smaller engines and the less favorable surface-to-volume ratio in the combustion chamber contribute to the larger deterioration factors of smaller four-stroke engine designs.

3.2.3.4 Costs of Four-stroke Handheld Engine Technology -- The costs of converting handheld two-stroke to four-stroke technology was estimated by ICF in their 1996 report (see reference 1 to this Chapter). ICF included as part of their cost analysis a tear down and comparison of a Ryobi two-stroke engine and the Ryobi four-stroke handheld engine. ICF estimated costs for two annual production sizes, 90,000 and 400,000 units per year, which they estimated as typical for the handheld industry. Ryobi provided its own cost estimates in response to the SNPRM (Docket Item IV-D-47). Table 3-01 summarizes the cost information developed by ICF and compares it with the very similar estimates from Ryobi. Echo, another small SI engine manufacturer, also provided an estimate of the cost of converting to four-stroke technology of $10.00 in discussions with EPA. (Docket Item IV-E-79).

Table 3-01
Summary of per Engine Cost for Conversion of Handheld Two-stroke Technology to Four-stroke Technology (data from ICF, 1996 and Ryobi)

Cost Item	Engine Family Annual Production = 90,000	Engine Family Annual Production = 400,000
Additional Parts Estimate	$8.88	$8.88
Additional Labor + Overhead	$1.05	$1.05
Fixed Costs	$4.09	$1.73
Total	$14.02	$11.66
Ryobi Estimate	$15.00 (less than 1 million)	$10.00 (1 million or more)

It should be noted that, while ICF utilized 90,000 and 400,000 as representative engine family productions in their 1996 study, production estimates contained in EPA's 1998 Phase 1 certification database shows that 88 percent of the 183 engine families (Classes III through V) have productions under 67,000 (mean=5,200), only 8 percent have productions near 90,000 and only 4 percent of the engine families have productions above 190,000. As stated in the report by

ICF (ICF, 1996), ICF "anticipate(s) that the small engine manufacturer may make certain decisions to reduce the costs of this conversion, such as purchasing the four-stroke engines from a larger handheld engine manufacturer. On balance between savings both capital and engineering labor and the need to purchase the engines, the small manufacturers may realize a modest savings over manufacturing the engines themselves." EPA is extending this assumption to small-volume engine families produced by larger manufacturers. EPA therefore expects most engine manufacturers with smaller engine families to choose another technology due to the cost-effectiveness of this option[17].

3.2.3.5 Impact on Equipment Design from Use of Four-stroke Handheld Engine Technology -- The conversion of two-stroke to four-stroke technology may likely have some impact on the design of handheld equipment. Impacts of the new four-stroke designs include the redesign of the shroud design around the engine, replacement of the fuel/oil tanks and air cleaner as well as potentially lower power-to-weight ratios in some engine sizes.

The lower power-to-weight ratios would likely not be noticeable to consumers using applications such as lower power residential string trimmers, brush cutters, edgers, blowers, portable generators, and portable pumps. The Agency has heard from handheld engine manufacturers that for engines in the fractional to approximately 1.5kW range, residential users typically do not use the full power rating of the engines to perform the intended work. Therefore, the Agency believes four-stroke designs could be competitive from a performance perspective with two-stroke designs in this power range.

However, in larger displacement, higher power engines, the potential power-to-weight disadvantage of the four-stroke engine could become noticeable, and, if so, could impact the user through fatigue from the added weight of the engine, thus potentially limiting the functionality of the equipment. The high powered commercial chainsaws in the Class V category (displacement >50cc) are typically designed for maximum power per cubic centimeter of displacement. In these categories, the four-stroke engine could present a performance problem for users. Two handheld manufacturers have specifically commented that acceleration of the four-stroke engine is a concern in larger engines; both of these companies have either produced or examined the possibility of producing four-stroke engine use.

One benefit of the traditional four stroke engine design is that the consumers would no longer need to pre-mix fuel with two-stroke oil. However, consumers would need to maintain crankcase oil levels at an acceptable level, and perform periodic oil changes. The cost impact of 4-stroke oil use (and maintenance) compared to 2-stroke engines we anticipate will be available

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[17] Manufacturers might choose to manufacturer four-stroke engines if their engine families have many similar components and total a significant number of sales to make four stroke production cost-effective.

is negligible.

3.2.3.6 Impact on Noise, Safety, and Energy of Two-stroke to Four-stroke Conversion -- The Agency expects the conversion of two-stroke to four-stroke designs would lower the noise levels from handheld equipment. Two-stroke designs are well known for their relatively high noise levels as compared to four-stroke engines. A large source of noise from two-stroke designs comes from pressure pulses generated by the exhaust gas at the exhaust port. These pressure pulses tend to be higher in a two-stroke design compared to four-stroke engines because the two-stroke engine requires the higher cylinder pressure to begin the blow-down process (see Chapter 2 “Engine Fundamentals”, Patterson, 1972, Ref. 15 to this Chapter).

The Agency would expect no adverse change in the safety of handheld equipment from the conversion of two-stroke to four-stroke designs. As discussed previously, the overall design and use of handheld equipment would not change from the conversion to four-stroke engines, so no change is expected with regards to safety. In addition, the Ryobi 4-stoke handheld equipment has been available for several years, and the Agency is not aware of any safety problems which have occurred from this equipment which can be attributed to the engine type. One area of potential concern is with the increased weight of this four-stroke engine design and extended user use of the product. However, recent four-stroke engine designs, for the Class IV trimmer market in which they have been used, have been advertised at weights comparable to their two-stroke counterparts. No catalysts are needed on 4-stroke engines to comply with the Phase 2 standards, so catalyst shielding and elevated exhaust temperatures are not a concern.

However, most, if not all, handheld four-stroke engines have not been extended into Class V in the marketplace. The power-to-weight ratio and acceleration of a four-stroke engine in Class V has been raised as a concern by engine manufacturers that manufacture four-stroke engines. This area raises the only potential safety concerns that may need to be considered in the application of this technology.

The Agency would expect significant improvements in the fuel economy from the conversion of two-stroke to four-stroke designs. The loss of fuel from the scavenging process for two-stroke engines results in poor fuel economy which the four-stroke design does not experience. Compared to a typical Phase 1 technology two-stroke engine, the four-stroke engine is expected to achieve about a 30 percent improvement in fuel economy based on information supplied by Ryobi).

3.2.4 Application of Catalytic Convertors to Handheld Engines

3.2.4.1 Description of Catalyst Technology -- Catalytic convertors are add-on devices used to lower exhaust emissions from engines after they exit the combustion chamber. Typically, a catalyst consists of a ceramic or metallic support (often called the substrate), that is coated with a wash-coat which contains catalytic material (typically a rare-earth element such as platinum, rhodium and/or palladium). The catalytic material initiates a chemical reaction which can, depending on the catalyst material chosen, oxidize hydrocarbons and carbon monoxide, and/or reduce oxides of nitrogen.

Additional information regarding the fundamentals of catalytic convertors, and information specific to catalyst and small engines can be found in "Report - Exhaust Systems Subgroup of the Technology Task Group", a report published by a task group established during the Regulatory Negotiation for Small Engine Phase 2 Rulemaking.(Ref. 4)

3.2.4.2 Current State of Catalyst Technology Development -- Historical data indicate that catalysts have seen limited use on small engines in the U.S. Prior to EPA or California ARB small engine regulations, catalysts were used in limited numbers, on some types of indoor equipment such as indoor propane fueled floor buffers (also called floor burnishers), but no handheld applications utilized catalyst technology[18].

Today, Husqvarna has certified several engine families using two-stroke technology with a low-efficiency catalyst[19]. These Husqvarna families have been developed for string trimmer/brush cutter applications and are currently being sold in the U.S. and Europe. The catalyst technology on these engines is of a unique flat plate design rather than the honeycomb design used in automobiles. The catalyst was added to the engine only after emission reduction improvements were made to the engine. Emissions had to be reduced from the engine such that the catalyst conversion efficiency could be sufficient to reduce emissions notably and also remain below the temperature limit requirements set by the U.S. Forest Service, as will be discussed later in this section. The engine went under a number of design changes as is described in MECA's NPRM comments to the docket(Ref. 5) "First, Husqvarna reduced the crankcase volume which increased crankcase pressure. The increased crankcase pressure, combined with the higher back pressure in the muffler, made it possible to optimize the intake cycle and fuel retention. Second, the carburetor was equipped with adjustment caps to prevent it from being set too rich. Third, the remaining unburned fuel and other gas components were converted by a lightweight catalytic converter (10 grams). The standard metal baffle in the muffler was replaced with a special metal plate treated with a catalytic coating. The converter has low mass which

[18] Chainsaws with catalytic converters have been sold in Europe; however, these models have not been sold in the U.S. and, according to their manufacturer, currently do not meet the U.S. Forest Service temperature limits.

[19] As MECA's comments to the NPRM in March 1998 indicates, "For handheld engines, the types of engine design changes needed to allow a catalyst to achieve 30 to 50 percent efficiency at the end of the engine's useful life are well illustrated by the design changes made by Husqvarna." The exact conversion efficiency of the Husqvarna catalysts are not readily known.

ensures lower heat retention than earlier versions. Finally, the muffler contour was redesigned such that cooling air flow was optimized to minimize surface temperatures." However, based on the certification levels of Husqvarna's currently certified engines equipped with catalysts as presented in Table 3-03 (which range from 155 g/kW-hr to 184 g/kW-hr HC+NOx on a new engine), it can be seen that more internal improvements are needed to meet EPA's finalized Phase 2 standards. A letter from MECA to EPA on October 19, 1998 states that there are an estimated 300,000 Husqvarna catalyst-equipped two-stroke engines in equipment for sale in the US and Europe.

3.2.4.3 Exhaust Emission Performance of Catalysts -- Several sources of information exist on this topic. They include the report entitled "Report - Exhaust Systems Subgroup of the Technology Task Group" (Ref. 10), data from catalysts used on Husqvarna engines that are sold in the marketplace(Ref. 6), EPA test data on Phase 2 engine technologies (Ref. 7) and the most recent California ARB certification data (Ref. 8).

The Exhaust Systems Subgroup of the Technology Task Group Report contains a summary of new engine data on the HC and NOx reduction potential from the application of traditional honeycomb catalysts to two-stroke and four-stroke small engines, see Table 3-02. The majority of these engines were uncontrolled or Phase 1 technology gasoline engines with a prototype catalyst added on.

Table 3-02
Observations of Emission Changes with Catalysts
(Exhaust Systems Subgroup of the Technology Task Group Report)

Engine Design	HC	Class IV Engine Emission Range for HC (g/kW-hr)*	NOx	Class IV Engine Emission Range for NOx (g/kW-hr)*
Four-stroke	40-80% dec	range: 15.7-37.6 avg: 29.6	20-80% dec 25-50% inc	range: 0.7-2.7 avg: 1.7
Two-stroke	20-80% dec	range: 96.7-235 avg: 181	10-20% dec up to 40% inc	range: 0.3-3.1 avg: 0.94

* - Emission data is from EPA's Phase 1 certification database as of September 1998 and not the Exhaust Systems Subgroup Report

Husqvarna is the first manufacturer to show the feasibility of catalyst use on handheld equipment in the US marketplace[20]. Husqvarna has certified several engine families under EPA's Phase 1 program which utilize a low efficiency flat plate catalyst on two-stroke engines. The engine has incorporated at least one internal engine improvement in addition to use of a catalyst. The information in Table 3-03 is from the EPA Phase 1 certification database and is from the rich setting of the carburetor.

Table 3-03
New Husqvarna Phase 1 Certification Engines
With Catalysts Class IV Trimmer/Edgers (g/kW-hr)

Engine Family	Power	Displacement	HC	CO	NOx
XHVXS.0254EB	0.86kW	24.5cc	181.9	622.3	0.3
XHVXS 0274 EA	0.9kW	25.4cc	183.9	663.1	0.2
XHVXS.0314EA	1.07kW	30.8cc	157.0	551.2	0.2
XHVXS.0364EA	1.31kW	36.3cc	154.5	595.8	0.3

During the summer of 1999, EPA tested the John Deere LE engine and the Komatsu Zenoah stratified scavenged with lean combustion engine with and without catalysts (Ref. 7). John Deere provided one catalyst for testing and three catalysts provided by a major catalyst manufacturer were tested on the Komatsu Zenoah engine. Optimization of the catalyst conversion efficiency and heat management were not of concern in this testing. The emission results are summarized below. Note that additional repeat tests were not included.

[20] Several catalyst-equipped chainsaws are sold in the European marketplace, since Europe has no temperature restrictions due to use of the professional equipment in winter weather and conditions that are not representative of those in the U.S.

Table 3-04
EPA Emission Testing of John Deere's Compression Wave
With and Without a Catalyst (g/kW-hr)
Tests 99-8695 to 99-8700 (Ref. 7)

Tests	HC	NOx	CO
Baseline engine (w/o Catalyst) results (average of 2 tests)	50.5	1.26	124
With Catalyst - Engine on Lean Setting (average of 2 tests)	20.6	1.75	40
With Catalyst - Engine on Rich Setting (1 test)	19.5	1.07	95
% Decrease with Catalyst (lean/rich)	59.2/ 61.4	-39/15.1	67.7/23.4

Table 3-05
EPA Emission Testing of Komatsu Zenoah's Stratified Scavenged with
Lean Combustion With and Without Catalysts (g/kW-hr)
Tests 99-8673 to 99-8680 (Ref. 7)

Tests	HC	NOx	CO
Baseline engine (w/o Catalyst) results (average of 2 tests)	71.2	1.29	221
With Catalyst SU00895 (average of 3 tests)	39.07	0.947	116.3
% Decrease with Catalyst SU00895	45.1%	26.6%	47.4%
Baseline engine (w/o catalyst) results	68.3	1.28	201
With Catalyst SU00908 (average of 3 tests)	38.5	0.62	113
With Catalyst SU00910 (average of 3 tests)	27.9	0.61	95
% Decrease with Catalyst SU00908	43.6%	51.4%	43.8%
% Decrease with Catalyst SU00910	59.2%	52.2%	52.7%

The California ARB certification data as of January 12, 2000 contained information on several engines with catalysts. In addition, it contained information on a Stihl 27.2cc engine which was certified with and without a catalyst, both at 50 hours. The HC+NOx emissions from the engine without a catalyst were 102 g/hp-hr (137 g/kW-hr). The HC+NOx emissions from the engine with a catalyst were 42.5 g/hp-hr (57 g/kW-hr). Based on these results, the catalyst efficiency with respect to HC+NOx emissions is calculated to be 58 percent. The deterioration factor for the engines indicated in the California ARB certification is 1.0, both with and without the catalyst. Other certification engines with catalysts have indicated HC+NOx deterioration factors ranging from 1.0 to 1.281 at certification useful lives up to 300 hours.

Additional catalyst deterioration is available from MECA's letter of October 19, 1998. The data shows results of one two-stroke Husqvarna trimmer with a catalytic converter plate with an acoustic muffler after 300 hours. Results are an HC deterioration factor of 1.40[21] (Ref. 6). As noted in the previous paragraph, engine manufacturers have not claimed such high deterioration. Deterioration of catalyst efficiency is caused from several mechanisms, including the physical deterioration of the substrate from mechanical shock, vibration, and extreme temperatures, and the deactivation of the catalyst material from chemical poisoning (such as sulfur). Catalysts on Phase 2 technology engines, such as four-stroke, stratified scavenged with lean combustion or compression wave technologies, are anticipated to experience less deterioration due to the fact that there is significantly less unburned fuel and oil flowing through the exhaust pipe, and therefore through the catalyst. Lower engine out emissions should result in less catalyst deterioration as well.

The limiting factor for achieving the maximum conversion efficiency will be the ability of the engine manufacturer to manage the heat generated by the catalyst such that the certain measurement points relating to the application meet the temperature limits set by the U.S. Forest Service[22]. Testing of the redesigned Tanaka 39.8cc two-stroke engine with a catalyst (used in a trimmer) by EPA in the summer of 1999 (Ref. 7), showed that the catalyst (and presence of such) resulted in a conversion of 67 g/hr HC. Based on the California ARB certification data of 45.11 g/hp-hr (60.5 g/kW-hr) for this 1.6 hp (2.14 kW) engine, comparison of 67 g/hr reveals this is a medium-high conversion catalyst. Temperature measurements on the equipment (Ref. 7) reveal that it is slightly below the exhaust gas plane temperature requirement of the U.S. Forest Service. It is also likely below the exposed surface plane temperature specified by U.S. Forest Service. Only the muffler skin surface temperature was obtained, but EPA believes this will

[21] Engine manufacturers who have worked with catalysts have indicated that catalysts are more emission durable in-use than indicated here.

[22] As of May 1999 it is known that industry has visited the U.S. Forest Service to discuss with them the applicability of the temperature limits to an engine with a catalyst (it is understood that the limits were set on an engine without a catalyst). The manufacturers are planning to conduct testing to verify if there are any specific concerns of temperatures on engines with catalysts that are not currently covered by the U.S. Forest Service requirements.

meet the temperature requirements because of the large distance between the muffler skin and the exposed surface plane. For application of this engine in a trimmer, Tanaka has designed the equipment shroud a significant distance away from the muffler and has also placed the muffler outlet at the top of the muffler which is also some distance away from the shroud outlet. The shroud is also designed to allow maximum cooling from the environment due to the large mesh like design of the shroud around the muffler. Techniques such as pulling cooling air into a passage at the exit of the muffler and adding additional shrouding around the muffler are additional ways to allow the use of higher efficiency catalysts.

However, the amount of heat that must be dealt with in handheld applications is dependent on size, application, ability to reduce the engine out emissions and ability of the engine to handle additional heat. Relating to size, if the exhaust pollutants, in g/kW-hr, were the same on varying size engines (20 to 90cc for example), the larger size engines (higher kW) would generate a higher amount of heat due to the amount of exhaust flow from the engine which must be converted by the catalyst. Therefore, in order to reduce the heat from the catalyst, the catalyst's percentage conversion efficiency must be reduced or the amount of unburned HC and CO coming out from the engine needs to be reduced. The ability to reduce engine out emissions is the major factor in the percentage efficiency catalyst that can be used on an engine. Favorably, the larger the engine, the easier it is to lower the emission rate per amount of work (i.e., g/kW-hr) tending to offset at least part of the exhaust mass flow rate (i.e, g/hr) with larger engines. An engine that is of four-stroke design or incorporates some form of stratified scavenging with lean combustion and related internal engine improvements, will also have lower engine out emissions than Phase 1 engine designs. The catalysts can then achieve higher efficiency conversion for they are converting a reasonable amount of pollutants in the exhaust stream, and thereby the heat produced is manageable.

Lastly, relating to the ability of the engine to handle additional heat, Phase 2 engines will have significantly less fuel cooling (due to enleanment or changes in fuel/oil flow inside the engine) than current Phase 1 designs and therefore will depend more on air cooling. To the extent that the forced air cooling (e.g., via a fan design) passes over the engine fins for engine cooling, less cooling capacity may be available for the muffler as well. In addition, the engine with a catalyst will be exposed to some heat from the catalyst. Thus, cooling redesign will need to consider extra cooling due to higher engine combustion temperatures, potential for heat transfer to the engine from a close-coupled catalyst and finally the cooling of the exhaust system. To EPA's knowledge, manufacturers of low emitting two-stroke engine designs with enleanment, such as compression wave technology by John Deere or stratified scavenged with lean combustion by Komatsu Zenoah, have not fully addressed issues relating to application of catalysts to these designs which are currently being certified with the California ARB without catalysts. It has been indicated by one manufacturer that engine redesign will be necessary to minimize and accommodate the heat that is created by the use of a catalyst. For those engines being certified to California ARB standards with a catalyst, some potential additional cooling design might be necessary if engines run leaner to meet EPA's Phase 2 standards. This phenomenon will have to be examined on a per engine family basis. Relating to application, blowers have much more cooling air available to them than other applications and therefore can handle a higher temperature catalyst.

For the standards being finalized, EPA assumes that a medium to a medium-high efficiency catalyst will be used on the majority of engines in Classes III and for a portion of the engines in Class IV, since the standards presently cannot be met solely with the technologies of compression wave or stratified scavenged with lean combustion technologies. Engines with the four-stroke engine technology need not employ a catalyst. Engines in Class V will be able to meet the finalized standards using the engine technologies noted previously, and therefore not employ a catalyst.

3.2.4.4 Costs of Catalysts -- Costs are available from three sources and include (1) the ICF 1996 report (see reference 1 to this Chapter - the costs of applying a catalyst to a two-stroke engine were estimated), (2) MECA's comments submitted in the response to the January NPRM, and (3) Echo's comments to the SNPRM (Docket Item IV-D-37).

The 1996 ICF report presented costs on application of a catalyst only to four-stroke engines. The Agency estimates the costs of applying a catalyst to a four-stroke engine would be similar, particularly for the engineering research and development work. ICF's analysis considered the costs for both a metallic honeycomb substrate and for a ceramic honeycomb substrate, with the estimated cost of a metallic substrate being higher. (The catalyst used on the Husqvarna E-TECH engines discussed earlier, is a metal plate catalyst, which is simpler and less expensive than a metallic honeycomb catalyst.) Table 3-06 is a summary of the cost information contained in the 1996 ICF report for application of catalysts to two-stroke engines.

Table 3-06
Summary of per Engine Cost for Application of a Catalyst
to a Handheld Two-stroke Engine (data from ICF, 1996)

Cost Item	Engine Family Annual Production = 90,000, ceramic honeycomb substrate	Engine Family Annual Production = 90,000, metallic honeycomb substrate	Engine Family Annual Production =400,000, ceramic honeycomb substrate	Engine Family Annual Production =400,000, metallic honeycomb substrate
Catalyst	$4.00	$8.00	$4.00	$8.00
Catalyst Assembly Labor	$0.58	$0.58	$0.58	$0.58
Catalyst Fixed Cost	$1.20	$1.20	$0.30	$0.30
Muffler/ Heat Shield Hardware Cost	$0.90	$0.90	$0.90	$0.90
Muffler/ Heat Shield Fixed Costs	$0.98	$0.98	$0.24	$0.24
Total	$7.66	$11.66	$6.02	$10.02

MECA provided NPRM comments on the cost of catalysts (Docket Item IV-D-13), of several conversion efficiencies, for Class IV. Table 3-07 presents a summary of the data supplied by MECA. MECA states that the costs may decrease over time if catalyst technology is encouraged to develop. MECA's cost estimates do not include a number of costs including other costs of the catalyst system (as shown in Table 3-06), the production steps to install the catalyst, or related components on the engine.

Table 3-07
Summary of MECA per Engine Cost Estimate for Catalyst of Specific HC+NOx Conversion Efficiency per Class

Units of Production	Class IV 1.0hp 2s cat eff 40%->20%* Engine new 172g/kW-hr	Class IV 1.0hp 2s cat eff 60%->30% Engine new 172g/kW-hr	Class IV/V 1.7hp 2s cat eff 40%->20% Engine new 172g/kW-hr	Class IV/V 1.7hp 2s cat eff 60%->30% Engine new 172g/kW-hr	Class IV 0.85hp 4s cat eff 40%->20% Engine new 54 g/kW-hr
5,000	--	--	$6.28	$6.83	--
10,000	$6.25	$6.33	--	--	$4.72
several million	$4.13	$3.50	$4.03	$3.83	$3.05

* - Note: the range of efficiency represents catalyst new and catalyst used

Combining the catalyst cost from Table 3-07 and the labor, fixed and hardware costs from Table 3-06, the cost of adding a ceramic honeycomb substrate catalyst to an engine could range from $5.52 (industry wide, several million units) to $8.35 (5,000 to 10,000 units for one catalyst manufacturer)[23] depending on the conversion efficiency of the catalyst, engine out emissions and volume of industry usage. Echo provided comments in their response to the SNPRM (Docket Item IV-D-37) that their estimate for the cost of a catalyst system including the holder, shrouding and cooling requirements is approximately $15.00. (For a discussion of the catalyst cost assumptions for the final rule cost analysis, see Chapter 4.)

The costs shown in Tables 3-06 and 3-07 account only for the cost of adding a catalyst to a Phase 1 technology two-stroke engine, not for internal improvements that are necessary to the engine. Internal engine improvements are necessary in order to lower engine out emissions and increase engine out in-use durability prior to the application of a catalyst. Total costs for various technologies to employ a catalyst are discussed in three respective sections (Sections 3.2.1.4, 3.2.2.4 and 3.2.3.4).

3.2.4.5 Impact on Equipment Design and Use of Catalyst -- Conversion of pollutants by catalysts contained within the muffler result in increased exhaust gas and muffler skin

[23] MECA provided the estimate of several million based on the concept that it was an industry-wide market, not engine family specific. The cost estimate for 5,000 and 10,000 is based on engine family annual volume. EPA is assuming that this can also be interpreted to mean that 5,000 or 10,000 is the only volume that the catalyst manufacturer sees from the industry.

temperatures. The amount of improvements needed by the equipment will be governed by the degree of cooling required by the engine with the new technologies, specifically catalysts. The following paragraphs describe the test data on catalyst temperatures on Phase 2 technology engines and then describe the likely impact on equipment.

Test data on temperature measurements with and without catalysts were collected by EPA in its testing of the John Deere LE engine and the Komatsu Zenoah stratified scavenged with lean combustion engine with and without a catalyst. Both the John Deere engine and the Komatsu Zenoah engine tested by EPA were prototypes of the designs currently certified by the manufacturers with the California ARB for the 2000 model year. Therefore, the absolute temperature results are not necessarily indicative of the currently certified engines. However, the effect of the catalyst on temperatures is useful information, especially if a base equipment design (i.e., the equipment without a catalyst) is close the U.S. Forest Service temperature requirements. Testing included temperature measurements to determine the amount of temperature increase with an associated catalyst conversion efficiency specific to these engine technologies. The following results are taken from Reference 7. It should be noted that while EPA did attempt to test according to the U.S. Forest Service test requirements, the EPA laboratory where the testing was performed is not officially licensed to do this test and it was the first time that these tests were conducted at the laboratory, and they are therefore considered preliminary. In addition, in many cases, it was discovered that the muffler skin temperatures were taken in error when it was to be the exposed surface plane temperature as outlined in the test guidelines. However, the increase in temperatures, between catalyst and non catalyst use is still noteworthy.

The prototype John Deere LE engine was tested without and with a catalyst. The catalyst used in the testing was one which was provided by John Deere and contained a long tube attached to the muffler outlet. Therefore, exact exhaust temperatures are not available for comparison. In testing, the plane for the exhaust gas temperature on the baseline muffler was approximately 3/4 of an inch away from the exhaust muffler outlet. The exhaust gas temperature on the catalyzed muffler was measured 3/4 of an inch from the opening of the tube, which was 2.16 inches long from the muffler surface. These temperatures are not taken in the same respective place and therefore cannot be directly compared. The shroud had also been removed during previous tests in the EPA test program. The results of the testing show that the cylinder temperature rose approximately 10° C with the use of the catalyst, the muffler skin temperature rose approximately 20° C with the use of the catalyst, and the exhaust gas temperature rose approximately 147° C. (As noted above, the exhaust gas temperature measurement placement was not at the same location in the base engine and the catalyzed engine tests.)

Temperature measurements for the Komatsu Zenoah Air Head Engine were also obtained during the EPA test program both on the base engine and the engine equipped with three different catalysts. The thermocouple placement for the exposed surface plane was not correct for the test and therefore no exposed surface plane temperature data is available. However, exhaust gas plane temperature and muffler skin temperature data were gathered. Complete results of the testing are available in the final test report.(Ref. 7) For the engine tested with the first catalyst (catalyst SU00895), the test results show an increase in engine cylinder temperature of 17-25° C due to the catalyst, an increase in exhaust gas temperature of 67-115° C due to the catalyst, and an increase in muffler skin temperature of 14-50° C due to the catalyst. For the engine tested with the second catalyst (catalyst SU00908), the test results show an increase in engine cylinder temperature of 7-9° C due to the catalyst, an increase in exhaust gas temperature of 85-100° C due to the catalyst, and an increase in muffler skin temperature of 66-97° C due to the catalyst. (Data for an additional catalyst are not presented here due to concern over the validity of the test data..)

A 40cc Tanaka engine, which incorporated internal engine redesign and a catalyst, was also tested by EPA in the summer of 1999 (Ref. 7.) and the outer design of the muffler and engine shroud was noted. The design was found to incorporate several unique changes when compared to other conventional engine designs. First, the muffler exhaust is on top of the muffler and points to the side of the engine housing. Second, the engine housing shroud exhaust area is placed on the side of the muffler housing some distance away from the muffler exit. Third, the engine's plastic shroud incorporates wide open slots around the muffler. These changes are possible on equipment such as trimmers and blowers, which allow for extra room around the muffler and whose engine shroud need be designed to keep a relatively small amount of debris away from the muffler. However, the application of all of these changes will likely require adjustment when an engine manufacturer is addressing a chainsaw.

Applications with less available space for extension may incorporate internal design changes to the mufflers. Internal redesign may include passages for additional air flow to the exhaust gas stream in order to decrease the exhaust gas temperature. This may be done through changes in the internal design of the muffler and/or the addition of an outer skin to the muffler which would make the muffler larger than its current size and therefore require engine shroud redesign. The shroud around the muffler may need to be extended in order to provide room for the addition of heat shielding or other safety shields to protect the engine and the user from excessive muffler skin temperature.

Extra cooling will likely be required by the engine as well to assure it does not seize due to less fuel cooling and presence of an additional potential heat source (a closely coupled catalyst). This may require a larger engine fan and redesigned engine fins which may require expansions in the engine shroud design. The path of air cooling may also need to be designed in the engine shroud.

The addition of a catalyst would also add weight to the engine, however, the added weight would likely be negligible compared to the dry weight of the engine and equipment. For a metal plate design, such as that used by Husqvarna, the catalyzed plate replaces an existing baffle plate in the muffler so weight would not be increase appreciably. For an add-on to a muffler, the weight of the catalyst and housing will depend on the size of the catalyst. EPA estimates this weight to be 50 grams or less. This compares to the weight of handheld equipment that currently is in the range of 5 to 25 pounds. Changes to shrouding should, for the most part, involve changes in configuration, not changes in the mass of the shrouding.

3.2.4.6 Catalyst Technology Impact on Noise, Safety, and Energy -- The Agency would expect little impact on engine noise from the application of catalysts to small engines. If any impact on noise did occur, it is likely the catalyst plus a redesigned muffler would act to lower the noise generated by an engine, since the catalyst would absorb and not generate sound.

Engine manufacturers have raised concerns regarding the safety of catalysts on small engines. The principal concerns relate to increases in muffler skin temperature and exhaust gas temperature from the use of a catalyst. Title 36 CFR 261.52 directs the Forest Service to prohibit the operation or use of “any internal or external combustion engine without a spark arresting device properly installed, maintained and in effective working order meeting either :(1) Department of Agriculture, Forest Service Standard 5100-a; or (2) appropriate Society of Automotive Engineers (SAE) recommended practice J335 and J335(a).” SAE J335 contains instructions for determining planes at which to measure exhaust gas and surface temperatures and states recommended performance levels (i.e.: temperatures) which should not be exceeded. In order to continue to meet the requirements of the J335, manufacturers may need to limit the conversion efficiency of the catalyst in order to maintain a comfortable margin of safety below the requirements, and/or redesign the muffler system to enhance the heat shielding of the muffler. Echo responded to the SNPRM (IV-D-37) that “ burning more than 15 grams of THC may cause heat and safety concerns. Handheld equipment is operated and controlled by the operator. As such, it comes in very close proximity to the operator’s hands, arms, face and body. Heat dissipation to prevent operator injury is a primary concern.”

Currently, Husqvarna has four engine families certified to EPA’s Phase 1 standards which utilize a low efficiency catalyst and continue to meet all applicable U.S. Forest Service requirements (see Table 3-08). In addition, Stihl, Echo, and Mitsubishi have all certified handheld engines meeting the California ARB’s 72 g/kW-hr HC+NOx standard for the 2000 model year that also employ catalysts. Thus, it is proven that at least for designs meeting the California HC+NOx standard of 72 g/kW-hr, adequate control of catalyst safety concerns is available. As long as similar efficiency catalysts are used to meet the standard, given sufficient engine cooling is available, then it is assumed there will be little if any problems with catalyst feasibility. However, higher conversion efficiencies and increased cooling needs by the engine may raise concerns.

To meet the more stringent EPA Phase 2 standards, for Class III and IV engines, either a higher conversion efficiency catalyst or lower engine out emissions will be required. Higher conversion efficiency catalysts are available, however, their use will result in higher exhaust temperatures if no other changes are made to the engine or the equipment. EPA has already identified several technologies which will lower the engine-out emissions including compression wave and stratified scavenging two-stroke technologies and four-stroke designs as an alternative to the two-stroke engine. Clearly, the compression wave and four-stroke technologies can meet the California ARB's 72 g/kW-hr HC+NOx standard without catalysts as they have already demonstrated this through certification. Four-stroke engines will not need to use catalysts to meet the EPA Phase 2 standards. Two-strokes with compression wave or stratified scavenging technology are assumed to use catalysts for Class III engines. For Class IV engines, John Deere has estimated that less than 50% of their applications will require the addition of catalysts. For these Class III and IV engines requiring catalysts, with compression wave technology, the amount of exhaust gas conversion should be no greater than that already occurring on engines using other engine technologies plus a catalyst to meet the California ARB standards. Thus, the same heat mitigation measures should be available: engines using compression wave and a catalyst to meet EPA's Phase 2 standards can also incorporate cooling, shrouding, etc. and meet the U.S. Forest Service requirements.

For engine designs currently meeting the California ARB HC+NOx standard of 72 g/kW-hr but with a catalyst, additional cooling and shrouding is available to handle the extra heat generated by a high conversion efficiency catalyst installed to meet the more stringent EPA Phase 2 standards. This additional cooling and/or shrouding is especially available for applications such as string trimmers and blowers. Such applications should be able to be redesigned to provide all the necessary extra cooling and shrouding necessary to meet the U.S. Forest Service requirements and adequately protect the operator.

The most difficult applications are the chainsaws and similar applications where packaging constraints are most significant. For Class IV chainsaws it is possible to improve air flow, increase engine fin area, and reconfigure the shroud without significantly affecting weight or other ergonomic features. These changes will suffice to handle the excess heat due to the use of a catalyst (or a higher efficiency catalyst compared to a design meeting the less stringent California ARB standards.) Alternatively, the manufacturer may take advantage of the averaging program and install catalysts on their "easier" designs (e.g., string trimmers and blowers), and generate excess credits to offset higher emission on the "more difficult" designs (e.g., chainsaws), obviating the need to redesign the equipment in response to these potential heat concerns. Finally, the manufacturer may choose to go to an alternative engine technology than currently being used to meet the California ARB's HC+NOx standard of 72 g/kW-hr in order to achieve lower engine out emission levels, thus addressing this catalyst heat concern.

In conclusion, the engine and equipment manufacturer must carefully consider the cooling and safety implications of catalyst installation and reflect this in its design strategy for the engine and equipment. Several options are available including the application of those design features already incorporated on handheld equipment which have designed for safe operator use and in compliance with the U.S. Forest Service requirements.

The addition of a catalyst would have no significant impact on the energy consumption of an engine. Catalysts are add-on devices which would have minimal, if any, impact on the engine's air/fuel ratio or power output, and therefore no change in fuel consumption is anticipated. Other changes to the engine, made in order to reduce emissions to more easily utilize a catalyst, would be credited with fuel consumption savings.

3.2.5 Internal Two-stroke Engine Redesign With a Catalyst

As noted in section 3.2.4., some technologies have been developed to meet a standard of 54 g/hp-hr (72 g/kW-hr) as required by the California ARB. Improvements in internal two-stroke engine design (transfer ports, piston, combustion chamber, etc.) and the addition of a catalyst will allow low emissions such as the 72 g/kW-hr HC+NOx level to be achieved on some engine sizes and applications. The amount of emission reduction achievable with this technology package will largely depend on the level of emissions exiting the engine prior to the catalyst. The level to which emissions can be reduced with engine improvements determines the percentage conversion efficiency catalyst that can be used on the engine. The catalyst conversion efficiency is limited by the heat produced, by oxidation of pollutants, such that temperatures in predefined planes are in accordance with the U.S. Forest Service temperature requirements and other company specific safety requirements.

3.2.5.1 Description of Technology -- The simply designed two-stroke engine has room for improvement when it comes to emission reduction. Internal design changes will improve emissions characteristics. As listed in the Stratified scavenging with lean combustion section on Komatsu Zenoah, changes include the following:

1. Higher compression by reducing crankcase volume
2. Change combustion chamber geography. (E.g., slightly dome the piston to mate with hemispherical combustion chamber and is fit it with two compression rings)
3. Move spark plug to a straight up, dead center location to maximize combustion dynamics.
4. Alter timing and spark energy

Other internal engine improvements include design improvements in the engine transfer ports. The use of a catalyst provides additional emission reduction.

3.2.5.2 Current State of Technology Development --

3.2.5.2.1 Husqvarna E-TECH Engine -- The E-TECH engine is an engine equipped with a new type of crankshaft enclosure which gives increased crankcase pressure. The higher crankcase pressure and higher pressure in the exhaust system gives the E-TECH engine unique possibilities for lower emissions and a high level of performance. The E-TECH engine is equipped with a new type of lightweight catalytic converter for handheld products. The entire catalytic converter installation gives a weight increase of only 10 grams. The E-TECH design reduces both hydrocarbon and nitrogen oxide emissions.

3.2.5.2.2 Tanaka Stratified Charge Engine With Catalyst -- An in-depth description of the Tanaka technology has been published in Power Equipment Trade July/August 1998. Excerpts from the article are included below. The article states that "Tanaka's PureFire technology cuts scavenging losses by changing and better controlling air/fuel from crankcase to combustion chamber."

1. "The air/fuel charge enters the crankcase like any piston ported two-stroke -- through the cylinder intake port as the piston goes up. As the piston comes down, the air/fuel mixture is compressed as usual. However, instead of squirting up into the combustion chamber via transfer ports, the Pure Fire intake charge is forced through a small port on the bottom of the crankcase." (The transfer channel formed in the crankcase mounting surface runs from the bottom of the crankcase up into the cylinder mounting surface. The four transfer ports are fed through this plumbing system.)

2. "As it travels through the crankcase channel, the fuel charge absorbs crankcase heat, which improves atomization. Furthermore, the channel's small volume and curved route increase flow speed and cause a centrifugal effect." According to Tanaka this "causes a higher content of the fuel (portion of the mixture) to be delivered into the cylinder during the combustion stroke."

3. "The now layered intake charge flows under the cylinder and into its four closed transfer ports. They are located so that the more concentrated air/fuel are farthest away from the exhaust port."

4. The U-shaped piston ridge's "open end is aimed toward the exhaust port. When the piston is at bottom-dead-center, the ridge is opposite the four transfer ports. In this position, the bottom of the ridge is about level with the bottom of the exhaust port. The top is about half the height of the port. The ridge doesn't block the port, but it acts like a dike that directs the transfer charge away from it. This setup greatly reduces cross-cylinder flow and exit of unburned air/fuel mix."

5. "As the piston moves up, the ridge traps the intake charge and concentrates it around the spark plug electrode. Remember, the top of the cylinder is mirror image of the piston ridge. The two components mesh to form a concentrated combustion chamber.... This design allows more complete combustion which results in fewer emissions. Catalytic mufflers can't do the job alone, and they can't survive if the exhaust is too dirty so this is important."

6. The muffler contains a catalytic converter and the spark arrestor setup is typical. The catalyst is cylindrical and it is welded to a square plate which is welded to the inside surface of the muffler. The catalyst is 1 3/8 inches in diameter and 1.5 inches long. The honeycomb substrate is covered with a washcoat of noble metals. Exhaust gas must pass through the honeycomb substrate; the material gets extremely hot. It takes a few minutes of operation to get the catalyst up to its working temperature. The catalytic muffler represents about 40 percent of Pure Fire's emissions reducing technology. The other 60 percent takes place in the crankcase and cylinder.

This is a quality engine and the engine contains a connecting rod and three piece crankshaft which are quality forgings. Rod ends float on caged needle bearings and the big end is slotted to improve lubrication. The engine uses a conventional intake system with standard Walbro WYJ rotary valve carburetor.

3.2.5.3 Exhaust Emissions Performance --

3.2.5.3.1 Husqvarna's E-Tech -- Husqvarna's E-tech engine has achieved compliance with California ARB's 1995 standards, however it has not yet reached levels as finalized in this rulemaking and none are yet certified to the California ARB's model year 2000 standards. There are, however, additional internal upgrades that may be made as are identified in the Tanaka and Komatsu Zenoah technologies. It is likely that the application of these additional improvements will reduce emissions from where they are currently.

Husqvarna's EPA Phase 1 certification data contains the information contained in Table 3-03. The table is presented again below as Table 3-08. These emission results are from the rich setting of the engine (note: engines must meet emissions in the full range of the carburetor adjustment and therefore worst case is presented here.)

Table 3-08
New Husqvarna Phase 1 Certification Engines With Catalysts
Class IV Trimmer/Edgers (g/kW-hr)

Engine Family	Power	Displacement	HC	CO	NOx
XHVXS.0254EB	0.86kW	24.5cc	181.9	622.3	0.3
XHVXS 0274 EA	0.9kW	25.4cc	183.9	663.1	0.2
XHVXS.0314EA	1.07kW	30.8cc	157.0	551.2	0.2
XHVXS.0364EA	1.31kW	36.3cc	154.5	595.8	0.3

3.2.5.3.2 Tanaka Pure Fire -- Tanaka's 39.8cc two-stroke engine achieves levels of 45.11 g/hp-hr (60.5 g/kW-hr) HC+NOx and 117 g/hp-hr (157 g/kW-hr) CO after 300 hours of in-use as shown by certification to the California ARB standards. The 26cc engine has certified at 45 g/hp-hr (60 g/kW-hr) HC+NOx and 85 g/hp-hr (114 g/kW-hr) CO. These emission levels do not meet EPA's finalized Phase 2 standards. In order to determine whether additional catalyst efficiency is possible with this design, EPA included a 40cc trimmer engine in its small engine test program (Ref. 7). It was determined that the catalyst on the engine in the test program converted 67 g/hr HC for the 1.2 kW engine. Based on the in-use certification value of this engine, this is already near 50 percent conversion efficiency and a total of 65.5 percent conversion efficiency would be needed to meet 40 g/kW-hr (to allow for compliance margin to the final 50 g/kW-hr standards). It is unknown as to whether this high of a conversion efficiency is possible on small engines due to the short residence time of the exhaust gas as it passes through the catalyst at a specific space velocity. However, higher conversion efficiencies may be possible as shown in the California ARB certification in Appendix D because Stihl has certified a 27.2cc engine, also used in trimmers, both with and without a catalyst. The catalyst is estimated to have a conversion efficiency of approximately 60 percent based on the certification levels of the two engine families.

3.2.5.4 Technology Cost --

3.2.5.4.1 Husqvarna -- Publicly available cost information on modifications for the E-tech, and potential future E-tech engine designs, is not available.

3.2.5.4.2 Tanaka with Catalyst – Based on Tanaka's statement about its engine, as noted below, the cost increase is estimated to be around 5%. Tanaka's grass trimmer/ brushcutter equipment, which use Class IV engines, retail for $450 to $500. The estimated increase in retail cost would therefore be around $22.50 to $25. Backing out retail markup (estimated to be 29 percent for this analysis) results in a price impact of $17.44 to $19.38.

3.2.5.5 Impact on Equipment Design -- Based on the engine/equipment design relationship, there can be a range of equipment design impacts. The equipment must employ measures to assure that the equipment meets the U.S. Forest Service requirements and this may mean adding additional shrouding around the muffler to mix air with the exhaust gas before it exits the muffler. Changes in the crankcase may influence the equipment shrouding to the extent that it influences the outer dimensions of the engine.

Tanaka has stated the following: (1) their engine has two ounces more weight, (2) 10 percent less power (therefore moving toward slightly larger displacements), (3) 5 percent more cost, (4) this technology may be applicable only to pro-quality equipment for the cost impact might be too high for low-cost consumer-quality engines, (5) the weight of the equipment is 18.5 pounds, and is fueled with 50:1 ratio of gas/oil mix.

3.2.5.6 Technology Impact on Noise, Safety and Energy --

3.2.5.6.1 Husqvarna E-Tech -- This engine technology employs a catalyst and the equipment meets the U.S. Forest Service temperature requirements for exhaust gas plane and exposed surface plane. The technology will result in less fuel consumption based on the internal improvements made in the engine. As relates to noise, there is likely a slight benefit, due to the presence of the catalyst.

3.2.5.6.2 Tanaka Pure Fire -- We presume this engine as certified for use in equipment meets the U.S. Forest Service temperature requirements. Tanaka states that the engine achieves a 30 percent reduction in fuel consumption. As relates to noise, there is likely a slight benefit, due to the presence of the catalyst.

3.2.6 Spark-Ignition Technology

3.2.6.1 Description of Technology -- During the summer of 1998, Pyrotek presented EPA with information on a spark-ignition technology that it had developed. It is a very simple technology and has shown to yield lower emissions in two-stroke engines. The technology described herein is considered a supplemental technology based on the fact that an engine manufacturer cannot rely on the technology alone to meet the finalized standards. Initial data (Ref. 9) showed that it may provide a benefit over the useful life of the engine. More recent data (Ref. 10) , on catalyzed two-stroke engines aged over 25 hours, indicates there is minimal advantage with use of the spark plug due to the fact that the differences in the catalysts efficiencies on two different engines outweighed the advantages with the spark plug technology. Therefore, this technology is best considered when no catalyst is used. The following discussion is focused on the data contained in Reference 9.

3.2.6.2 Current State of Technology Development -- Versions of the spark-ignition technology are in the marketplace today, however the inventors have investigated those technologies and note that theirs has some benefits that have not yet been included in previous designs.

3.2.6.3 Exhaust Emissions Performance -- Pyrotek has performed a number of tests of the technology on two-stroke and four-stroke engines. They have seen a notable benefit in new engine values on two-stroke. The tests have confirmed improved BSFC and it is believed that the absence or reduction of combustion chamber deposits over time would contribute to improved emission deterioration over time. Some durability tests have been performed on two-stroke engines.

The engines selected for the study were two-stroke Homelite super 2 chainsaw engines (Model No. 246Y, air-cooled, single cylinder, piston ported, supplied with a DJ7Y plug 32.4 cubic centimeter displacement). The engines were tested new and the emission levels noted in Table 3-09 were achieved. Refer to the report for testing specifics.

Table 3-09
Engines At New (0 hours)

Parameter	Engine #2 Conventional	Engine #1 Pyrotek	Engine #1 Conventional
Power (kW)	1.03	0.98	0.99
HC (g/kW-hr)	154.0	166.0	165.5
CO (g/kW-hr)	292	268	310
CO2 (g/kW-hr)	936	1010	965
NOx (g/kW-hr)	2.42	2.51	2.00
BSFC (g/kW-hr)	653.4	676.2	691.8
Fuel Flow (g/hr)	673.4	661.5	684.0

After 25 hours of operation the results in Table 3-10 were seen.

Table 3-10
Emission Results After 25 and 50 Hours

Parameter	25 Hours		50 Hours	
	Engine #1 Pyrotek	Engine #2 Conventional	Engine #1 Pyrotek	Engine #2 Conventional
Power (kW)	0.97	0.93	0.97	0.85
HC (g/kW-hr)	135.6	158.40	125.4	178.2
CO (g/kW-hr)	193	260	215	342
CO2 (g/kW-hr)	1096	1030	965	985
NOx (g/kW-hr)	6.29	4.11	2.85	2.35
BSFC (g/kW-hr)	700.9	754.6	750.2	803.6
Fuel Flow (g/hr)	676.5	701.4	726.7	686.4

The report points out that the emissions from the engine with the Pyrotek spark plug has lower emissions by 25 percent for CO and 14 percent for HC after 25 hours. The differences in HC and CO in both engines compared to data in Table 3-09 are partly due to the different ambient humidities for the 0 and 25-hour tests.

The engines were run for another 25 hours (total of 50) and the emissions were measured. It should be noted that the engine with the conventional spark plug had trouble starting and therefore the start procedure was repeated for 10 minutes until it finally started. The engine with the Pyrotek spark plug started without difficulty. Results show the engine with the Pyrotek plug was lower than the engine with the conventional plug by 37 percent for CO and 29 percent for HC. The report states that "it is likely that the high level of HC emission of the engine with the conventional spark plug may have been partly caused by the amount of priming used when starting difficulties were experienced."

Upon completion of the test, each engine was dismantled and examined. The report stated that "the engine fitted with the conventional spark plug had a considerable build-up of soot-like deposits in the piston-ring grooves and around the exhaust port. Also, the piston face and combustion chamber walls of this engine showed many regions of small discoloration/damage on the piston face of the engine with the Pyrotek plug was considerably less and much more uniform. The Pyrotek spark plug exhibited a light brown discoloration of the insulation around the center electrode, while this region of the conventional plug was considerably darker." Photographs of the engine are available in the report.

3.2.6.4 Technology Cost -- In recent correspondence with EPA, Pyrotek estimated the cost of the technology would not exceed a total cost of $1.97 per unit.(Ref. 11)

3.2.6.5 Impact on Equipment Design -- The spark-ignition technology would replace the existing spark plug. Therefore, besides an increase in exhaust and cylinder head temperatures at wide open throttle of approximately 20° C for the Pyrotek spark plug, which additional fins may be able to dissipate, there is no expected impact on the equipment.

3.2.6.6 Technology Impact on Noise, Safety and Energy -- No changes are expected based on this spark plug technology.

3.2.7 DIPS

3.2.6.1 Description of Technology - - During the Fall of 1999, EPA was presented with information on a new spark-ignition technology that shows promise to reduce emissions from two-stroke engines. As described by the developer, the DIPS technology is a combination of two technologies including the FAST system, an air assisted direct fuel injection technology, and the "split uniflow engine with asymmetric timing". The advantages of this technology include 1) use of air as scavenger, 2) a high degree of atomization of the fuel thereby leading to complete combustion of the fuel, 3) less fuel consumption, 4) keeps high power to weight ratio in a compact package (an engine with this technology can be the same size as the existing engine). Preliminary testing of the technology in a 25cc trimmer prototype resulted in new engine HC emissions of 21.1 g/kW-hr at WOT. The projected cost for this technology is $6.00 plus licensing fee. It could be a competitive option for the industry since it may not need to employ a catalyst to reach EPA's Phase 2 standards. Because of the preliminary nature of this information, we have not considered this technology as part of our cost or feasibility analysis. Additional information on this technology can be found on the Internet at www.dipspower.com.

3.3 Exhaust HC+NOx Standards for Class III, IV and V Engines

This section contains information the Agency used to determine the appropriate standards contained in the regulations. Additional information is contained in the Preamble for this Rulemaking.

The handheld engine industry is made up of manufacturers that make small engines for a variety of applications and intended users (residential and commercial). Engine families certified to the Class III standards are used almost solely in trimmers/edgers/cutters and the majority of engines are sold mainly to low use residential consumers. The engine families certified in Class IV cover a wider range of applications from trimmers/edgers/cutters, generator sets and blowers to chainsaws for use by low use residential consumers and high use commercial users. Engine families certified in Class V are mainly used in chainsaws, rammers, and cutoff saws aimed at the commercial users. Very few trimmers and blowers are certified in this class.

The Agency expects the finalized in-use standards can be met through conversion to four stroke, stratified scavenged with lean combustion engine with a medium/high efficiency catalyst (in Classes III and IV) and without a catalyst (in Class V), and compression wave technologies with a medium efficiency catalyst (in Classes III and IV) and without a catalyst (in Class V). Other supporting technologies include engine redesign plus catalyst and potentially spark-ignition technologies. It should be noted, however, that there are currently limitations to the application of some of these technologies to all engine sizes covered by this rulemaking.

Limitations for some of the technologies include limited loss in power, engine technology size and/or technology performance. Technologies in which there have been measured limited losses of power from the original engine design include engines that incorporate stratified scavenging. However, it should be noted that the stratified scavenging design from Komatsu Zenoah also utilizes lean combustion and therefore the engine power loss is much less than could be anticipated with just stratified scavenging. Four-stroke technology has several issues for engines in the upper size range of Class V engines. The concerns are over the power/weight ratio as well as the acceleration of the engine, which relates to technology performance. Technology performance also relates to concerns over medium and high efficiency catalysts, especially in Class V engines that have not reduced engine out emissions significantly. The volume of exhaust flow is much greater on larger engines and therefore the ability of a catalyst to convert the same efficiency of pollutant, as on a smaller engine, and still remain cool enough to meet the U.S. Forest Service temperature limits, has proven difficult for manufacturers.

John Deere has indicated that they see no reason for limitation of use of the LE technology on all small engines. Engine manufacturers of professional use products in Class V have expressed concerns with the technology on their products. Specific concerns include lubrication in high speed and high load applications, such as chainsaws, and smooth fuel system operation across all modes of equipment use. Based on the most up to date information from John Deere (SNPRM comments, Docket Item IV-D-48 and California ARB certification), EPA is optimistic that manufacturers will be able to apply the technology to slightly modified existing two-stroke engines in all applications and sizes, while achieving significant emission reductions.

Without further improvements to current designs, the addition of a medium efficiency or a medium/high efficiency catalyst will be required in order for the technologies of John Deere LE and Komatsu Zenoah stratified scavenging with lean combustion to achieve the Phase 2 standards in Class III and IV applications. (As noted earlier, John Deere has estimated that with averaging available, approximately 50% of their Class IV applications can be certified without the use of a catalyst.) However, information on application of a catalyst to engines with these technologies is limited because manufacturers have been focusing on meeting standards for California ARB which do not require catalysts. EPA has tested the John Deere LE engine and the Komatsu Zenoah stratified scavenging with lean combustion engines with catalysts, very close to the efficiencies that will be required, and has observed that there will be cooling issues for the manufacturers to address. However, given the leadtime before full implementation of the standards, we are confident that manufacturers can address such issues successfully.

Table 3-11 contains a summary of publicly available emission data from a number of technologies described earlier in this chapter. The in-use HC+NOx values are listed next to the related technology. Some in-use values are estimated and some are from manufacturer data as certified to California ARB standards. A column has been included which estimates emissions if a catalyst is utilized on the engine. With the low engine out emissions achieved by these technologies, a 30g/kW-hr catalyst may be possible for most applications.

Table 3-11
Technologies and Likely Achievable In-Use HC+NOx Emissions

Technology/ Manufacturer	HC+NOx (g/kW-hr)	Methodology for Calculation of in-use emission	Class and Application	Assuming cooling is available, emissions w/ 30g/kW-hr Catalyst for III & IV
Stratified Scavenging Lean Combustion*/ Komatsu-Zenoah (25.4cc)	66.0	California ARB cert data (300 hrs)	Class IV trimmer	36.4
Stratified Scavenging Lean Combustion*/ Komatsu-Zenoah (33.6cc)	53.1	California ARB cert data (300 hours)	Class IV trimmer	22.9
Four-stroke*/ Honda (49.4cc)	25.4	California ARB cert data (300 hours)	Class IV generator	NA
Four- stroke/ Honda (31.1cc)	40.9	California ARB cert data (300 hours)	Class IV	NA
Four-stroke /FUJI (24.5cc)	17.0	California ARB cert data (125 hours)	Class IV	NA
Four-stroke/Ryobi (26.2cc)	15.0	California ARB cert data (50 hours)	Class IV	NA
Four-stroke/Ryobi (26.2cc)	21.0	California ARB cert data (300 hours)	Class IV	NA
LE Engine Technology/ John Deere Consumer Products	66.8	Docket Item IV-G-32 with assumed 1.1 df	Class IV trimmer	36.8
	61.1	California ARB certification data as (125 hours)	Class IV	31.1
LE Technology/ John Deere on 70cc Stihl - preliminary prototype	50.0**	Docket Item IV-D-48 with assumed 1.1 df	Class V chainsaw	meets standard

* - Technologies may be limited in applicability to all sizes and applications of handheld engines.

**- These results are from use of preliminary fuel system. On the Class IV trimmer, emission results increased with latest fuel system design and it is expected the same will happen if the fuel system were applied to the Class V engine. Also, issues of application of technology to professional Class V engines, including lubrication, etc. remain unanswered due to no further work on prototype. However, the Class V HC+NOx standard of 72 g/kW-hr is much higher than the prototype achieved.

Due to the feasibility of technologies, or very promising technologies, demonstrated by manufacturers in Class IV engines, as shown in Table 3-11, it is believed that low emissions are achievable. Based on information available at the time this document was prepared, EPA believes four stroke technology will be very cost-effective for high production engine families and technologies such as the John Deere LE engine or Komatsu Zenoah stratified charge will be relatively cost-effective for low and high volume engine families. While the engine cooling capabilities of an engine will need to be improved due to less fuel/oil cooling (due to the use of stratified scavenging or reduced scavenging designs), EPA believes that there is some additional cooling available for the application of a medium/high efficiency catalyst. Therefore, the Agency is finalizing an average in-use HC+NOx standard of 50 g/kW-hr for Classes III and IV. These standards would be applicable for the useful life categories of 50, 125, and 300 hours. The Phase 2 standards would phase-in from model year 2002 through 2005 for Classes III and IV as shown in Table 3-12.

For Class V engines, Table 3-11 shows results for only one engine and it is on a preliminary prototype using the John Deere LE technology on a 70 cc Stihl engine.[24] The EPA is optimistic that the John Deere LE technology and Komatsu Zenoah stratified scavenged with lean combustion technology will both be applicable to professional equipment in Class V, even though they have not yet been proven in the marketplace. The application of catalysts in addition to these technologies is currently not seen as feasible due to the lubrication and cooling requirements of the low emitting technologies as applied to professional chainsaws which make up the majority of equipment in this class. Chainsaws have tight packaging around the engine and related components, such as the muffler, and therefore limited additional cooling when compared to other applications such as trimmers. The cooling that is available is best utilized to account for the cooling requirements of low emission technologies rather than catalysts, mainly due to the potential for emission reduction and lower deterioration of the technologies compared to catalysts. However, if the compression wave or stratified scavenging with lean combustion technologies need to be run richer than on the Class IV engine to provide sufficient lubrication, then possibly the available cooling not required by the technology can be used to cool a muffler with a low efficiency catalyst. Based on this analysis, a standard of 72 g/kW-hr is being finalized for Class V engines.[25] The standard would be phased-in from 2004 to 2007 for Class V as shown in Table 3-12 in order to provide additional development time for application of low emitting technologies to this class and specific applications which have only been completed in limited prototype to date. The phase-in period plus the lead time anticipated will allow manufacturers two to seven years to make the necessary changes to existing product lines in order to meet the

[24] It is understood that there are limitations in the application of four-stroke technology across the entire range of Class V engines due to the power/weight and acceleration in Class V applications.

[25] 72 g/kW-hr is the same as the Phase 2 standard the California ARB has set for a portion of such engines (<65cc) which are not exempt from their rulemaking.

standards[26]. Flexibilities for small-volume engine families and small-volume engine manufacturers allow a slightly longer timeframe.

Phase 2 technology two-stroke engines will result in approximately a 70 percent reduction in the in-use emissions of small spark-ignition handheld engines at or below 19kW once fully implemented.

Table 3-12
Phase-in HC+NOx Standards (g/kW-hr) for Handheld Engines*

Engine Class	Model Year					
	2002	2003	2004	2005	2006	2007+
Class III	238	175	113	50	50	50
Class IV	196	148	99	50	50	50
Class V	(Ph 1)	(Ph 1)	143	119	96	72

* - The finalized standards are based on a 25, 50, 75, and 100 percent phase-in of 50 g/kW-hr standard for Class III and IV, and 72 g/kW-hr for Class V.

26 Small volume engine manufacturers and small volume engine families have until three years after the last date of the phase-in to comply with the Phase 2 standards. This means 2008 for Classes III and IV and 2010 for Class V.

Chapter 3 References

1. "Cost Study for Phase Two Small Engine Emission Regulations", Draft Final Report, ICF Consulting Group and Engine, Fuel, and Emissions Engineering, Inc. Oct. 1996, Docket Item IV-A-01.

2. "The Basic Design of Two-Stroke Engines", Gordan P. Blair, Society of Automotive Engineers, Inc., 1990.

3. "The Internal Combustion Engine in Theory and Practice, Volume 1", C.F. Taylor, The M.I.T. Press, 1985. See Chapter 12, 'The Performance of Unsupercharged Engines'

4. "Exhaust Systems Subgroup of the Technology Task Group - Report", September 25, 1995. Available in Docket Item II-D-17.

5. "WrittenTestimony of the Manufacturers of Emission Controls Association on Proposed Phase 2 Emission Standards for New Nonroad Spark-Ignition Engines at or Below 19 Kilowatts", March 13, 1998, Docket Item IV-D-13.

6. Letter from Bruce Bertelsen of MECA to Bob Larson of the EPA, October 19, 1998, Docket Item IV-G-25.

7. "Final Test Report: Emission Testing program for Handheld Engine Technologies for the Reproposed Phase 2 Regulations", October 1999, Docket Item VI-A-01.

8. California ARB Certification Data as of January 2000 (see Appendix D).

9. "Technical Summary and Report Spark-Ignition Device Research", Pyrotek, Inc., November 13, 1998, Docket Item IV-G-29.

10. Technical Report No. 4 to Norman Garrett and Todd Arey, Pyrotek by Giles Brereton, November 10, 1999 , Docket ItemVI- G-39.

11. Letter from Steven Todd Arey of Pyrotek to Robert Larson of the EPA, January 11, 2000, Docket Item VI-G-39.

Chapter 4: Technology Market Mix and Cost Estimates

This chapter analyzes the variable costs and fixed costs per engine family modified in each class. These are costs to the manufacturer. This chapter also presents a "schedule" for how these engine modifications would be phased-in. The focus of this chapter is on engines in Classes III-V and not Class I-A or Class I-B. This is due to the fact that Class I-A engines (0cc-65cc) are the same as the handheld engines, mentioned herein, that are used in nonhandheld applications. Also, the Class I-B engine standard (65cc-100cc) is achievable with existing Class I Phase 1 certified engines.

The Clean Air Act at section 213(a)(3) requires that EPA must consider cost in establishing standards that achieve the greatest degree of emission reduction. This Chapter presents the Agency's estimation of costs for expected technologies including associated variable costs (hardware and production), fixed costs (production and research and development), related equipment costs, engine fuel savings and engine compliance costs. Details of the methodology for determining the compliance costs are presented in Chapter 5.

To calculate estimated costs incurred by engine manufacturers, market mix[27] percentage estimates for pre-Phase 2 (Phase 1) and Phase 2 engines must first be assessed. This is done by determining the Phase 1 engine market mix from estimates provided by manufacturers as part of their 1998 model year certification applications. Analysis of this data formed the assumed product mix that will be in place as a result of the Phase 1 rulemaking. A comparison was then made to the assumed product mix (including technical enhancements) that would need to be in place to meet the Phase 2 standards. A description of the methodologies and resultant market mixes for these estimates are described in section 4.1., entitled "Engine Technology Market Mix Estimates."

Several of the emission reduction technologies assumed feasible for this rule include changes in manufacturer production, such as changes in the cylinder die designs and the number of tools. The following definitions were utilized to separate costs for emission reduction technologies into variable hardware, variable production, fixed production and fixed research and development. Variable hardware costs are those costs which are associated with pieces of hardware added to an engine. Examples include rocker arms and push rods that are added to an engine that is converted from two-stroke to four-stroke OHV. Variable production costs are those costs which relate to inputs in production. These costs consist of additional production tasks, such as assemblers for additional components for a four-stroke line which were not in place for assembly of a two-stroke line. Variable hardware and production costs are determined by estimating variable costs for each emission reduction technology and applying those costs to

[27] Market mix is the percentage of engines of specific engine design sold in the marketplace (e.g., four-stroke and two-stroke) compared to others in the same engine class.

that portion of the Phase 2 product mix assumed to have required that technical change. The methodology for estimating variable hardware and production costs for applying emission control technology are presented in section 4.2., entitled “Variable Hardware and Production Cost Estimates per Engine Class.”

Fixed production costs are those costs which are related to added or modified piece(s) of machinery to an existing engine line due to this final rule, such as tooling and die design changes. Fixed costs of research and development are those costs associated with development of engine and engine component designs to meet emission standards. These costs are incurred prior to production and amortized for recovery over 5 years and therefore do not apply on a per engine basis as do variable cost estimates. Discussion of the methodology utilized to estimate fixed costs is presented in section 4.3., entitled “Fixed Production and Research and Development Cost Estimates per Engine Class.”

Engines are utilized in equipment which may require alterations due to changes in the engines that would be required to meet the Phase 2 finalized standards. A discussion of equipment impacts is presented in section 4.4., entitled “Equipment Cost Estimates.” Lastly, Section 4.5. details fuel savings and changes in power expected with the Phase 2 engine technologies. Cost impacts from changes in maintenance, engine durability and life expectancy were not quantified or included in this cost analysis. These factors are expected to remain the same as in current product for consumer applications due to the concept that consumers take a long time to use the life of the product and once reached will purchase another equipment rather than have it repaired. While some directional changes regarding maintenance, etc. are anticipated and noted in the following sections, the impact on cost to the manufacturer and consumer will be slight and is considered insignificant and not quantified in this cost analysis.

4.1 Engine Technology Market Mix Estimates

Market mix estimates consist of the number of engine families and sales estimates of engine designs (i.e., two-stroke, four-stroke) per class (i.e., Classes III through V). Market mixes are determined for the 1998 model year (to characterize technology under the Phase 1 regulation) and the first year of full implementation of the Phase 2 emissions regulation. The following describes the methodology used to estimate market mix and emission reduction technologies for Small SI engines. This analysis includes those engine families and base production volumes certified to EPA’s Phase 1 standard as of September 1998. A summary of results are in Tables 4-01 to 4-04 with manufacturer specific details and emission data in Appendix B.

4.1.1 Phase 1 Market Mix

The most accurate and up-to-date information source on engine families and manufacturers in the marketplace today is the EPA Phase 1 engine certification list. The list, as of September 1998, was utilized to estimate the number of engine families per engine design and technology for Classes III through V[28] as shown in Table 4-01. (Table B-01 in Appendix B contains breakout per manufacturer.) Table 4-02 summarizes the sales in each engine class per engine design.

Table 4-01
Phase 1 Technology Mix
Engine Families per Technology Type

Engine Class	Two-stroke	Two-stroke w/cat	Mini four-stroke	Total
III	9	--	--	9
IV	116	2	3	121
V	50	--	3	53
Total	175	2	6	183

Table 4-02
Assumed Phase 1 Sales per Class and Technology Type
(Source: EPA Phase 1 Certification Database as of September 1, 1998)

Engine Class	Two-stroke	Two-stroke w/cat	Mini four-stroke	Total
III	1,287,500	--	--	1,287,500
IV*	8,250,728	conf (included in two-stroke)	conf (included in two-stroke)	8,250,728
V*	501,570	--	conf (included in two-stroke)	501,570
Total	10,039,798	some	some	10,039,798

* - For Classes IV and V, some of the blocks state "conf." This is done to honor the manufacturer's claim of confidentiality if only one or two companies contribute to the total number of engines in that block.

[28] There are special cases in which engines do not have to meet the Phase 1 standards. These include engines utilized solely in wintertime equipment, such as ice augers, that only have to meet the CO standard.

4.1.2 Phase 2 Market Mix

To determine the Phase 2 market mix, the need for emission reduction technologies was determined by viewing the Phase 1 certification emission data (using Sept 1998 Phase 1 certification database). Based on comparison of the emission levels of engine in the Phase 1 database and the stringency of the Phase 2 standards, even with the use of ABT, it is assumed that all engine families will need to be improved except 4-stroke designs. The likely technologies were assumed (see Table 4-04) and the percentage usages of such technologies were estimated through EPA's knowledge of technologies that manufacturers had on the marketplace or were developing. If no information was known, then the compression wave technology was assumed for it is currently seen as the most applicable technology to the wide range of engine families.

4.1.2.1. Potential Emission Reduction Technologies -- Potential emission reduction technologies were based on information provided in discussions with a number of industry manufacturers and independent companies. As of January 2000, a number of technologies have been certified to meet the California ARB's 72 g/kW-hr HC+NOx standard. At least three engine/equipment manufacturers have certified a mini four-stroke engine (Ryobi, Honda and Robin America). Komatsu Zenoah has certified engines using stratified scavenging with lean combustion engine. John Deere has certified their LE technology engine using compression wave technology. Other low emitting technologies, such as two-stroke engine redesign with a catalyst, have also been certified for the California market as of January 2000. However, such redesigned engines with catalysts may not be able to meet EPA's more stringent final Phase 2 standards unless the engines are further redesigned for lower emissions or a higher conversion efficiency catalyst is used, or some combination of these two technology options. Currently known technologies that are being used to meet the California ARB 2000 model year standards are presented in Table 4-03.

Table 4-03
Emission Reduction Technologies Certified with the California ARB

Engine Technology	Technologies for the California ARB
Two-stroke	- four-stroke engine design - Compression Wave Technologies (e.g., John Deere LE engine) - Stratified scavenging with lean combustion - Improved two-stroke with catalyst -Leaner calibration and improved engine cooling -Improved carburetor with more precise intake mixture control -Improved combustion chamber design to promote more complete combustion (more spherical and squish area) -Improved transfer port design to reduce scavenging losses -Higher manufacturing quality with reduced assembly tolerances and component variation -Optimization for a single engine operating point
four-stroke	- No changes needed

For EPA's final Phase 2 HC+NOx standards of 50 g/kW-hr for Class III and IV, and 72 g/kW-hr for Class V,[29] EPA assumes the following technologies will be utilized. For Class III and IV we assumed mini overhead valve four-stroke, stratified scavenged with lean combustion with a catalyst, compression wave engine technology, and compression wave technology with a catalyst. For Class V we assumed stratified scavenged with lean combustion, and compression wave engine technology. Improved two-stroke engines with a higher efficiency catalyst is also being used in California and may also be used to meet federal standards especially in applications such as back pack blowers and string trimmers where catalyst cooling and shielding are easiest. In such cases, this technology may be preferable to some manufacturers if this represents a lower cost option and requires less development resources prior to implementation. However more development is required to meet the finalized emission standards and, as a simplifying assumption for this cost analysis, improved 2-stroke with catalyst will not be considered for the final cost impact analysis..[30] A list of technologies used in this analysis are listed in Table 4-04. The table also includes technologies for Class I-A and I-B which are included in this rulemaking.

Table 4-04
Assumed Technology Improvements Available to Manufacturers

Engine Class	Engine Design	Assumed Technologies
I-A,	two-stroke or four-stroke	-Same technologies as assumed for Classes III through V
I-B	four-stroke SV and OHV	-Current technologies
III and IV	two-stroke	-Four-stroke OHV -Compression Wave Technology, with and without a catalyst -Stratified Scavenging with Lean Combustion with a catalyst
IV	four-stroke	-No changes
V	two-stroke	-Compression Wave Technology -Stratified Scavenging with Lean Combustion

29 It should be noted that while these engine technologies are focused on reducing HC+NOx emissions, it is expected that CO emissions will decrease due to further enleanment of the engines due to internal engine improvements made to decrease HC+NOx.

30 Manufacturers may incorporate such improvements on some engines families and thereby need less credits from other lower emitting engine families.

4.1.2.2 Extent of Use of Emission Improvement Technologies -- The standards for handheld engines are phased-in over several years (2002 to 2005 for Classes III and IV and 2004 to 2007 for Class V) with the average in-use standard decreasing each year. ABT is available to these classes and across all classes[31]. Small-volume engine families in Classes III and IV and small-volume manufacturers with these engine families have until 2008 to certify. Small-volume engine families and manufacturers of Class V engines have until 2010 to certify. This cost analysis assumes manufacturers use these cost-saving flexibilities.

To determine the number of engine families and corresponding production volume that would need to incorporate emission or emission durability improvements, we examined the certification database for emissions and sales characteristics of each engine family.[32,33] Based on the high emission characteristics of nearly every engine family and the stringency of the standard, it was determined that all engine families would require improvements with the exception of those which are wintertime only products, such as ice augers. The percentage of engines phased in was determined from the declining emission standard (25%, 50%, 75% and 100%). While several engine manufacturers have single engine families which are very high volume, it is assumed that competition in the marketplace, especially for consumer priced products, will require that the Phase 1 versions of the engines will be produced at the same time as their cleaner, slightly more expensive Phase 2 counterpart.

Table 4-05 shows the assumed engine family phase-in for all handheld classes and Class I-B. Table 4-06 shows the resultant engine production that are represented by the number of engine families in Table 4-05. Handheld engine families meet the standards with conversion to mini four-stroke design, stratified scavenging with a catalyst, and compression wave technology with and without a catalyst. We have made our best assumptions with regard to which technologies manufacturers will use based on input from individual manufacturers. For those manufacturers where we did not have input, we have assumed they will use a technology which costs the same as the compression wave technology (including payment of the full licensing costs as proposed by John Deere). Table 4-07 presents the resulting market mix used in the cost analysis for the Phase 2 standards.

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31 Engine families will need to certify with FEL's of 72 g/kW-hr or below in order to carry credits forward to future years.

32 The database contains several entries per engine family as manufacturers show that the engine family meets the emission standard among its adjustable parameters (particularly the carburetor). For such engine families, the maximum emission rate for HC+NOx was utilized in setting the point at which the engine family emitted for Phase 1.

33 Refer to Tables B-02 through B-06 in Appendix B for specific emission data for each engine manufacturer and each of their engine families.

Table 4-05
Assumed Phase-In Schedule of Handheld and Class I-B Engine Family Changes
(Number of Engine Families)

Engine Class	2002	2003	2004	2005	2006	2007	2008	2009	2010
III	1	0	1	4	--	--	3*	--	--
IV	21	5	33	13	--	--	49*	--	--
V	--	--	3	7	3	10	--	--	30*
I-B	4	--	--	--	--	--	--	--	--

* - These families represent small-volume engine families/manufacturers which have three years of additional flexibility at the end of the phase in.

Table 4-06
Production Volume (and Percent of Total per Class)
Represented by Engine Families

Engine Class	Specific Technology Change Assumed for this Analysis	Upon Full Implementation (Based on 1998 Sales Estimates)	
		# of Engines	% Within Class
III	Compression wave technology with catalyst, Stratified scavenge with catalyst	1,258,500	100%
IV	Mini four-stroke, Compression wave technology with and without catalyst, Stratified scavenge with catalyst	8,250,728	100%
V	Compression wave technology	501,570	100%

Table 4-07
Phase 2 Technology Mix (Upon Full Implementation)
Engine Families Per Technology Type Assumed for Cost Analysis

Engine Class	Mini four-stroke	Two-stroke with compression wave (Class III - with catalyst, Class IV - with and without catalyst, Class V - without catalyst)	Two-stroke with stratified scavenge (with catalyst)	Total*
III	--	9	--	9
IV	7	90**	24	121
V	3	50	--	53
Total	10	149	24	183

* - This analysis assumes the same number of engine families before and after Phase 2. There is the possibility that some engine families may be dropped or some may be combined in order to reduce costs. Also, one manufacturer has exited the marketplace since September 1998. Their engine families have been removed. However, their sales have been included in the class total production estimates used in this analysis.

** - We analyzed two scenarios with regard to catalyst usage on the compression wave technology. In the first scenario we assumed, based on input from John Deere, that they would use catalysts on 50% of the Class IV engines. In the second scenario we assumed that all manufacturers of Class IV engines using the compression wave technology would use catalysts on only 50% of the engines.

Table 4-08
Assumed Phase 2 Sales per Class and Technology Type*
(Based on Phase 1 Database as of September 1998)

Engine Class	Mini four-stroke	Two-stroke with compression wave (Class III - with catalyst, Class IV - with and without catalyst, Class V - without catalyst)	Two-stroke with stratified scavenge (with catalyst)	Total
III	--	1,287,500	--	1,287,500
IV	1,500,000	5,750,728**	1,000,000	8,250,728
V	--	501,570	--	501,570
Total	1,500,000	7,539,798	1,000,000	10,039,798

* - Baseline sales without projected growth

** - We analyzed two scenarios with regard to catalyst usage on the compression wave technology. In the first scenario we assumed, based on input from John Deere, that they would use catalysts on 50% of the Class IV engines. In the second scenario we assumed that all manufacturers of Class IV engines using the compression wave technology would use catalysts on only 50% of the engines.

4.2 Variable Hardware and Production Cost Estimates per Engine Class

EPA developed cost estimates for variable hardware and production costs for Phase 2 engines. The cost estimates were taken based on information from engine manufacturers, information from a catalyst manufacturer association, and the cost report from ICF and EF&EE (Ref. 1a). Table 4-09 contains the variable hardware cost and production cost for each emission reduction technology per class and engine design on which this cost analysis is based. The costs listed in Table 4-09 are based on information presented in Chapter 3 for the different technologies. The final variable hardware and production estimates, used in the cost-effectiveness calculation for Class III, through V engines, are listed in Appendix E (Table E-02) and are based on the numbers presented in Table 4-09. The value chosen from the range of cost estimates is influenced by the estimated sales production per engine family (from the Phase 1 September 1998 certification database) and assumptions about the likelihood of the latest cost estimates based on development of the technology from discussions with engine manufacturers, for example John Deere who is developing the Compression Wave technology. Since California's standards go into effect in year 2000, a minimum of 2 years prior to federal standards, costs incurred developing technology for California which can be used in meeting these federal standards is not included except to the extent required to represent expanded production or additional applications.

For the long-term, there are factors that EPA believes are likely to reduce the costs to manufacturers. As noted above, we project fixed costs to be recovered by manufacturers during the first five years of production, after which they would expire. For variable costs, research in the costs of manufacturing has shown that as manufacturers gain experience in production, they are able to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve which has been used by EPA in previous rulemaking to account for reductions in manufacturing cost for new engine/emission control system technologies. For a detailed description of how EPA has used learning curves in the past, and for why they are an appropriate tool for estimating emission control costs, refer to the Tier 2 RIA[34]

The learning curve is a well documented phenomenon dating back to the 1930s. The general concept is that unit costs decrease as cumulative production increases. Learning curves are often characterized in terms of a progress ratio, where each doubling of cumulative production leads to a reduction in unit cost to a percentage "p" of its former value (referred to as a "p cycle"). The organizational learning which brings about a reduction in total cost is caused by improvements in several areas. Areas involving direct labor and material are usually the source of the greatest savings. Examples include, but are not limited to, a reduction in the number or complexity of component parts, improved component production, improved assembly speed and processes, reduced error rates, and improved manufacturing process. These all result in higher overall production, less scrappage of materials and products, and better overall quality.

[34] See the Regulatory Impact Analysis for the Tier 2 Final Rulemaking, Chapter V, Air Docket A-97-10.

As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable plateau, beyond which increased production does not necessarily lead to markedly decreased costs.

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services(Ref. 1). The distribution of these progress ratios is shown in Figure 4-1. Except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

The learning curve is not the same in all industries. For example, the effect of the learning curve seems to be less in the chemical industry and the nuclear power industry where a doubling of cumulative output is associated with 11% decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

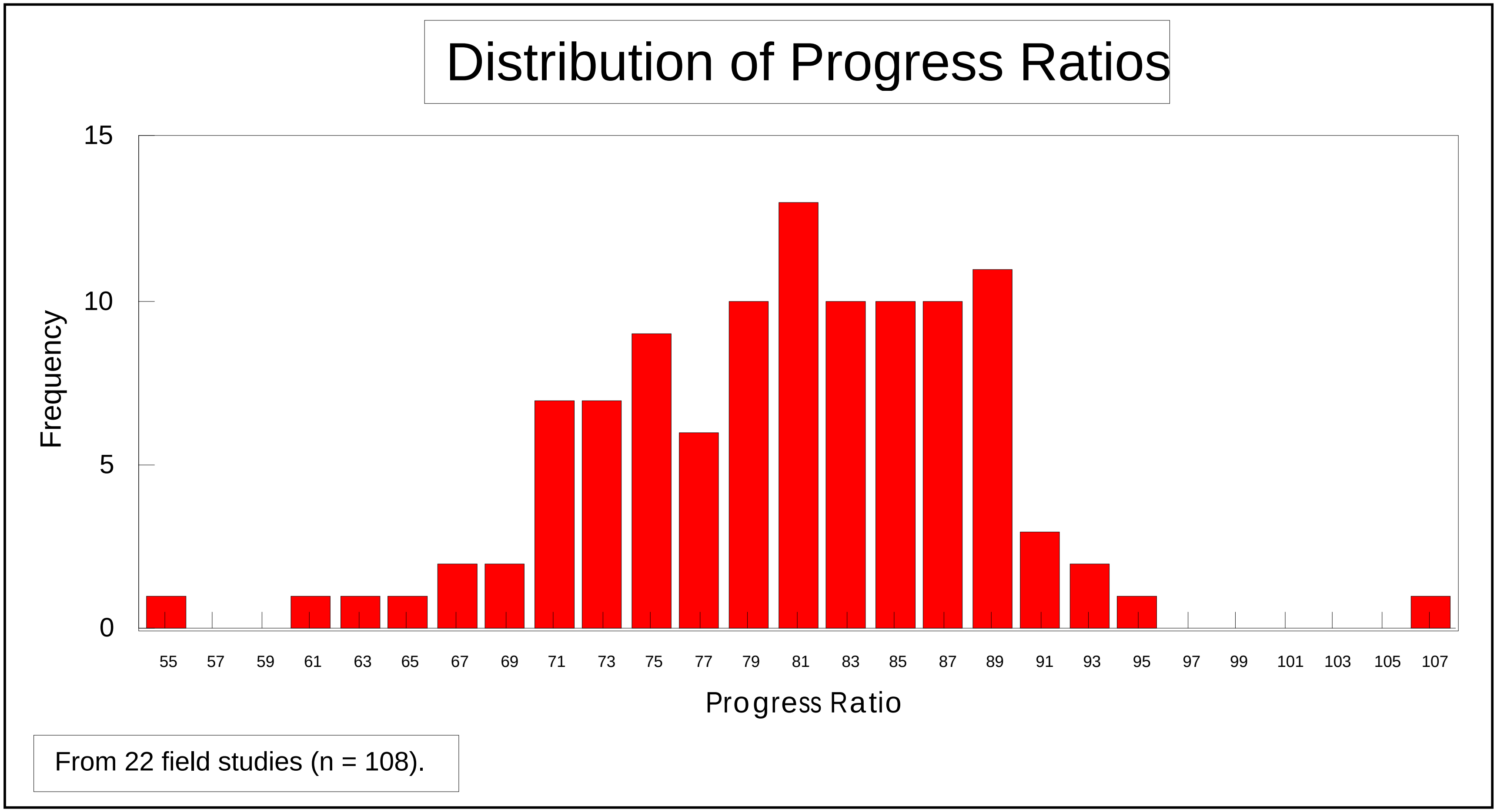

Figure 4-1. Distribution of Progress Ratios
(Dutton and Thomas, 1984)

The learning curve discount accounts for improvements in technology design and production processes that will likely occur over time as manufacturers work to develop the technology, or develop new technologies, over their product line and reduce costs for competitive reasons. We believe this learning curve impact on variable costs is especially appropriate with respect to handheld equipment, most of which is sold for residential use, since the engines manufacturers have emphasized the importance of cost competitiveness for this market. Considering that these emission standards will cause substantial redesign of all two-stroke engines and, for the first time the wide spread use of catalyst, it is reasonable to anticipate opportunity for continued improvement in design and production of these new engine designs within the first few years of their introduction.

We applied a p value of 80 percent in this analysis beginning in the first full year of implementation of the final standards (2005 for Classes III and IV and 2007 for Class V). Arguably, the learning should start with initial production, that is 2002 for Classes III and IV and 2004 for Class V. By delaying the start of this learning curve application, we effectively increase the cost estimate for this rule and raise the cost - effectiveness estimates. Using one year as the base unit of production, the first time the cumulative production would double would occur at the start of the third model year of production - 2007 for Classes III and IV and 2009 for Class V; at that time we assume the variable costs of production are reduced by 20 percent. Beyond that time, we did not incorporate further cost reductions due to the learning curve. This is a conservative assumption especially when we consider how much change in engine and emission control system design is expected. This conservative assumption effectively raises the estimated cost and therefore raising our cost - effectiveness estimate. Since the technology is evolving so rapidly, we are less certain how learning curves will impact production costs in the longer term and therefore are making no explicit assumption.

One change has been made since the July 1999 SNPRM was published and that is the estimated cost for catalysts and related components. Based on comments received, this cost analysis is estimating a sales weighted catalyst cost in Class II and IV which reflects the high and low volume catalyzed substrate costs provided by MECA and packaging costs as estimated by ICF. Since we do no know the mix of large and small volume families the industry will elect to certify equipped with a catalyst in a specific year of the phase in of standards, we have assumed a sales-weighted cost based upon the current engine family sales distribution in Class III and IV. This average cost is $6.15 for Class III and $7.29 for class IV. Class V is assumed to not require the use of catalysts based on the stringency of the standard and the likely capabilities of developing technologies such as the compression wave and stratified scavenged with lean combustion.

We note that the MECA cost estimates are based on the cost of a catalyst which reduces the emissions of a 172 g/kW-hr engine by 60 % when new and 30% at the end of its useful life. Such a catalyst is oversized and thus to some extent overpriced for Phase 2 engines which are anticipated to have much lower engine out emission levels. However, we have insufficient information to appropriately lower these catalyst costs to account for the lower engine out emissions anticipated for typical Phase 2 engines. Further, this cost estimate is close to that estimated by NERA for Class III and IV in comment to this SNPRM. Echo estimated $15 for professional equipment but we believe this estimate is high and may reflect Echo’s estimate based upon current experience in California where some manufacturers are using catalysts on improved but still relatively high emitting Phase 1 engines which would necessarily require a more robust and expensive catalyst.

Table 4-09 provides an overview of the ranges of potential costs for the various technology options considered for the cost effectiveness analysis performed for this final rule. The costs included in Table 4-09 are first year costs and do not include the effect of the learning curve discussed earlier. The cost of adding a catalyst system to a technology is based on a weighting of the cost of large volume and small volume catalysts. Where a range in cost for engine technologies is presented in Table 4-09, the range represents the estimated cost when applied to a small volume family versus a large volume family. Licensing fees need to be added for engines electing to use proprietary designs. We note that, within the uncertainty of this analysis, manufacturers have a choice of cost competitive technology options.

Table 4-09
Estimated Variable Hardware Costs (1998$) for Technology Changes to Two-stroke Engines

Engine Class	Specific Technology	Hardware Variable ($)	Production Variable ($)	Total Variable ($)
III	Compression Wave Technology with Catalyst	($4.00 to $7.50*) + $6.15	$1.11	$11.26 to $14.76 + licensing fee**
IV	Four-stroke	--	--	$10.00 to $15.00***
	Stratified scavenging with lean combustion with Catalyst	$8.50 + $8.35	$1.22	$18.07
	Compression Wave Technology	$4.00 to $7.50*	$1.11	$5.11 to $8.61 + licensing fee**
	Compression Wave Technology with Catalyst	($4.00 to $7.50*) + $6.92	$1.11	$12.03 to $15.52 + licensing fee**
V	Compression Wave Technology	$4.00 to $7.50*	$0.50	$5.50 to $8.00 + licensing fee**

Sources: (See Chapter 3) Engine manufacturers, MECA, and 1996 ICF Cost Study (Ref. 1). Costs from the 1996 ICF Cost Study were increased to 1998$ through use of GDP Implicit Price Deflators for 1996, 1997 and 1998 of 1.9%, 1.9% and 1.0% respectively.

* - For 500,000 and 10,000 annual production respectively.
** - It is not known whether John Deere will also pay a portion of this licensing fee to the originator of the technology. Therefore, we analyzed two scenarios for this analysis. For the high-cost scenario we assumed that John Deere pays the full fee. For the mid-cost scenario we assumed that John Deere pays no fee. In both scenarios, all other manufacturers assumed to be using the compression wave technology were assigned the cost of the full fee. The potential licensing fee for the stratified scavenge design is not known.
*** - Based on Ryobi's estimates for sales <1 million (the $15 figure) and >1 million (the $10 figure).

Costs that were not included in this variable cost analysis include any additional label lettering, updated service manuals (writers, documentation) and seminars for dealers and training for technicians. These costs are included in the fixed cost estimates below as they tend to represent one time incremental expenditures due to the adoption of new technology.

Since we have only limited information on which technology option any specific manufacturer will select, we have made the following assumptions for the purpose of estimating the cost impact of this rule.

For John Deere equipment, we assume the compression wave technology will be used. For licensing, our "high cost" scenario assumes John Deere pays the full licensing fee assumed for other manufacturers. For our "mid-cost" scenario, we assume John Deere will not pay a fee for the use of this technology. Further we assume that John Deere's Class II engines will require catalysts although with the availability of averaging across classes, this may not be necessarily true. For Class IV engines, 50 % of the John Deere engines will require catalysts.

For manufacturers we know will be converting to 4-stroke technology, the 4-stroke variable cost is added for those applications currently using 2-stroke engines. For manufacturers currently producing 4-stroke engines, the same variable cost as applied for those switching from is assumed. This simplifying assumption overstates costs for such manufacturers.

For manufacturers we anticipate to be converting to stratified scavenge engines, the stratified scavenge variable cost is assumed. For manufacturers currently producing stratified scavenge engines for national sale, we have assumed the stratified scavenge variable cost. This simplifying assumption overstates costs for such manufacturers. Catalyst costs are added to all anticipated stratified scavenge designs in Classes IV. No licensing fee is added.

For all other manufacturers, we do not know what technology they will use but are assuming the costs of compression wave technology including the licensing fee proposed by John Deere. Additionally, we assume catalyst costs for all Class III engines. For Class IV engines, we assume a "high-cost" scenario in which all these engines will require a catalyst. For the "mid-cost" scenario, we assume these other manufacturers are just as technically capable as John Deere and will similarly try to minimize costs; therefore only 50% of their Class IV engines will require catalysts just as anticipated by John Deere.

4.3 Fixed Production and R&D Cost Estimates per Engine Class

Many of the technology changes that would be required to meet Phase 2 standards require the manufacturer to expend capital on production and research and development. Production costs include new tooling machines, molds, dies and other equipment needed to produce the changed or additional parts; the costs of changing the production line to accommodate the changes in the assembly process and in the size and number of parts; and the costs of updating parts lists. Research and development (R&D) costs include engineering time and resources spent to investigate emissions on current engines, and design and prototyping of engine design changes and/or emission reduction technology. At the first sign of stringent regulations by the California ARB, small engine manufacturers began research and development activities to address emission reductions on a portion of their production. EPA has not removed any costs manufacturers may have already incurred to meet California ARB's standards for 2000 and beyond except as identified below. EPA's standards require new technologies compared to those required by the California ARB's standards for some manufacturers and some applications. The research and development costs for engines used in farm and construction applications that California does not regulate (includes most Class V engines) still need to be applied to the federal rule. However, we anticipate that all 4-stroke engines certified to meet California standards will meet EPA's standards; no additional R&D expense will be required. Additionally, John Deere will have invested the vast majority of the R&D funds required to meet federal standards as a result of their compression wave technology development to meet California standards; we assume additional fixed cost of $50,000 per John Deere engine family to bring these California-certified designs into compliance with federal standards, largely assure full production capacity. For Komatsu Zenoah for their stratified scavenging technology, and other manufacturers whose technologies to meet EPA's standards will be extensions of their technologies to meet the California standards, we have assumed no fixed cost other than to expand production. These manufacturers of 2-stroke engines in Classes III and IV being carried over from their California designs will need to invest R&D for the addition of a catalyst. These catalyst-related cost are assumed. Also, while this cost analysis assumes catalysts on all 2-stroke Class III engines, and many Class IV engines, with the availability of the ABT program, it is expected that most likely some smaller sales volume engine families can be marketed as designed to meet the current California 72 g/kW-hr HC+NOx standards for Class III and Class IV engines with their FELs above the 50 g/kW-hr HC+NOx EPA standard averaged with credits generated on catalyst-equipped families with FELs below the EPA standard. For these "California families" marketed nationwide, no additional R&D would be required. However, as a simplifying assumption, we have not tried to account for the cost impact of federal sale of these "California families."

Handheld Classes III through V are assumed to require fixed costs for research and development and production for this cost analysis. As previously stated, the expected technologies range from mini 4-stroke to stratified scavenged with lean combustion with catalysts or compression wave technologies with catalysts. The fixed cost estimates for the technologies presented in Table 4-10 were based on estimates contained in the ICF cost study[35] for 4-stroke and stratified scavenged technologies, and estimates made by John Deere (from Docket Item IV-G-30[36]) for the compression wave technology. The costs from the ICF Cost study were updated from 1996$ estimates to 1998$ estimated by multiplying by the GDP Implicit Price Deflators for 1996, 1997 and 1998.

For the 4-stroke engines, we assessed cost on the basis of engine family production using the ICF cost estimates for a 400,000 unit production family as appropriate for families over 200,000 units and ICF's cost estimates for a 90,000 unit production family as appropriate for

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[35] The ICF report lists cost estimates for two cases of different annual production. The two cases are 400,000 units and 90,000 units. The EPA Phase 1 certification database was used to estimate engine family production levels.

[36] These estimates were completed in December 1998 and a good amount of subsequent work has been completed during 1999 as John Deere brings this design to market in California; therefore it is estimated that these cost estimates will decrease (particularly for John Deere) as developed technology is transferred to nationwide applications.

families 200,000 units or under; this assumption considered the specific engine family production volumes for the relatively few manufacturers anticipated to use 4-stroke technology.

Similarly for stratified scavenge families, we estimated costs on the basis of specific engine family production estimates for the manufacturers anticipated to used this technology.

The compression wave technology fixed costs are estimated to, for the most part, be R&D costs. While some tooling change will be necessary to, for example, drill ports in different locations of the fuel metering system, the engine is still basically a 2-stroke design and production line modifications should be minimal. While John Deere estimated no fixed production cost will be necessary since they anticipate changing tooling as the existing tooling wears out, we are allocating $25,000 fixed production cost per engine family to assure any impacts on fixed production cost are adequately accounted.

Table 4-10
Fixed Costs For Handheld Engine Families From the
ICF Cost Study and Docket Item IV-G-30 (updated to 1998$)*

Engine Class	Engine Design	Technology	Fixed Production	Fixed R&D	Total Fixed Costs*
III and IV	Two-stroke	Four-stroke (Class IV only)	$3,749,000	$577,000	$4,326,000
		Stratified scavenging with lean combustion with Catalyst	$493,000	$561,000	$1,054,000
		Compression Wave Technology	$25,000**	$50,000-$250,000	$50,000-$275,000
		Compression Wave Technology with Catalyst	$25,000**	$438,000-$638,000	$438,000-$663,000
V	Two-stroke	Stratified scavenging with lean combustion	$493,000	$173,000	$666,000
		Compression Wave Technology	$25,000**	$50,000-$250,000	$50,000-$275,000
		Improved Scavenging and Combustion Chamber Design and Catalyst	$147,000	$357,000	$504,000

* - Converted to 1998$ through Use of GDP Implicit Price Deflators for 1996, 1997 and 1998

** - While Docket Item IV-G-30 does not estimate any capital cost for production, anticipating tooling changes as part of the normal replacement cycle, it is assumed there will be some for manufacturers adopting this technology. We estimate $25,000 fixed production cost for each family of different displacement. John Deere estimated $75,000 to $300,000 in R&D for each new engine family, representing high and low cost estimates partly based on production volume. However, in developing its production to meet California regulations, John Deere will have completed its initial development work. Information gained will be easily transferable as it expands production and adjusts designs to meet federal regulations. For other manufacturers, we reduced John Deere's "High" cost estimate of $300,000 for R&D by $50,000 to account for the transfer to other manufacturers of the technology development completed by John Deere in bringing its products to market. Further, john Deere's estimates tend to be high as they were made before its products were fully developed and anticipated 100% implementation of federal standards in 2001, therefore anticipating higher incremental expenses than will be necessary.

The fixed cost estimates to be applied to engine families in this rulemaking was determined from the information in Table 4-10 and other considerations. The first of such considerations is that the fixed cost estimates for stratified scavenging with lean combustion engines was estimated by ICF before the current Komatsu Zenoah Air Head engine design was available; anticipating that the design will be in production before the federal rules take effect suggests that some of the development will be transferable and the development cost will be less.

Second, estimates for the compression wave technology were developed in the preliminary development stage of the technology and therefore anticipated the need for additional development; much of the necessary development by John Deere will have taken place in bringing this product to production for California and will be transferable to other manufacturers electing to used this technology to meet federal standards. Third, manufacturers will also have invested development resources in bringing catalyst equipped designs into production for California. [37] Fourth, these estimates for Class V engine families may underestimate cost due to the more extensive testing and evaluation performed on new technologies for professional equipment which have longer useful lives and are used in a larger number of challenging applications including chainsaws. Lastly, the September1998 certification database is used as the basis for the number of engine families to which fixed costs are applied. This would result in an overestimate of expected costs if applied to all families since review of the certification database shows that there are a number of engine families with the same displacements and differing applications.[38] It is very likely that once an engine family of a unique displacement has incorporated a technology that only slight modifications are required to apply it to differing applications and therefore the full development cost is not necessary. Based on these considerations, the (1998$) capital costs used in the cost-effectiveness calculations are as listed in Table 4-11.

[37] Equipment which incorporate low efficiency catalysts are currently in the marketplace by Husqvarna. Additional use of catalyst is expected due to the California ARB's Tier 2 standards for handheld engines taking effect in 2000.

[38] It is also likely that several engine families are developed from a similar block size and development costs can largely be spread across these families of various displacement but based upon the same block. However, the details of this are unknown at the time of this final rulemaking and therefore the assumption is simplified to only engine families of the same displacement. This simplifying assumption overestimates development costs.

Table 4-11
Capital Cost for Handheld Engines Used in the Cost-effectiveness Analysis (1998$)

Engine Class	Engine Design	Technology	Total Fixed Costs*
III	Two-stroke	Compression Wave Technology with Catalyst	$463,000-$688,000
IV	Two-stroke	Four-stroke	$4,351,000
		Stratified scavenging with lean combustion with Catalyst	$413,000-$691,000
		Compression Wave Technology	$75,000-$300,000
		Compression Wave Technology with Catalyst	$463,000-$688,000
V	Two-stroke	Compression Wave Technology	$75,000-300,000

* - Converted to 1998$ through Use of GDP Implicit Price Deflators for 1996, 1997 and 1998. These estimates include a one time fixed cost of $25,000 per engine family for updating manuals and training materials.

Engines in Class I-A already in production in the handheld classes, particularly mini four-stroke engines, will not require any changes due to their new engine emission level and deterioration compared to two-stroke engines. Engines in Class I-B are also assumed to need no improvements.

4.4 Equipment Cost Estimates

Small engines are utilized in a wide variety of equipment from handheld trimmers to chain saws, as described in Table 4-12.

Table 4-12
Common Equipment Types Per Class

Class III	Class IV	Class V
trimmers	trimmers chain saw blower/vacuum pump augers	chain saw augers

The wide variety of equipment designs, and the varying ease of designing equipment which use Small SI engines, presents a challenge when estimating costs for these classes of engines. Thereby, the analyses have been performed on the most common equipment types for each class as shown in Table 4-12. Data for the analysis is provided by the 1996 PSR OELINK database(Ref. 2), the EPA Phase 1 certification database and the ICF cost study (Ref. 1). Results from this analysis are shown in Table 4-13. These estimates are an average over all equipment engine families, types and sales per class. The actual cost increase will depend on the equipment application and flexibility of the original equipment design to incorporate a new engine.

It should be noted that this analysis has assumed the full cost of die replacement and this likely results in overestimated costs. Changes to an equipment manufacturer's line (or engine/equipment manufacturer's line since this industry is mostly vertically integrated) may be made more economical with planning. For instance, the timing of new dies in relation to the useful life of the existing dies can minimize an equipment manufacturer's costs. According to ICF, typical equipment dies last 3-10 years and produce upwards of 250,000 units. Due to the fact that there is substantial lead time for this rulemaking, it is expected that equipment manufacturers will purchase new dies near or at the end of the useful life of their existing dies. However, such a reasonable cost-minimization cost technique has not been incorporated in this cost analysis. Thus, these cost estimates exceed the actual production line costs expected. The few equipment-only manufacturers will have to work closely with engine manufacturers to ensure the availability of engine designs in a reasonable time frame for equipment engineering requirements.

Estimates for equipment changes have been based on the estimated engine changes for Classes III through V engines. Handheld engines are expected to utilize technologies of mini four-stroke, compression wave technology, compression wave technology with a catalyst, or stratified scavenged with lean combustion engine with a catalyst. Specific strategies are assumed for this analysis.[39] At the time of this final rule, EPA does not have an available resource for estimating the number of equipment models in the marketplace. Discussions with several engine manufacturers reveals that the number of models are dependent on the marketplace desire for different product from their competitors. For example, one engine may have a larger cc displacement than another engine, although it is inherently the same engine with just a slightly larger bore size, piston and rings. The EPA Phase 1 database is a source of engine manufacturers

[39] Table E-05 contains the assumptions made in this analysis on the percentage of engine families per technology. The assumptions are based on the assumed use of four-stroke and stratified scavenging by manufacturers developing or likely to use the technology and the compression wave technology was assumed to fill in the remaining need. For these other manufacturers, in Class III it is assumed 100 percent of the engines will use compression wave with catalyst. For these other manufacturers in Class IV, it is assumed all will use compression wave technology with 50% also adding a catalyst. For Class V, it is assumed 100 percent of the engines will use compression wave.

and a number of engine families. It is known that manufacturers engines are incorporated into a number of equipment types. For this analysis, EPA assumed that there were two times the number of equipment models as engine families. It is likely that this is an underestimation of the number of equipment models. However, different equipment models offered within an engine family often are quite similar in engine application (e.g., a shaft driven product) and can incorporate the same engine mounting brackets, exhaust systems, heat shields, etc. Therefore, assuming the full cost of equipment modification for two pieces of equipment per engine family is a reasonable method to approximate the anticipate equipment modification costs across all equipment offerings within an engine family. Further, handheld engine manufacturers also normally manufacturer the equipment in which there engines are installed.. Thus they can anticipate the change in engine design required to meet federal regulations and coordinate that with changes in equipment design to minimize costs. For example, the engine manufacturers may modify their dies during the time of die replacement which happens 1 or 2 times per year for large volume equipment models. This is the practice John Deere assumed as good manufacturing practice. (See Docket Item IV-G-30) Therefore the costs for this change would be minimum engineering time. However, for engine families that are low volume, it is possible that the same dies may be replaced before they are worn out. On the other hand, this may not be the case if the low volume engine families are updated on a longer lead time as allowed in this rulemaking phase-in.

As stated in the above paragraph, the majority of handheld equipment manufacturers make the engines with the exception of a few companies, such as auger manufacturers. If the current engines used by the auger manufacturers are not available upon Phase 2, then the auger manufacturers may need to incorporate changes to the auger's transmission box in order to accommodate modifications to the engine's speed-torque signature. EPA is aware of the number of engine families needing to be updated based on discussions with auger manufacturers.

Table 4-13
ICF Cost Estimates For Handheld Equipment Changes (Classes III through V)

Application	Fixed Costs (per line)	Variable Hardware (per unit)	Variable Production (per unit)
Four-stroke for chainsaws and trimmers	$164,670	$0	$0
Four-stroke for backpack blowers and pumps	$77,189	$0	$0
Redesigned, Stratified Scavenged with Lean Combustion or Compression Wave Technology engine with a Catalyst	$298,465	$1.67	$0
Redesigned, Stratified Scavenged with Lean Combustion or Compression Wave Technology w/o cat	$30,876	$0.00	$0
Ice and Earth Augers*	$60,000	$0	$0

* - Based on 1996 ICF Cost Study and discussions with and comments from (January 1998 NPRM) auger manufacturers.

4.5 Fuel Savings and Impacts on Performance

Section 213(a)(3) of the 1990 Clean Air Act requires that EPA give appropriate consideration to factors including energy, noise and safety associated with the application of technologies estimated for this rulemaking. This section discusses EPA's assessment of the effects of this rulemaking on energy (i.e., fuel economy) and power. Impacts on noise, safety and maintenance can be found in Chapter 3.

4.5.1 Fuel Consumption

This rulemaking will result in fuel savings for the consumer. This is based on the technologies to be applied on these engines to meet the Phase 2 standards as described below. The tables contained in this section present the background data utilized for estimating the fuel consumption per engine per class. These data were incorporated into the NONROAD model to calculate the fuel savings per year for all equipment types given scrappage rates, growth, engine power, engine load factor, residential or commercial usage and useful life. We assumed changes in fuel consumption as engines age over time would be the same compared to existing engines. Additional calculations for the expected reductions in fuel consumption and the resultant cost savings are presented in the Chapter 7 analysis of aggregate costs.

For two-stroke handheld engines in Classes III through V, EPA estimates that the technologies of mini four-stroke, stratified scavenging with lean combustion and compression wave will result in a 30 percent decrease in fuel consumption. This is based on an estimate that expected Phase 2 technology will reduce the approximate 30 percent of the fuel that exits the engine unburned due to fuel scavenging and incorporate technologies that will result in improved fuel combustion, thereby allowing the manufacturers to enlean the engine. Limited publicly available test data, contained in Table 4-14, illustrates the basis for the expected fuel usage due to Phase 2 technology.

Table 4-14
Fuel Consumption of Class IV Two-stroke Engines
(NOTE: weightings have been changed from 90/10 to 85/15)

Manufacturer	BSFC (g/kWh)	Reference
Husqvarna E-tech	556	Testing at EPA
John Deere LE Prototype	585	Testing at John Deere
Komatsu Zenoah Stratified Scavenged	475	Testing at EPA

The values listed in Tables 4-15 and 4-16 contain the fuel consumption values utilized to estimate fuel savings for Phase 1 and Phase 2 engines, respectively, used in EPA's NONROAD model. The Phase 1 fuel consumption levels contained in Table 4-15 were developed for EPA Phase 1 rulemaking. The fuel consumption levels presented in Table 4-16 for Phase 2 engines were determined by reducing the Phase 1 levels (in Table 4-14) by 30 percent.

Table 4-15
Phase 1 Fuel Consumption Estimates Per Engine Per Class (g/kWh)

Engine Class	OHV	Two-stroke
III	--	720
IV	515	720
V	--	529

Source: Small Engine Phase 1 RSD(Ref. 3)

Table 4-16
Phase 2 Fuel Consumption Estimates Per Engine Per Class (g/kWh)

Engine Class	OHV	Two-stroke
III	--	504
IV	515	504
V	--	370

4.5.2 Power

The power from handheld engines redesigned to utilize compression wave technology is not expected to change. Testing on developed prototypes by John Deere indicates this (se Docket Item IV-G-30). While one engine prototype developed by John Deere did experience a significant power loss (as noted by some commenters), this was a large chainsaw application using a competitors product (John Deere currently does not make that large of an engine), was constructed using an available but seriously undersized carburetor and was the result of only two weeks of development effort. Therefore we believe that given the development time available in the rule, such potential performance problems are solvable for all applications using compression wave technology. For engines redesigned to use a stratified scavenged with lean combustion design, the engine power would be expected to decrease minimally without a change in the engine size. Current designs have up to a 7 % power loss. This is not significant for typical consumer applications such as string trimmers or blowers as the engines used in such equipment usually supplies much more than the necessary power. It is also possible that with additional development, engineering solutions which minimize this power loss will be available for those applications (such as commercial chain saws) which place demands on the engine closer to its peak power capability. If that is not possible, in some cases engine manufacturers may choose to increase the size of the engine to obtain similar power to Phase 1 engines. This can be done without adding weight by boring out the cylinder, for example. This would require a change in tooling which could be anticipated and incorporated in the normal tooling replacement cycle. Any costs associated with the potential The need to increase engine size to maintain power cannot be quantified at this time and the options available to the engine manufacturer are depend on the base engine and the specific equipment needs. While these changes, especially as it may impact the cost analysis for this rule are anticipated to be small at most, they have not been quantified.

4.5.3 Oil Consumption

With conversion to a four-stroke design which has a separate oil lubrication system separate from the fuel system and with improvement in two-stroke combustion which reduces the amount of fuel-oil mixture consumed, oil consumption will also decrease with a resultant decrease in consumer cost. Since the cost of the oil currently used in 2-stroke engines is a small operating cost (engines typically operate with 50 parts gasoline to one part oil and the oil costs about $5 per quart in residential quantities), the impact on this cost will also be small. However, this decrease in oil consumption and oil cost has not been estimated.

4.5.4 Assumed Amortization Period

All fixed costs are amortized over 5 years. This is a simplifying assumption which accelerates the cost allocation for certain new equipment required to be added by manufacturers to meet these rules. For example, the addition of a new press machine might be required and would appropriately be amortized over 10 years. This simplifying assumption, while easing calculations, tends to overstate costs, especially for situations where significant new production hardware would be required such as in changing from 2-stroke production to 4-stroke production.

Chapter 4 References

1a. ICF and Engine, Fuel and Emissions Engineering, Incorporated; "Cost Study For Phase Two Small Engine Emission Regulations", Draft Final Report, October 25, 1996, Docket Item IV-A-1.

1. J.M Dutton and A. Thomas, *Academy of Management Review*, Rev. 9, 235, 1984.

2. Power Systems Research, OELINK database, St. Paul, Minnesota, 1996.

3. US EPA, "Regulatory Impact Analysis and Regulatory Support Document Control of air Pollution; Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts", May 1995, EPA Air Docket A-93-25, Docket Item V-B-1.

Chapter 5: Compliance Program Costs

The Phase 1 rule is a "new engine certification only" rule in that the standards need only be met after a short number of break-in hours (less than 12 hours) prior to production and SEA. This Phase 2 regulation will bring the concepts of useful life and emission deterioration to the emission regulation of handheld small spark ignited engines at or below 19kW. These program elements will work to assure that actual production engines meet standards throughout their useful lives.

The costs accounted for in this chapter are those costs that are above those required in Phase 1. Appendix C contains the detailed cost spreadsheet results for each compliance program. A summary of the cost results for each program per engine class and the overall cost methodology is included at the end of this chapter. Reductions in costs for small-volume engine manufacturers or small-volume engine families are accounted for in this analysis.

5.1 Background

General assumptions and cost estimates for the various compliance programs for handheld engines are described herein.

5.1.1 Engine Families

The program costs are calculated on the number of engine families per class. This data is taken from EPA's Phase 1 certification database as of September 1998 (Appendix C contains nonconfidential database information). While a reliable source for engine families for the Phase 1 program, we expect that manufacturers may make changes during the years in which the Phase 2 program is in effect. However, it is difficult to predict these changes at this time. Consequently, this analysis makes no assumption as to a different number of engine families from the Phase 1 database. The costs associated with record keeping requirements for each program is included in the ICR's submitted with this rulemaking.

5.1.2 Assumed Costs

The number of break-in hours and the costs for bench age hours and emission testing for this analysis are included in Table 5-01.

Table 5-01
Common Costs Among Compliance Programs

Topic	Estimate	Resource
Hours for break-in	4.2	Average from EPA Phase 1 certification database for Classes III-V.
Bench age ($/hour)	$15.00	EMA/OPEI NPRM Comments
Emission test ($)	$300.00	EPA estimate from "Cost Study for Phase Two Small Engine Emission Regulations", ICF and EF&EE, October 25, 1996 (Ref. 1) and other industry data.

5.2 Certification

The Phase 2 rule continues the fundamental certification program that began in Phase 1. The most significant additional component to certification that affects all engines under Phase 2 is the need to predict emissions for an engine family to its full useful life. This is done, for all engine classes, through bench aging up to the chosen useful life hours. A deterioration factor must also be established for the engine family to be used in conducting the Production Line Testing program and therefore the engine must be tested two times. The first time is just after break-in and the second is at the end of its useful life. Small-volume engine families and engine families of small-volume manufacturers may utilize assigned deterioration factors(df) for the specific engine design. However, this analysis assumes that manufacturers of small-volume engine families and small-volume engine manufacturers bench age their engine families in order to obtain an engine specific df since it is a one time cost and due to the impact on using a potentially higher assigned df (based on the stringency of the standards).

5.2.1. Cost Inputs and Methodology-- As stated previously, the number of engine families chosen for the various useful lives was determined through examination of EPA's Phase 1 certification database as of September 1998 and assumptions of each engine manufacturer's market tendencies (see Table 5-02). We assume that the same number of engine families certified today will be certified in the Phase 2 program.

We estimated the number of engine families certified to the individual useful life categories. The basis of the estimation was the industry to which the manufacturer was known, be it low cost consumer or high quality commercial. No split was made between engine families within an engine manufacturer (in other words, assuming a portion was for consumer and a portion was for commercial). For the 50-hour useful life category, we assigned those manufacturers, and related engine families, geared toward the consumer market. For the 300-hour useful life category, we considered those manufacturers, and related engine families, with ties to the automotive market. Lastly, for the 125-hour useful life, we assumed the remaining engine manufacturers and related engine families. For Class I-B engine families, we assumed the 125 useful life hour which is the first certification useful life hour category for nonhandheld engine families.

The analysis assumes that certification occurs twice per engine family throughout the phase-in of the Phase 2 standards. This is assumed due to the fact that the standards are average standards for all classes and all engine families must be certified the first year to which they are applicable, whether or not they are in their final Phase 2 configuration. We assume carryover for certification will be used until the engines are updated for emission compliance at which time they will be recertified. All families are included in the analysis based on the analysis, with ABT, of engine manufacturers engine families which shows that the large majority of handheld engine families will likely be updated due to the magnitude of difference in the emission standards from Phase 1 to Phase 2.

Costs for the emission tests, break-in hours, and bench aging (on a dynamometer) are listed in Table 5-01. (A summary of the total certification costs per year (2002 to 2011) per class are listed in Table 5-04.) Certification costs are treated as fixed costs and are amortized at a rate of 7 percent over 5 years.

Table 5-02
Number of Phase 1 Certification Families per Useful Life Category Assumptions for Handheld Engine Classes and Class I-B
(Includes Small Volume Engine Families)

Engine Class	Useful Life Category			
	50	125	300	125
III	4	1	4	--
IV	22	40	59	--
V	3	15	35	--
I-B	--	--	--	4

Engine families that may qualify for Class I-A may utilize the same data as qualification for Classes III-V and therefore no costs are assumed for Class I-A engine families. For Class I-B, the EPA 1998 certification database shows that there are three engine families that would qualify for this class. We are aware of at least one engine family not yet certified, however the sales production estimate is unknown.

5.3 Averaging, Banking and Trading

Averaging, banking and trading (ABT) will enable handheld manufacturers to comply with the HC + NOx standard on a production-weighted average basis. By essentially allowing a manufacturer to produce some engines that exceed the standards when it can generate or obtain offsetting credits from engines that are below the standards, and the required emission level, the ABT program will reduce the capital costs of complying with the Phase 2 standards. Manufacturers will be able to distribute capital across engine families to obtain the most cost-effective emission reductions, as long as the ABT calculation is acceptable to prove compliance to the standards. The optional ABT program adds no costs to the certification process, but does necessitate limited tracking of engines for credit accounting purposes. Related costs are addressed in the certification ICR's for this program. While the ABT program is optional for all engine manufacturers, this analysis assumes that all engine manufacturers will utilize this option. The analyses also assumes that manufacturers will work to optimize the number of engine families that will need to be improved to meet the emission standards in this rulemaking. Optimization is achieved by choosing those engine families that have high emission rates and high production volumes that will result in influencing the manufacturers' production weighted average the most.

5.4 Production Line Testing

5.4.1 Rationale for Production Line Testing

The certification process is performed on prototype engines selected to represent an engine family. A certificate of conformity indicates that a manufacturer has demonstrated its ability to design engines that are capable of meeting standards. Production line testing indicates whether a manufacturer is able to translate those designs into actual mass production engines that meet standards.

Manufacturer run Production Line Testing (Cum Sum) is a new program to the EPA requirements for small engines. Therefore all of the costs are allocated to the Phase 2 program. Note that engine manufacturers will be conducting quality audit testing for California's ARB and therefore will likely utilize the same data for EPA's PLT program[40]. However, it is likely that manufacturers do not sell all of their product line for use in California and therefore will incur additional costs to test their whole product line. Since the estimated volume per engine family per manufacturer sold in California is unknown, and likely varies amongst engine manufacturers, no costs were subtracted for CARB quality audit testing.

5.4.2 Cost Inputs and Methodology

All engine manufacturers will conduct PLT and it is to be conducted on each engine family certified to the standard each year. Therefore all Class III and Class IV engine families except those eligible for the small volume flexibilities must be tested in the PLT program in 2002 and, similarly, Class V engines families in 2004. Testing will be performed on 2 to 30 engines. A value of 7 tests per engine family are assumed for this analysis. PLT is performed on new engines and therefore an initial engine break-in and emission test is required. Table 5-03 contains the assumed engine family phase in schedule for the PLT program. Small engine families and engine families from small volume manufacturers may not perform PLT. This analysis assumes that PLT will not be performed on such families and therefore the small volume families are not

[40] If the data are from 50 state engine families sold nationwide and if the test engines are appropriately selected and tested.

included in Table 5-03.

All engine families would be required to be tested beginning with the first year of the phase-in. The average break-in hours for each engine per class, emission test costs and break-in costs were utilized in this analysis as described in Table 5-01. A summary of the PLT costs per year (2002 through 2027 (Class III and IV) and 2004 through 2027 for Class V) per class for the requirements in this section are listed in Table 5-05.

Table 5-03
Assumed Engine Family Phase-In Per Class Per Year

Year	Class III	Class IV	Class V	Class I-B
2002	6	72	--	2*
2004	--	--	23	--

PLT performed for each engine family, regardless if same engine certified with various fuel specifications. PLT an option for small volume engine families.
*Number of engine families (not including small volume) taken from EPA Phase 1 certification database as of September 1998 (one additional Class I-B engine family is not yet certified to Phase I, but will be certified to Phase 2)

5.5 Cost Summary Tables

The costs for each program were estimated in 1996, 1997 and 1998. The GDP Implicit Price Deflator for 1996, 1997 and 1998 were used to bring all costs to 1998. Tables 5-04 to 5-05 present the estimated costs for the certification and PLT compliance programs, respectively, as incurred through 2010. The total estimated compliance program costs, as incurred, are presented in Table 5-06. The total estimated compliance program costs, as recovered, are presented in Table 5-07. The administrative costs for these programs are included in the ICR's for this final rule.

Chapter 7 determines the uniform annualized cost and cost per engine for this rulemaking (with costs as recovered).

Table 5-04
Certification Costs Per Class Per Year As Incurred (1998$)

Calendar Year	Class III	Class IV	Class V and Class I-B
2002	$3,860	$77,843	$13,720
2003	$0	$15,463	$0
2004	$1,368	$108,878	$8,978
2005	$10,395	$43,653	$30,573
2006	$0	$0	$12,728
2007	$0	$0	$43,300
2008	$15,353	$185,883	$0
2009	$0	$0	$0
2010	$0	$0	$125,025

Table 5-05
Production Line Testing Costs As Incurred (1998$)

Calendar Year	Class III	Class IV	Class V and Class I-B
2002	$15,614	$187,366	$5,205
2003	$15,614	$187,366	$5,205
2004	$15,614	$187,366	$65,057
2005	$15,614	$187,366	$65,057
2006	$15,614	$187,366	$65,057
2007	$15,614	$187,366	$65,057
2008	$15,614	$187,366	$65,057
2009	$15,614	$187,366	$65,057
2010+	$15,614	$187,366	$65,057

Table 5-06
Total Compliance Program Costs Per Class As Incurred (1998$)

Year	Class III	Class IV	Class V and I-B
2002	$19,474	$265,208	$18,925
2003	$15,614	$202,828	$5,205
2004	$16,981	$296,243	$74,035
2005	$25,959	$231,018	$95,630
2006	$15,614	$187,366	$77,785
2007	$15,614	$187,366	$108,358
2008	$30,966	$373,249	$65,057
2009	$15,614	$187,366	$65,057
2010	$15,614	$187,366	$190,083
2011	$15,614	$187,366	$65,057
2012	$15,614	$187,366	$65,057
2013	$15,614	$187,366	$65,057
2014	$15,614	$187,366	$65,057
2015	$15,614	$187,366	$65,057
2016	$15,614	$187,366	$65,057
2017	$15,614	$187,366	$65,057
2018	$15,614	$187,366	$65,057
2019	$15,614	$187,366	$65,057
2020	$15,614	$187,366	$65,057
2021	$15,614	$187,366	$65,057
2022	$15,614	$187,366	$65,057
2023	$15,614	$187,366	$65,057
2024	$15,614	$187,366	$65,057
2025	$15,614	$187,366	$65,057
2026	$15,614	$187,366	$65,057
2027	$15,614	$187,366	$65,057

Table 5-07
Total Compliance Program Costs Per Class As Recovered (1998$)

Year	Class III	Class IV	Class V and I-B
2002	$16,555	$206,351	$8,551
2003	$16,555	$210,122	$8,551
2004	$16,889	$236,676	$70,593
2005	$19,412	$247,323	$78,050
2006	$19,412	$247,323	$81,154
2007	$18,470	$228,338	$88,368
2008	$22,215	$269,902	$88,368
2009	$21,881	$243,347	$86,178
2010	$19,358	$232,701	$109,215
2011	$19,358	$232,701	$106,111
2012	$19,358	$232,701	$95,550
2013	$15,614	$187,366	$95,550
2014	$15,614	$187,366	$95,550
2015	$15,614	$187,366	$65,057
2016	$15,614	$187,366	$65,057
2017	$15,614	$187,366	$65,057
2018	$15,614	$187,366	$65,057
2019	$15,614	$187,366	$65,057
2020	$15,614	$187,366	$65,057
2021	$15,614	$187,366	$65,057
2022	$15,614	$187,366	$65,057
2023	$15,614	$187,366	$65,057
2024	$15,614	$187,366	$65,057
2025	$15,614	$187,366	$65,057
2026	$15,614	$187,366	$65,057
2027	$15,614	$187,366	$65,057

- Certification costs are amortized at 7% over 5 years.

Chapter 5 References

1. ICF and Engine, Fuel and Emissions Engineering, Incorporated; "Cost Study For Phase Two Small Engine Emission Regulations", Draft Final Report, October 25, 1996, Docket Item IV-A-01.

Chapter 6: Environmental Benefit

This chapter presents the methodology used to quantify the emission reduction benefits that will be realized from the final Phase 2 HC+NOx emission standards for Small SI handheld engines. Benefits, in terms of HC+NOx emission reductions, are presented in the form of aggregate benefits for all three handheld engine classes combined. These benefits are estimated in terms of future 50-state emission reductions from affected Small SI engines used in a variety of handheld equipment types (engines subject to California regulations are estimated to meet the California standard of 72 g/kW-hr prior to the implementation of federal regulations while other engines are estimated to meet the federal Phase 1 emission regulations). Estimated benefits illustrate the future effect of the final Phase 2 standards on the emission inventory. Air quality benefits are discussed qualitatively for all pollutants.

Many of the detailed results discussed below are presented in separate tables included in Appendix F. EPA has made some revisions to the NONROAD Model inputs since the SNPRM was published in July 1999. The changes were made based on discussions with manufacturers during the Phase II rulemaking process. The three sets of inputs that were impacted were (1) residential/commercial population splits for two-stroke Chainsaws, Trimmers/Edgers/Brush cutters, and Blowers/ Vacuums, (2) load factors and hence the "Median Life at Full Load" values for the above-mentioned applications, and (3) "Median Life at Full Load" for Class V Trimmers/Edgers/Brush Cutters. The following sections highlight areas where differences exist between modeling performed for the July 1999 SNPRM and that for the final rulemaking.

For a complete description of EPA's NONROAD model, the reader is referred to the technical reports and program documentation prepared by EPA in support of NONROAD model development. Copies of the technical reports and model documentation are available at EPA's web site for nonroad modeling (http:/www.epa.gov/omswww/nonrdmdl.htm).

6.1 Estimated Emissions Reductions

To estimate the average annual emissions at baseline (Phase 1), EPA calculated the tons per year estimates based on revised Phase 1 emission factors. The in-use factors have now been determined as a multiplicative rather than an additive (as was the case for the Phase 1 rulemaking) function of new engine emission factors and a deterioration factor which is a function of engine hours of use. As before, total emissions are calculated for each type of equipment using the equation :

$$MASS_{i,j}=N_{i,j}\times HP_{i,j}\times LOAD_i\times HOURS_i\times EF_{i,j}$$

Where,

$N_{i,j}$ = nationwide population of i[th] equipment type using engine j
$Hp_{i,j}$ = average rated horsepower of engine j used in equipment type i
$LOAD_i$ = ratio (%) between average operational power output and rated power for the i[th] equipment type
$HOURS_i$ = average annual hours of usage for the i[th] equipment type
$EF_{i,j}$ = brake specific in-use emission rate (kilowatts/hr) for engine type j used in equipment i
$MASS_{i,j}$ = annual nationwide emissions (grams) for the j[th] engine type used in equipment i

For the benefits analysis described here, EPA performed separate calculations for the major equipment categories, each one of which is equipped with one or more of seven different engine types with average power ratings as displayed in Table F-01. Population and activity information used to construct the inventories relied predominantly on data available in a commercially available marketing research database that includes most types of nonroad equipment (Ref. 1a). As noted above, EPA did update the load factor information in the NONROAD model for the three largest handheld applications. The updated load factor information was gathered by engine manufacturers (Ref. 1b) in support of their recommendation for a slightly modified test cycle for the Phase 2 program. The updated load factor information is presented in Table F-03.

6.1.1 Aggregate HC+ NOx Reductions

The calculation of aggregate HC+ NOx reductions is described in this section. The calculation takes into account U.S. population of Small SI handheld engine/equipment types, excluding those engines regulated by the state of California, hours of use, average power rating and related equipment scrappage rates as described below. Along with estimated values for Phase I and Phase II in-use engine emission rates, EPA has determined nationwide annual emissions under the baseline and controlled scenarios through calendar year 2027.

6.1.1.1 In-use Population --In order to estimate future emission totals, some projections of future populations of Phase1 and Phase 2 controlled engines are needed. The NONROAD model has determined population estimates of nonroad equipment covered by the now final standards using certain growth factors. For the base population estimates, the NONROAD model uses the 1996 population estimates from the Power Systems Research (PSR) PartsLink database. To check on PSR population estimates, the population for several high sales applications (i.e.: trimmers, blowers and chainsaws) were checked, using historical sales data and engine manufacturer production estimates from the EPA 1998 certification database, and were adjusted accordingly. As noted above, for this analysis, the population estimates were adjusted to exclude engines that are covered by California's Small Off-Road regulations.

6.1.1.2 Growth Estimates -- The NONROAD model projects future year (post-base year) equipment populations by applying a growth rate to the base year equipment population. The determination of the growth rate uses a methodology which is different from that used for the Phase 1 rulemaking. For a detailed description of population growth in the various categories of handheld equipment the reader is referred to a paper presented by EPA at the AWMA Emission Inventory Conference, New Orleans, LA on 12/9/98 titled "Geographic Allocation and Growth in EPA's Nonroad Emission Inventory Model."

However, it should be recognized that, while national growth is measured at the level of the economy as a whole, growth in specific areas of the country is likely to vary from area to area in response to the specific demographic and commercial trends in those areas. These effects should be taken into account in estimating growth at the local level. Table F-02 in Appendix F contains the estimated in-use populations for the major handheld equipment populations in various years.

6.1.1.3 Scrappage-- The NONROAD model uses a scrappage curve to determine the proportion of equipment that has been scrapped as a function of equipment age. The default scrappage curve used in the NONROAD model is based on a cumulative Normal Distribution representing accumulated scrappage at various ages. The scrappage curve is scaled to the average lifetime of the equipment such that half of the units sold in a given year are scrapped by the time those units reach the average expected life and that all units are scrapped at twice the average life expectancy. The median life of the different handheld equipment types are presented in Table F-03 in Appendix F.

6.1.1.4 Emission Factors -- For the Phase 2 scenario, the new engine emission factor values were obtained by back-calculation, using (1) the final in-use emission factors (Phase 2 standards) and (2) a multiplicative deterioration factor (DF). For the pre-control (Phase1) scenario, in-use emission factors were determined using the same methodology. For both scenarios, the deterioration factor as defined below was determined for HC and CO using the ratio of maximum emission level and the new engine level. This value was then used to calculate the coefficient 'A' in the deterioration factor equation below:

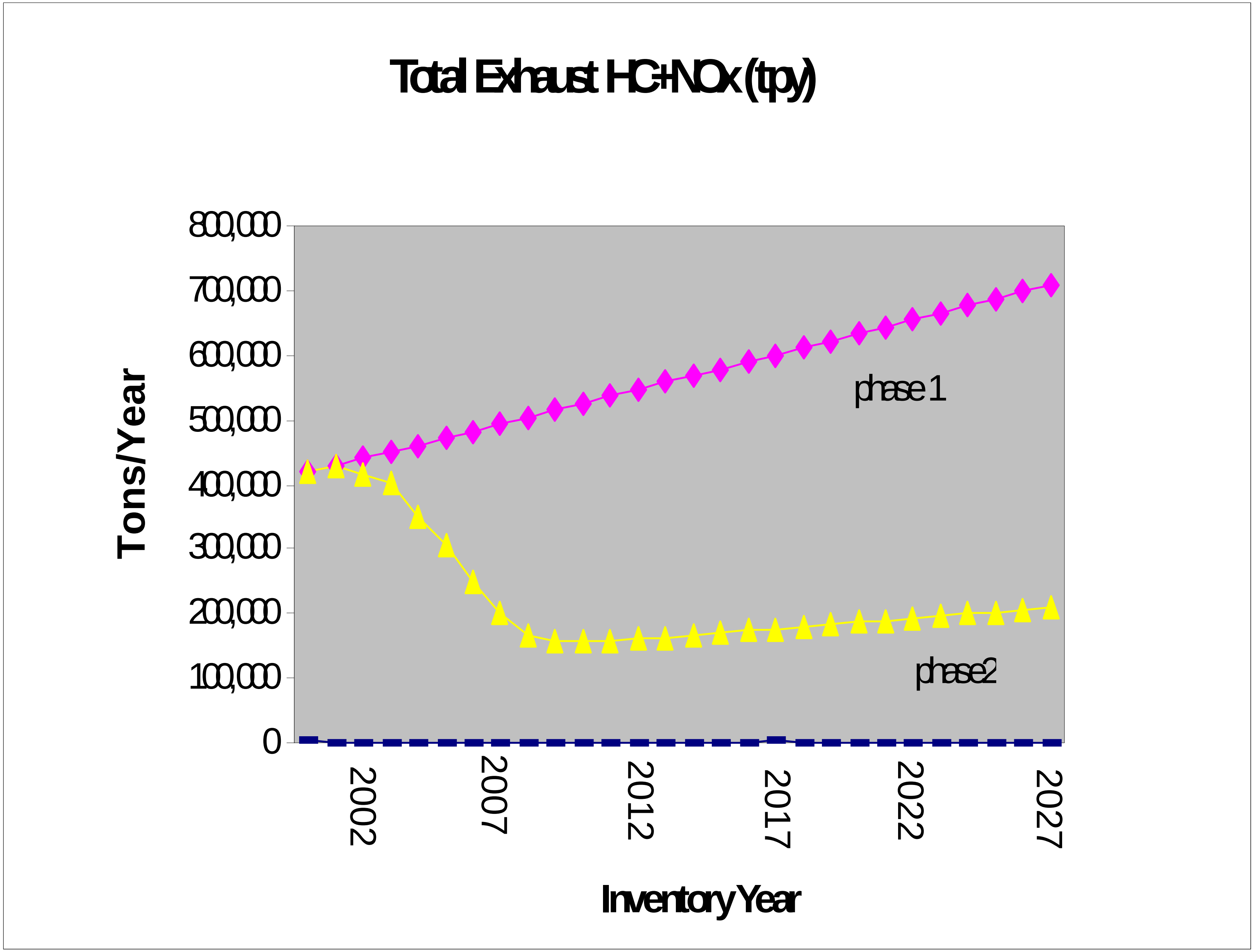
$$DF = 1 + A\times(\text{Agefactor}) \qquad \text{for agefactor}<1.0$$
$$= 1+A \qquad \text{for agefactor}>=1.0$$

For NOx, the deterioration factors were set to 1.0, resulting in an A value of zero. The exhaust emission factors for HC, NOx and CO along with those for Fuel Consumption are displayed in Table F-04 in Appendix F. The table also lists the value of the coefficient A, the slope of the deterioration factor equation.

For a detailed explanation of the deterioration factor function, the reader is referred to EPA's technical report no. NR-011 , titled “Emission Deterioration Factors for the NONROAD Emissions Model.”

6.1.1.5 Emissions reductions-- EPA calculated baseline emissions using in-use emission factors for Phase 1. To obtain average annual emissions for engines controlled to the levels that will be required to comply with EPA's final Phase2 emission standards , emissions were recalculated using post-control activity and in-use Phase 2 emission factors (see Table F-04 in Appendix F).

Table F-05 in Appendix F presents total annual nationwide emissions from engines addressed in this rule under both the baseline (Phase 1) and the controlled (Phase 2) scenario. The nationwide emissions are shown graphically in Figure 6-01.



Total Exhaust HC+NOx (tpy)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Tons/Year
phase 1
phase2
2002
2007
2012
2017
2022
2027
Inventory Year

In Figure 6-01, the annual benefit of the regulation in terms of reduction in total exhaust HC+NOx is indicated by the difference between the upper and lower curves. The area between the curves represents the net benefit of the regulation during the time required for the nonroad Small SI handheld engine and equipment fleet to completely turn over. The results indicate that the Phase 2 standards represent on average a 70.5 percent reduction in annual HC+NOx emissions from handheld engines compared to Phase 1 levels, by the year 2027.
In addition, the rule is expected to reduce Fuel Consumption in handheld engines by approximately 30 percent from Phase1 levels by year 2027. This will have a beneficial impact on HC refueling losses as well.

6.2 Air Quality Benefits

This section describes the public health and welfare concerns associated with the pollutants impacted by this rulemaking, including ozone, air toxics, and carbon monoxide. These benefits are discussed qualitatively for all pollutants.

6.2.1 Ozone

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and nitrogen oxides (NOx) in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. Volatile organic compounds (VOCs) are a broad group of compounds composed mainly of hydrocarbons (HCs). Aldehydes, alcohols, and ethers are also present, but in small amounts. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs also are emitted by natural sources such as vegetation. NOx is emitted largely from motor vehicles, nonroad equipment, power plants, and other sources of combustion.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight.[41] As a result, differences in NOx and VOC emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and produce more ozone than typically would occur on a single high temperature day. Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NOx emissions.

[41] Carbon monoxide also participates in the production of ozone, albeit at a much slower rate than most VOC and NOx compounds.

Emissions of NOx and VOC are precursors to the formation of ozone in the lower atmosphere. For example, small amounts of NOx enable ozone to form rapidly when VOC levels are high, but ozone production is quickly limited by removal of the NOx. Under these conditions, NOx reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NOx limited.” Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are low can be NOx limited.

When NOx levels are high and VOC levels relatively low, NOx forms inorganic nitrates but little ozone. Such conditions are called “VOC limited.” Under these conditions, VOC reductions are effective in reducing ozone, but NOx reductions can actually increase local ozone. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities.

Rural areas are almost always NOx limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC or NOx limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NOx, VOC, and ozone, all of which change with time and location.

Based on a large number of recent studies, EPA has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the country (Ref. 1, 2). Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. For example, studies conducted in the northeastern U.S. and Canada show that ozone air pollution is associated with 10-20 percent of all of the summertime respiratory-related hospital admissions. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma. Prolonged exposure to ozone can cause repeated inflammation of the lung, impairment of lung defense mechanisms, and irreversible changes in lung structure, which could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema, chronic bronchitis and chronic asthma.

Children are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest. For example, summer camp studies in the eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors. Further, children are more at risk than adults from ozone exposure because their respiratory systems are still developing. Adults who are outdoors and moderately active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during periods of moderate exertion.

Evidence also exists of a possible relationship between daily increases in ozone levels and increases in daily mortality levels. While the magnitude of this relationship is still too uncertain to allow for direct quantification, the full body of evidence indicates a likely positive relationship between ozone exposure and premature mortality.

In addition to human health effects, ozone adversely affects crop yield, vegetation and forest growth, and the durability of materials. Because ground-level ozone interferes with the ability of a plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. Ozone causes noticeable foliar damage in many crops, trees, and ornamental plants (i.e., grass, flowers, shrubs, and trees) and causes reduced growth in plants. Studies indicate that current ambient levels of ozone are responsible for damage to forests and ecosystems (including habitat for native animal species). Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and, to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

VOC emissions are detrimental not only for their role in forming ozone, but also for their role as air toxics. Some VOCs emitted from motor vehicles are toxic compounds. At elevated concentrations and exposures, human health effects from air toxics can range from respiratory effects to cancer. Other health impacts include neurological, developmental and reproductive effects. Section 6.2.2. contains more information about air toxics.

Besides their role as an ozone precursor, NOx emissions produce a wide variety of health and welfare effects (Ref. 3, 4). These problems are caused in part by emissions of nitrogen oxides from motor vehicles. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NOx emissions are an important precursor to acid rain and may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems (“eutrophication”) in the Chesapeake Bay and several nationally important estuaries along the East and Gulf Coasts. Eutrophication can produce multiple adverse effects on water quality and the aquatic environment, including increased algal blooms, excessive phytoplankton growth, and low or no dissolved oxygen in bottom waters. Eutrophication also reduces sunlight, causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Deposition of nitrogen-containing compounds also affects terrestrial ecosystems. Nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of plants and microorganisms to utilize and retain the nitrogen.

Elevated levels of nitrates in drinking water pose significant health risks, especially to infants. Studies have shown that a substantial rise in nitrogen levels in surface waters are highly correlated with human-generated inputs of nitrogen in those watersheds (Ref. 5). These nitrogen inputs are dominated by fertilizers and atmospheric deposition.

Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and the value placed on scenic views. Section 6.2.4. further describes information about visibility impairment and regional haze.

Nonroad sources contribute substantially to summertime VOC and NOx emissions and winter CO emissions. The median contribution of total nonroad emissions to VOC and NOx inventories in summer ranges from 7.4 to 12.6 percent for VOC and 14.5 to 17.3 percent for NOx, depending on the area (Ref. 6). The lawn and garden equipment category is a major contributor to summertime VOC emissions, accounting for a median ranging from 2.4 to 4.7 percent of the total VOC inventory in tons per summer day, depending on the area.

EPA expects that reducing NOx and HC emissions from small nonroad spark-ignition engines will help mitigate the health and welfare effects of urban and regional tropospheric ozone formation and transport.

6.2.2 Air Toxics

Hydrocarbons are made up of hundreds of different compounds, some of which like benzene and 1,3-butadiene, are considered to be hazardous air pollutants. This section discusses the health and welfare of these two toxics and the benefits expected by this rulemaking.

6.2.2.1. Benzene

Benzene is an aromatic hydrocarbon which is present as a gas in both exhaust and evaporative emissions from motor vehicles. Benzene in the exhaust, expressed as a percentage of total organic gases (TOG), varies depending on control technology (e.g., type of catalyst) and the levels of benzene and aromatics in the fuel, but is generally about three to five percent. The benzene fraction of evaporative emissions depends on control technology (i.e., fuel injector or carburetor) and fuel composition (e.g., benzene level and Reid Vapor Pressure, or RVP) and is generally about one percent.

The EPA has recently reconfirmed that benzene is a known human carcinogen by all routes of exposure (Ref. 7). Respiration is the major source of human exposure. At least half of this exposure is by way of gasoline vapors and automotive emissions (EPA 1998a). Long-term exposure to high levels of benzene in air has been shown to cause cancer of the tissues that form white blood cells. Among these are acute nonlymphocytic[42] leukemia, chronic lymphocytic

[42] Leukemia is a blood disease in which the white blood cells are abnormal in type or number. Leukemia may be divided into nonlymphocytic (granulocytic) leukemias and lymphocytic leukemias. Nonlymphocytic leukemia generally involves the types of white blood cells (leukocytes) that are involved in engulfing, killing, and digesting bacteria and other parasites (phagocytosis) as well as releasing chemicals involved in allergic and immune

leukemia and possibly multiple myeloma (primary malignant tumors in the bone marrow), although the evidence for the latter has decreased with more recent studies (Ref. 8,9). Leukemias, lymphomas, and other tumor types have been observed in experimental animals that have been exposed to benzene by inhalation or oral administration (EPA 1985, Clement 1991). Exposure to benzene and/or its metabolites has also been linked with genetic changes in humans and animals and increased proliferation of mouse bone marrow cells (Ref. 10,11). Furthermore, the occurrence of certain chromosomal changes in individuals with known exposure to benzene may serve as a marker for those at risk for contracting leukemia (Ref. 12).

The latest assessment by EPA places the excess risk of developing acute nonlymphocytic leukemia at 2.2×10^{-6} to $7.7 \times 10^{-6}/\mu g/m^3$ (EPA, 1998a). In other words, there is a risk of two to eight excess acute nonlymphocytic leukemia cases in one million people exposed to $1 \mu g/m^3$ benzene over a lifetime (70 years). These numbers represent the maximum likelihood (MLE) estimate of risk, not an upper confidence limit (UCL).

A number of adverse noncancer health effects, blood disorders such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene (EPA 1985, Clement 1991, Ref. 13). People with long-term exposure to benzene may experience harmful effects on the blood-forming tissues, especially the bone marrow. These effects can disrupt normal blood production and cause a decrease in important blood components, such as red blood cells and blood platelets, leading to anemia (a reduction in the number of red blood cells), leukopenia (a reduction in the number of white blood cells), or thrombocytopenia (a reduction in the number of blood platelets, thus reducing the ability for blood to clot). Chronic inhalation exposure to benzene in humans and animals results in pancytopenia[43] ,a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets) (Ref. 14, 15). Individuals that develop pancytopenia and have

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responses. This type of leukemia may also involve erythroblastic cell types (immature red blood cells). Lymphocytic leukemia involves the lymphocyte type of white bloods cell that are responsible for the immune responses. Both nonlymphocytic and lymphocytic leukemia may, in turn, be separated into acute (rapid and fatal) and chronic (lingering, lasting) forms. For example; in acute myeloid leukemia (AML) there is diminished production of normal red blood cells (erythrocytes), granulocytes, and platelets (control clotting) which leads to death by anemia, infection, or hemorrhage. These events can be rapid. In chronic myeloid leukemia (CML) the leukemic cells retain the ability to differentiate (i.e., be responsive to stimulatory factors) and perform function; later there is a loss of the ability to respond.

[43] Pancytopenia is the reduction in the number of all three major types of blood cells (erythrocytes, or red blood cells, thrombocytes, or platelets, and leukocytes, or white blood cells). In adults, all three major types of blood cells are produced in the bone marrow of the vertebra, sternum, ribs, and pelvis. The bone marrow contains immature cells, known as multipotent myeloid stem cells, that later differentiate into the various mature blood cells. Pancytopenia results from a reduction in the ability of the red bone marrow to produce adequate numbers of these mature blood cells.

continued exposure to benzene may develop aplastic anemia,[44] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state (Ref. 16, 17). The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood (Ref. 18). A draft reference concentration (RfC) has been developed for benzene. The reference concentration (RfC) is an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious noncancer effects during a lifetime; these estimates frequently have uncertainty levels that span perhaps an order of magnitude. The draft benzene RfC is 9 $\mu g/m^3$, which means that long-term exposures to benzene should be kept below 9 $\mu g/m^3$ to avoid appreciable risks of these non-cancer effects (Ref. 19). This RfC is currently being revised.

Since benzene levels generally decrease proportionally to overall HC emissions, once newer emission control technology is applied, the amount of benzene produced by new Small SI engines should be reduced further from Phase 1 once this rule becomes effective.

6.2.2.2. Butadiene

1,3-Butadiene is formed in vehicle exhaust by the incomplete combustion of the fuel. It is not present in vehicle evaporative and refueling emissions, because it is not present in any appreciable amount in gasoline. 1,3-Butadiene accounts for 0.4 to 1.0 percent of total exhaust TOG, depending on control technology and fuel composition.

1-3-Butadiene was classified by EPA as a Group B2 (probable human) carcinogen in 1985 (Ref. 20). This classification was based on evidence from two species of rodents and *** epidemiologic data. EPA recently prepared a draft assessment that would determine sufficient evidence exists to propose that 1,3-butadiene be classified as a known human carcinogen (Ref. 21). However, the Environmental Health Committee of EPA's Scientific Advisory Board (SAB), in reviewing the draft document, issued a majority opinion that 1,3-butadiene should instead be classified as a probable human carcinogen (Ref. 22). In the draft EPA assessment, the MLE estimate of a lifetime extra cancer risk from continuous 1,3-butadiene exposure is about $3.9 \times 10^{-6}/\mu g/m^3$. In other words, it is estimated that approximately 4 persons in one million exposed to 1 $\mu g/m^3$ 1,3-butadiene continuously for their lifetime (85 years in this case) would develop cancer as a result of their exposure. Lower exposures are expected to result in risks that are lower.

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[44] Aplastic anemia is a more severe blood disease and occurs when the bone marrow ceases to function, i.e.,these stem cells never reach maturity. The depression in bone marrow function occurs in two stages - hyperplasia, or increased synthesis of blood cell elements, followed by hypoplasia, or decreased synthesis. As the disease progresses, the bone marrow decreases functioning. This myeloplastic dysplasia (formation of abnormal tissue) without acute leukemiais known as preleukemia. The aplastic anemia can progress to AML (acute mylogenous leukemia).

The unit risk estimates presented in EPA's draft risk assessment were not accepted by the SAB. The SAB panel recommended that EPA recalculate the lifetime cancer risk estimates based on the human data from Delzell et al. 1995 (Ref. 23) and revise EPA's original calculations to account for the highest exposure of "360 ppm-year" instead of "250+ ppm-year"and 70 years at risk instead of 85 years. Based on these recalculations (Ref. 24) the MLE estimate of lifetime cancer risk from continuous 1,3-butadiene exposure is $2.21 \times 10^{-6}/\mu g/m^3$. This estimate implies that approximately 2 persons in one million exposed to 1 $\mu g/m^3$ 1,3-butadiene continuously for their lifetime (70 years in this case) would develop cancer as a result of their exposure.

1,3-Butadiene also causes a variety of reproductive and developmental effects in mice and rats (no human data) when exposed to long-term, low doses of butadiene (EPA 1998c). The most sensitive effect was reduced litter size at birth and at weaning. These effects were observed in studies in which male mice exposed to 1,3-butadiene were mated with unexposed females. In humans, such an effect might manifest itself as an increased risk of spontaneous abortions, miscarriages, still births, or very early deaths. Long-term exposures to 1,3-butadiene should be kept below its reference concentration of 0.33 $\mu g/m^3$ to avoid appreciable risks of these reproductive and developmental effects (EPA 1998c).

1,3-Butadiene emissions appear to increase roughly in proportion to exhaust hydrocarbon emissions. Since hydrocarbons are decreased by the use of a catalyst on a motor vehicle, 1,3-butadiene emissions are expected to decrease proportionally with the use of any emission control technology that decreases total hydrocarbon emission.

6.2.3 CO

Carbon monoxide (CO) is a colorless, odorless gas produced though the incomplete combustion of carbon-based fuels. Carbon monoxide enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Healthy individuals also are affected, but only at higher CO levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

Several recent epidemiological studies have shown a link between CO and premature mortality and morbidity (including angina, congestive heart failure, and other cardiovascular diseases). EPA currently is in the process of reviewing these studies as part of the CO Criteria Document process.

Since 1979, the number of areas in the nation violating the CO NAAQS has decreased by a factor of almost ten, from 48 areas in 1979 to five areas (covering seven counties) in 1995 and 1996. In 1997, three counties, with a total population of nine million people, failed to meet the CO standard.

In addition to the substantial reduction in the number of areas where the NAAQS is exceeded, the severity of the exceedances also has decreased significantly. Nationally, CO concentrations decreased 38 percent during the past 10 years.[45] From 1979 to 1996, the measured atmospheric concentrations of CO during an exceedance decreased from 20-25 ppm at the beginning of the period to 10-12 ppm at the end of the period. Expressed as a multiple of the standard, atmospheric concentration of CO during an exceedance was two to almost three times the standard in 1979. By 1996, the CO levels present during an exceedance decreased to 10-30 percent over the 9 ppm standard.

Unlike the case with ozone and PM, EPA has not made any recent comprehensive projections of future ambient CO levels and attainment and maintenance of the CO NAAQS. However, section 202(j) of the CAA requires a separate study of the need for more stringent cold CO standards. EPA is currently conducting this study.

Although the final Phase 2 emission standards for handheld Small SI engines do not include significantly more stringent standards for CO, reductions in CO beyond Phase 1 levels, due to improved technology, is also to be expected by year 2025.

6.2.4 Visibility and Regional Haze

Visibility impairment is the haze that obscures what we see, and is caused by the presence of tiny particles in the air. These particles cause light to be scattered or absorbed, thereby reducing visibility. Visibility impairment, also called regional haze, is a complex problem that relates to several pollutants. Visibility in our national parks and monuments, and many urban areas of the country, continues to be obscured by regional and local haze.

The principle cause of visibility impairment is fine particles, primarily sulfates, but also nitrates, organics, and elemental carbon and crustal matter. Particles between 0.1 and one micrometers in size are most effective at scattering light, in addition to being of greatest concern for human health. Of the pollutant gases, only NO_2 absorbs significant amounts of light; it is partly responsible for the brownish cast of polluted skies. However, it is responsible for less than ten percent of visibility reduction.

In the eastern U.S., reduced visibility is mainly attributable to secondary particles, particularly those less than a few micrometers in diameter. Based on data collected by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network for visibility monitoring, sulfate particles account for about 50-70 percent of annual average light extinction in eastern locations. Sulfate plays a particularly significant role in the humid summer months, most notably in the Appalachian, northeast, and mid-south regions. Nitrates, organic carbon, and elemental carbon each account for between 10–15 percent of total light extinction in most eastern locations. Rural areas in the eastern U.S. generally have higher levels of impairment than most

[45] This value of the CO concentration decrease is measured by the composite average of the annual second highest 8-hour concentration.

remote sites in the western U.S., generally due to the eastern U.S.'s higher levels of man-made pollution, higher estimated background levels of fine particles, and higher average relative humidity levels.

The relative contribution of individual pollutants to visibility impairment vary geographically. While secondary particles still dominate in the West, direct particulate emissions from sources such as woodsmoke contribute a larger percentage of the total particulate load than in the East. In the rural western U.S., sulfates also play a significant role, accounting for about 25–40 percent of total light extinction in most regions. In some areas, such as the Cascades region of Oregon, sulfates account for over 50 percent of annual average light extinction. Organic carbon typically is responsible for 15–35 percent of total light extinction in the rural western U.S. and elemental carbon (absorption) accounts for about 15–25 percent, so the total carbonaceous contribution is between 30 and 60 percent. Soil dust (coarse PM) accounts for about 10–20 percent. Nitrates typically account for less than 10 percent of visibility impairment (Ref. 25).

The CAA requires EPA to protect visibility, or visual air quality, through a number of programs. These programs include the national visibility program under sections 169a and 169b of the Act, the Prevention of Significant Deterioration program for the review of potential impacts from new and modified sources, and the secondary NAAQS for PM_{10} and $PM_{2.5}$. The national visibility program established in 1980 requires the protection of visibility in 156 mandatory Federal Class I areas across the country (primarily national parks and wilderness areas). The CAA established as a national visibility goal, "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Federal class I areas in which impairment results from manmade air pollution." The Act also calls for state programs to make "reasonable progress" toward the national goal. In July 1999, EPA promulgated a program to address regional haze in the nation's most treasured national parks and wilderness areas (see 64 FR 35714, July 1, 1999).

Since mobile sources contribute to visibility-reducing PM, control programs that reduce the mobile source emissions of direct and indirect PM will have the effect of improving visibility. Western Governors, in commenting on the Regional Haze Rule and on protecting the 16 Class I areas on the Colorado Plateau, stated that, "...the federal government must do its part in regulating emissions from mobile sources that contribute to regional haze in these areas..." and called on EPA to make a "binding commitment to fully consider the Commission's recommendations related to the ... federal national mobile source emissions control strategies", including Tier 2 vehicle emissions standards (Ref. 26). The Grand Canyon Visibility Transport Commission's report found that reducing total mobile source emissions is an essential part of any program to protect visibility in the Western U.S (Ref. 27). The Commission identifies mobile source pollutants of concern as VOC, NO_X, and elemental and organic carbon.

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Chapter 7: Analysis of Aggregate Costs

This chapter develops the uniform annualized cost per class and the average cost per equipment per class for this rulemaking. This chapter also assesses the cost-effectiveness, in terms of dollars per ton of total emission reductions. This analysis relies on cost information from Chapters 4 and 5 and emissions information from the NONROAD model[46] presented in Chapter 6. Lastly, this chapter discusses possible economic effects of the regulation and compares the cost-effectiveness of the new provisions with the cost-effectiveness of other HC+NOx control strategies from previous EPA rulemakings.

Two cost scenarios, a “high cost” scenario and a “mid cost” scenario, based on differing assumption about catalyst usage in Class IV applications are presented in this chapter. The “high cost” scenario is based on the statement from John Deere that they will be able to meet the Phase 2 standard with only half of their product line using catalysts due to the use of ABT and further improvements in engine design and resultant emission reductions. Therefore, the high cost scenario utilizes the assumption that half of John Deere’s Class IV engines will use the compliance wave technology with a catalyst and the other half will use the compression wave technology without a catalyst. The “mid cost” scenario is based on the assumption that the small engine market is a competitive marketplace and therefore all manufacturers that utilize the compression wave technology, will attempt to improve engine emission out performance such that only half of their Class IV engine production will require catalysts in order to remain competitive with John Deere. In addition, the second scenario considers that John Deere will not need to pay the licensing fee for use of the compression wave technology and therefore this cost is removed John Deere’s Class IV production.

7.1 Aggregate Cost Analysis for the Period 2002 to 2027

The analysis examines total annual costs of the final standards for all applicable engines[47] from 2002 through 2027. (EPA analyzed costs over the period from 2002 to 2027 to ensure that the fleet was completely turned over to Phase 2 engines.) The complete year-by-year stream of costs over time that are summarized in this section can be found in Appendix E. The uniform annualized cost and average cost per equipment are calculated by class. Costs of variable hardware, production, research and development, and compliance programs are used and annualized where appropriate. Cost savings due to reduced fuel consumption are also addressed,

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46 The NONROAD emission model accounts for factors including various equipment types, residential or professional usage, lifetime of the equipment, and scrappage. See Chapter 6 for more details regarding the NONROAD model.

47 The analysis covers all engines sold in the United States except those sold in California which are covered by rulemakings established by the California ARB.

including the valuation of the reduced fuel consumption to the consumer. Total costs to society are presented as the aggregate costs to consumers with and without fuel savings.

This analysis is based on cost estimates for variable and fixed costs from the 1996 ICF and EF&EE cost study, comments to the January 1998 NPRM and July 1999 SNPRM, and manufacturer data. The 1996 cost estimates are adjusted by the GDP Implicit Price deflator for 1996, 1997 and 1998 for costs in 1998$. The costs for the compliance program were based on costs in 1997 and are also adjusted accordingly.

This analysis also accounts for estimates of the increased costs associated with complying with the new emission standards. We avoid predicting actual price increases, since this would depend on an assessment of complex factors such as demand elasticity, the availability of competitive models, and the general state of the economy. A 29 percent markup of the costs presented in Chapter 4 is used in this analysis to predict the costs related to the changes the engine manufacturers and their dealers (or mass merchandisers) need to make to comply with emission standards. Further downstream markups or other pricing strategies may further increase the price of the product, but these are not a necessary or direct impact of the new emission standards. Full cost pass through and profitability on increased costs are assumed. It should be noted that the markup was applied to the specific variable engine and equipment manufacturer costs (hardware and production) identified in this chapter.

7.1.1 Uniform Annualized Costs

A uniform annualized cost is an expression of the equal annual payments that would be equivalent to a given cash flow schedule for a known interest rate. This expression of an annualized cost was chosen due to the variety of the programs that makeup this Phase 2 regulation. The methodology used for calculating the uniform annualized costs is as follows.

The EPA Phase 1 certification database was utilized to determine the number of engines, and related number of models, that would likely be improved during the course of the phase-in (see Tables E-01 to E-03 in Appendix E). The costs per engine (variable and fixed costs) for emission improvements were estimated from the information listed in Chapter 4. The variable costs per engine are then multiplied by the number of engines in that year[48] to incorporate that technology or set of technologies. The fixed costs are amortized for five years for the engine and ten years for equipment starting in the phase-in years in which they are calculated to be

[48] The future sales growth estimates are based on the 1998 Phase 1 certification database industry production estimates and the growth assumptions utilized in the NONROAD model for the main types of equipment from 2002 to 2027 (average percentage increases (2 percent) are used for 1999 through 2001). The population estimates from the NONROAD model are converted to yearly percentage increases and then these percentages are applied to the 1998 estimated production to calculate resultant sales estimates for future years. EPA has not assumed any impact of increased cost for Phase 2 engines on future sales.

recovered.[49]

In order to determine the uniform annualized costs, the annual costs were discounted to the first year the Phase 2 standards are implemented (i.e., 2002 for Classes III and IV and 2004 for Class V) at a rate of seven percent (the consumption rate of interest). The uniform annualized cost was obtained by summing the discounted costs over the appropriate time period and dividing by the appropriate present worth factor (at an interest rate of 7 percent over the corresponding number of years). The sections below address each cost category separately. Section 7.3. contains the full 20 year analysis of total cost of the final standards.

7.1.1.1. Variable Costs -- Tables 7-01 contains the estimates for uniform annualized variable costs per class with consumer markup (see Table E-07 and Table E-11 in Appendix E for costs per year on which these tables are based). For Class IV, there are two results presented for the two different catalyst usage scenarios analyzed. The results are calculated to the first year of implementation which is 2002 for Classes III and IV, and 2004 for Class V. It should be noted that a learning curve discount of 20 percent was applied to the technology cost, not the licensing fee, in the first full year of implementation for each class, which is 2005 for Classes III and IV, and 2007 for Class V. None of the cost information used already anticipated such a learning curve; the John Deere information assumed the costs for 100 % implementation in 2001, not the subsequent decrease in these cost due, for example, to improved manufacturing processes. Thus it is to appropriate to add the effects of a learning curve to future production to account for the optimization of the technologies that will likely occur as manufacturers gain experience in producing these new emission reduction technology designs on a number of engine models.

[49] A learning curve discount of 20 percent on variable costs was applied in the first full year of implementation (i.e., 2005 for Classes III and IV, and 2007 for Class V). The reason for this is due to the likelihood that manufacturers will further optimize the engine design as they gain experience with applying the technology to other engine families, and decrease costs. Due to the notable number of engines that are certified several times due to changes to the engine for application differences, the EPA Phase 1 database was reviewed for these similarities. Once found, a major fixed cost was applied only once and a decreased fixed cost was assigned to the other families with the very similar engine.

Table 7-01
Uniform Annualized Variable Cost per Class With
Consumer Markup, for the Period 2002 to 2027 ($Thousands, 1998$)

Engine Class	Engine	Equipment	Total
III	$35,821	$3,120	$38,941
IV - "High Cost" scenario*	$252,281	$14,508	$266,789
IV - "Mid Cost" scenario*	$195,603	$9,349	$204,952
V	$14,639	$326	$14,965

* - Class IV is the only class for which there are different assumptions in the cost methodology under the two different scenarios.

7.1.1.2. Capital Costs -- Engine improvements, and thereby capital expenditures, are phased-in over time for Classes III through V. The phase-in and number of models for all classes were determined in Chapter 4. Capital costs are estimated to be recovered over 5 years for engines and 10 years for equipment, at a 7 percent interest rate. Costs are assumed to be incurred one year prior to the respective phase-in. Costs are assumed to begin to be recovered one year after they were incurred using a 7 percent interest rate.

Potential capital cost increases include costs for development and application of engine designs with reduced emissions and costs for production facilities. Capital costs were applied to each unique displacement engine per manufacturer. Engine families which had the same engine displacement, but different equipment type, were allotted a lesser capital cost.

EPA has estimated the uniform annualized fixed costs as shown in Table 7-02. The results are calculated to first year of implementation which is 2002 for Classes III and IV and 2004 for Class V. Appendix E contains the tables on which this table is based.

Table 7-02
Uniform Annualized Fixed Cost per Class, for the Period 2002 to 2027
($Thousands, 1998$)

Engine Class	Engine	Equipment	Total
III	$457	$412	$869
IV - "High Cost" Scenario	$6,226	$5,271	$11,497
IV - "Mid Cost" Scenario	$5,460	$3,998	$9,458
V	$1,433	$252	$1,685

* - Capital costs are the same for both the "high cost" scenario and the "mid cost" scenario.

7.1.1.3. Compliance Costs -- This rulemaking accounts for those costs that are above and beyond those for the Phase 1 program. These costs are the compliance program costs presented in Chapter 5. Compliance costs include costs for certification and production line testing (PLT). Certification costs are treated as fixed costs and production line testing costs are treated as variable costs for this analysis. Appendix E and Chapter 5 contain details on the program costs assumed for the compliance programs. The estimates for the administrative burden for these programs are estimated in the supporting statements for the Information Collection Requests submitted to OMB. These supporting statements contain estimates of the testing, record keeping, and reporting burden on industry that would occur under the final regulations.

Table 7-03 contains the uniform annualized compliance costs for all classes. The results are calculated to first year of implementation which is 2002 for Classes III and IV and 2004 for Class V.

Table 7-03
Uniform Annualized Compliance Programs, for the Period 2002 to 2027
($Thousands, 1998$)

Engine Class	Cost
III	$19
IV*	$232
V**	$87

* - Compliance costs are the same for both the "high cost" scenario and the "mid cost" scenario.

** - Note that this Class V analysis contains the four engine families (2 of which are assumed small volume) that will likely be certified to Class I-B.

The total uniform annualized costs for this rulemaking are presented in Table 7-04 for both the "high-cost" scenario and the "mid-cost" scenario..

Table 7-04
Total Uniform Annualized Costs Including Consumer Markups, for the Period 2002 to 2027 ($Thousands, 1998$)

Engine Class	"High-cost" Scenario	"Mid-cost" Scenario
III	$31,076	$31,076
IV	$219,392	$169,271
V	$33,966	$33,966
Total	$284,434	$233,773

- Classes III and IV are annualized to 2002, Class V is annualized to 2004.

7.1.1.4. Fuel Savings -- As explained in Chapter 4, the technological changes necessary to bring these engines into compliance with the final emission standards would cause a decrease in fuel consumption of approximately 30 percent for handheld engines. The tons per year savings per class (see Appendix E) are converted to gallons per year and then multiplied by $0.802 per gallon (1998$ adjusted by GDP) to determine the fuel savings.[50] Table 7-05 contains the uniform annualized fuel savings for all equipment types in each class which have been discounted 7 percent to the first year of implementation for each class. The total value is for all classes discounted to the year 2002 for Classes III and IV and 2004 for Class V. Table E-05 in Appendix E contains the yearly fuel savings information on which this analysis is based.

[50] EPA estimated a gasoline cost of $0.765 per gallon, based on the average refinery price to the end user in 1995 from the Energy Information Administration.

Table 7-05
Uniform Annualized Fuel Savings
and Comparison to Uniform Annualized Cost, for the Period 2002 to 2027
($Thousands, 1998$)

Engine Class*	Uniform Annualized Fuel Savings	"High Cost" Scenario - Uniform Annualized Cost	"Mid Cost" Scenario - Uniform Annualized Cost	"High Cost" Scenario - Resultant Costs	"Mid Cost" Scenario - Resultant Costs
III	$2,316	$31,076	$31,076	$28,760	$28,760
IV	$43,616	$219,392	$169,271	$175,776	$125,655
V	$48,482	$33,966	$33,966	($14,516)	($14,516)
Total	$94,414	$284,434	$233,773	$190,020	$139,359

* Classes III and IV to 2002, Class V to 2004

7.1.2 Average Cost Per Equipment

The average cost per equipment changes over time due to the recovering of capital costs and the increased production over which costs can be spread. Therefore this analysis calculates a range of cost that is based on the uniform annualized cost. Since the production of these engines is assumed to increase over the years of this analysis, this section presents a range of cost per equipment estimates. The uniform annualized cost is divided by the production in the first full implementation year (2005 for Classes III and IV and 2007 for Class V) and the last year (2027) accounted for in this analysis. Results are shown in Table 7-06. An average of this range is also presented.

Table 7-06
Average Cost Per Equipment per Engine Class
Based on Uniform Annualized Costs(1998$)

Engine Class	Cost in First Full Year*	Cost in 2027
III	$23.20	$16.10
IV - "High Cost" Scenario	$25.60	$17.80
IV - "Mid Cost" Scenario	$19.70	$13.70
V	$54.80	$37.80

* - 2005 for Classes III and IV, 2007 for Class V

7.1.2.1. Fuel Savings -- The resultant fuel savings per engine per class is calculated by taking the total fuels savings cost and dividing by the number of pieces of Phase 2 equipment in the class. The resultant cost per engine is then calculated by subtracting the fuel savings per engine from the total cost per equipment. Results are listed in Table 7-07 below.

Table 7-07
Annual Fuel Savings and Resultant Cost per Equipment
Based on Uniform Annualized Analysis (1998$)

Engine Class	Average Cost Per Equipment	Average Annual Fuel Savings Per Equipment	Average Resultant Cost Per Equipment
III	$19.60	$0.50	$19.10
IV - “High Cost” Scenario	$21.70	$1.70	$20.00
IV - “Mid Cost” Scenario	$16.70	$1.70	$15.00
V	$46.30	$30.80	$15.50

The differences seen in the fuel savings between handheld classes (Classes III through V) in Table 7-07 is due to factors contained in the NONROAD emission model from which they were calculated. Such factors include the equipment application, annual hours of use, equipment life, scrappage rates, and engine power. For example, Class V engines are higher in power and the majority are used in commercial equipment that are operated for high numbers of hours per year and therefore the fuel savings are significantly more notable. Class IV engines see a higher fuel savings per engine, primarily due to the higher power in this class compared to Class III engines.

The overall increase in price per equipment per engine class can be compared to the selling price of the equipment in which Small SI engines are used. Handheld equipment in Classes III include trimmers which can be found in the marketplace for $70. An increase of $19.60 per equipment is 28 percent of this price. Equipment in Class IV include trimmers, chainsaws and blowers for both consumer and commercial use. These equipment sell for approximately $200 and the increase of $23.40 (“High Cost” scenario) to $19.50 (“Mid Cost” scenario) is 12 to10 percent of this price. Class V equipment includes professional-use chainsaws which sell for approximately $400. An increase of $54.60 is 14 percent of this price.

7.2 Cost-effectiveness

The following section describes the cost-effectiveness of the finalized HC+NOx standards for the various classes of handheld Small SI engines. As discussed in Chapter 4, the estimated cost of complying with the provisions varies depending on the model year under consideration. The following section presents the total cost-effectiveness over all of the model years after the standards take effect. These cost-effectiveness numbers are calculated by taking the net present value of the total costs per year (including amortized capital and variable costs) over the 27 year time line, discounted by 7 percent, and dividing it by the net present value of the emission benefits discounted by 7 percent. Table 7-08 presents the resulting cost-effectiveness results for both the "High Cost" scenario and the "Mid Cost" scenario.

Table 7-08
Cost-effectiveness of Finalized Phase 2 Rulemaking for Handheld Engines

Scenario	"High Cost" Scenario - Cost-effectiveness ($/short ton)	"Mid Cost" Scenario - Cost Effectiveness ($/short ton)
Without Fuel Savings	$1,020	$830
With Fuel Savings	$750	$560

In an effort to evaluate the cost-effectiveness of the finalized handheld (HH) engine standards, EPA has summarized the cost-effectiveness results for several other recent EPA mobile source rulemakings. Table 7-09 summarizes the cost-effectiveness results from the Phase 2 Nonhandheld (NHH) Small SI final rule (Ref. 1), the Small SI Engine Phase 1 rulemaking (Ref. 2), the SI Recreational Marine Engine rulemaking (Ref. 3) and the recently final standards for nonroad compression-ignition (CI) engines (Ref. 4).

Table 7-09
Cost-effectiveness of Other EPA Nonroad Rulemakings (With Fuel Savings)

Rulemaking	Cost-effectiveness	Pollutants
Small SI, Phase 2 HH - "High Cost" Scenario	$750	HC+NOx
Small SI, Phase 2 HH - "Mid Cost" Scenario	$560	HC+NOx
Small SI, Phase 2 NHH (Ref. 1)	$-507	HC+NOx
Small SI, Phase 1 (Ref. 2)	$217	HC+NOx
SI Recreational Marine (Ref. 3)	$1,000	HC
Nonroad CI, Tier 2/Tier 3 (Ref. 4)	$410-$650	HC+NOx

7.3 20-Year Cost Analysis

Table 7-10 contains the year-by-year fleetwide costs and emission benefits associated with the finalized Small SI Phase 2 handheld engine standards for the 20-year period from 2002 to 2021 for the "High Cost" scenario. EPA has performed an aggregate costs analysis over a twenty year time frame in response to a request from the Office of Management and Budget.

Fuel savings are not included in this analysis as they would significantly reduce the costs of the program. The GDP Implicit price deflators for 1996-1998 were included to compute the costs per year based on 1996 and 1997 cost estimates for technology and compliance program costs respectively. (The numbers presented in Table 7-10 are not discounted).

Table 7-10
"High Cost" Scenario: Costs and Emission Benefits of the Small SI Phase 2 Handheld Engine Standards for the 20-Year Cost Analysis in 1998$
(Fuel Savings Not Included)

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons) HC+NOx
2002	$76,144,705	19,072
2003	$145,129,948	52,607
2004	$217,764,541	121,077
2005	$282,270,658	202,141
2006	$275,392,788	269,406
2007	$229,923,545	325,790
2008	$252,652,358	350,220
2009	$247,178,658	363,359
2010	$247,352,941	373,072
2011	$250,837,014	381,842
2012	$253,771,984	389,707
2013	$239,644,642	397,304
2014	$243,419,742	404,848
2015	$242,690,197	412,376
2016	$246,846,513	420,269
2017	$250,642,420	427,816
2018	$254,440,118	435,362
2019	$258,236,459	442,908
2020	$262,032,019	450,455
2021	$265,828,866	457,998

Table 7-11 contains the discounted year-by-year fleetwide costs and emission benefits associated with the finalized Small SI Phase 2 handheld engine standards for the 20 year period from 2002 to 2021 for the "High Cost" scenario. The year-by-year results were discounted to 2002 and a discount rate of seven percent was assumed for the analysis.

Table 7-11
"High Cost" Scenario: Discounted Costs and Emission Benefits of the Small SI Phase 2 Handheld Engine Standards for the 20-year Cost Analysis in 1998$
(Fuel Savings Not Included)

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons) HC+NOx
2002	$76,144,705	19,072
2003	$135,635,465	49,165
2004	$190,203,983	105,754
2005	$230,416,939	165,008
2006	$210,095,839	205,528
2007	$163,932,310	232,284
2008	$168,352,934	233,366
2009	$153,930,446	226,282
2010	$143,961,664	217,131
2011	$136,438,716	207,697
2012	$129,004,809	198,108
2013	$113,853,443	188,756
2014	$108,081,276	179,758
2015	$100,707,804	171,122
2016	$95,731,333	162,988
2017	$90,844,347	155,060
2018	$86,187,671	147,472
2019	$81,751,050	140,213
2020	$77,525,819	133,273
2021	$73,503,896	126,640

Summing the discounted annual costs and discounted emission reductions over the twenty year period yields a 20-year fleetwide cost of $2.6 billion and 20-year emission reductions of 3.3 million tons of HC+NOx for the "High Cost" scenario. The resulting 20 year annualized fleetwide costs and emission reductions are $242 million per year and 308,000 tons per year of HC+NOx for the "High Cost" scenario. The spreadsheets prepared for this analysis are contained in Appendix E. The reader is directed to the spreadsheets for a complete version of the analysis.

Table 7-12 contains the year-by-year fleetwide costs and emission benefits associated with the finalized Small SI Phase 2 handheld engine standards for the 20-year period from 2002 to 2021 for the "Mid Cost" scenario. As noted above, fuel savings are not included in this analysis as they would significantly reduce the costs of the program. The GDP Implicit price deflators for 1996-1998 were included to compute the costs per year based on 1996 and 1997 cost estimates for technology and compliance program costs respectively. (The numbers presented in Table 7-12 are not discounted).

Table 7-12
"Mid Cost" Scenario: Costs and Emission Benefits of the Small SI Phase 2 Handheld Engine Standards for the 20-Year Cost Analysis in 1998$
(Fuel Savings Not Included)

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons) HC+NOx
2002	$61,791,860	19,072
2003	$115,911,954	52,607
2004	$172,102,927	121,077
2005	$219,104,486	202,141
2006	$210,976,042	269,406
2007	$168,762,358	325,790
2008	$185,019,678	350,220
2009	$179,619,389	363,359
2010	$180,348,891	373,072
2011	$182,639,144	381,842
2012	$184,468,045	389,707
2013	$174,224,195	397,304
2014	$176,893,311	404,848
2015	$175,057,803	412,376
2016	$178,017,638	420,269
2017	$180,703,024	427,816
2018	$183,390,202	435,362
2019	$186,076,021	442,908
2020	$188,761,058	450,455
2021	$191,447,384	457,998

Table 7-13 contains the discounted year-by-year fleetwide costs and emission benefits associated with the finalized Small SI Phase 2 handheld engine standards for the 20 year period from 2002 to 2021 for the "Mid Cost" scenario. The year-by-year results were discounted to 2002 and a discount rate of seven percent was assumed for the analysis.

Table 7-13
"Mid Cost" Scenario: Discounted Costs and Emission Benefits of the Small SI Phase 2 Handheld Engine Standards for the 20-year Cost Analysis in 1998$
(Fuel Savings Not Included)

Calendar Year	Fleetwide Costs	Fleetwide Reductions (short tons) HC+NOx
2002	$61,791,860	19,072
2003	$108,328,929	49,165
2004	$150,321,362	105,754
2005	$178,854,527	165,008
2006	$160,952,612	205,528
2007	$120,325,229	232,284
2008	$123,286,424	233,366
2009	$111,857,928	226,282
2010	$104,964,697	217,131
2011	$99,343,593	207,697
2012	$93,774,200	198,108
2013	$82,772,660	188,756
2014	$78,542,745	179,758
2015	$72,642,765	171,122
2016	$69,038,309	162,988
2017	$65,495,092	155,060
2018	$62,120,606	147,472
2019	$58,906,903	140,213
2020	$55,847,586	133,273
2021	$52,936,797	126,640

Summing the discounted annual costs and discounted emission reductions over the twenty year period yields a 20-year fleetwide cost of $1.9 billion and 20-year emission reductions of 3.3 million tons of HC+NOx for the "Mid Cost" scenario. The resulting 20 year annualized fleetwide costs and emission reductions are $180 million per year and 308,000 tons per year of HC+NOx for the "Mid Cost" scenario. The spreadsheets prepared for this analysis are contained in Appendix E. The reader is directed to the spreadsheets for a complete version of the analysis.

7.4 Fuel Savings

Table 7-14 contains the year-by-year fleetwide gallon and monetary fuel savings associated with the finalized Small SI Phase 2 handheld engine standards of the 20-year period from 2002 to 2021. The numbers apply to both the "High Cost" and "Mid Cost" scenarios. (The numbers presented in Table 7-14 are not discounted).

Table 7-14
Fuel Savings of the Finalized Small SI Phase 2 Handheld
Engine Standards for the 20-year Cost Analysis in 1998$

Calendar Year	Fleetwide Savings	Fleetwide Savings (gallons)
2002	($4,464,205)	(5,564,331)
2003	($12,167,205)	(15,165,602)
2004	($29,998,435)	(37,391,029)
2005	($51,044,847)	(63,623,965)
2006	($68,935,507)	(85,923,468)
2007	($84,551,600)	(105,387,876)
2008	($90,595,534)	(112,921,233)
2009	($93,824,844)	(116,946,350)
2010	($99,725,771)	(124,301,459)
2011	($102,039,415)	(127,185,261)
2012	($104,164,591)	(129,834,149)
2013	($106,234,669)	(132,414,362)
2014	($108,292,214)	(134,978,953)
2015	($110,349,285)	(137,542,954)
2016	($112,472,096)	(140,188,895)
2017	($114,531,296)	(142,755,549)
2018	($116,588,605)	(145,319,846)
2019	($118,647,332)	(147,885,910)
2020	($120,706,768)	(150,452,859)
2021	($122,765,022)	(153,018,334)

Table 7-15 contains the discounted year-by-year fleetwide gallon and related monetary fuel savings associated with the finalized Small SI Phase 2 handheld engine standards for the 20 year period from 2002 to 2021. The year-by-year results were discounted to 2002 and a discount rate of seven percent was assumed for the analysis. Again, the results are applicable for both the "High Cost" and "Mid Cost" scenarios.

Table 7-15
Discounted Fuel Savings of the Finalized Small SI Phase 2
Handheld Engine Standards for the 20 year Cost Analysis in 1998$

Calendar Year	Fleetwide Savings	Fleetwide Savings (gallons)
2002	($4,464,205)	(5,564,331)
2003	($11,371,219)	(14,173,459)
2004	($26,201,795)	(32,658,773)
2005	($41,667,800)	(51,936,107)
2006	($52,590,568)	(65,550,602)
2007	($60,284,122)	(75,140,099)
2008	($60,367,630)	(75,244,186)
2009	($58,429,397)	(72,828,309)
2010	($58,041,307)	(72,344,581)
2011	($55,502,681)	(69,180,355)
2012	($52,951,996)	(66,001,098)
2013	($50,471,326)	(62,909,109)
2014	($48,083,038)	(59,932,269)
2015	($45,791,030)	(57,075,436)
2016	($43,618,618)	(54,367,671)
2017	($41,511,413)	(51,741,181)
2018	($39,492,594)	(49,224,859)
2019	($37,560,707)	(46,816,892)
2020	($35,712,777)	(44,513,572)
2021	($33,945,552)	(42,310,845)

Summing the discounted fuel savings over the twenty year period yields a 20-year fleetwide fuel savings of $858 million and 1.07 billion gallons of gasoline. The resulting 20 year annualized fleetwide fuel savings are $81 million per year and 101 million gallons of gasoline per year. These results are applicable to both the “High Cost” and “Mid Cost” scenarios. The spreadsheets prepared for this analysis are contained in Appendix E. The reader is directed to the spreadsheets for a complete version of the analysis.

Chapter 7 References

1. “Phase 2 Emission Standards for New Nonroad Spark-Ignition Nonhandheld Engines At or Below 19 Kilowatts; Final Rule”, Docket Item V-A-01.

2. “Control of Air Pollution; Emission for New Nonroad Spark-ignition Engines At or Below 19 Kilowatts; Final Rule”, US EPA, Federal Register, vol 60, No. 127, Monday, July 3, 1995, 40 CFR part 90, pg 34596.

3. “Air Pollution Control; Gasoline Spark-Ignition Marine engines; New Nonroad Compression-Ignition and Spark-Ignition Engines, Exemptions; Rule”, US EPA, Federal Register, vol 61, No. 194, Friday October 4, 1996, 40 CFR parts 89, 90 and 91, pg 52100.

4. ““Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines”, August 1998, Docket Item V-B-1.

Chapter 8: Assessment of Impacts on Small Entities

8.1 Introduction and Methodology

This chapter assesses the impact of today's rulemaking on small entities, to enable EPA to determine both the degree of impact and the number of small entities impacted. The analysis presents both a base case and a second case that shows the impact of small-volume manufacturer and small-volume engine family flexibilities that are being finalized in this rulemaking.

8.1.1 Regulatory Flexibility

Small entities include small businesses, small not-for-profit organizations, and small governmental jurisdictions. As noted in the Draft RIA, small not-for-profit organizations and small governmental jurisdictions are not expected to be impacted by this rulemaking, thus the analysis is focused on small businesses, specifically on the impact of today's rulemaking on handheld engine and equipment manufacturers.

8.1.2 Methodology.

The Draft RIA relied on information from a cost study and a small business impact study performed by ICF Incorporated under a contract with EPA, to determine the economic impact of the original proposed regulations on small entities.(Ref. 1) (Ref. 2) The other primary data sources for the small business impact analysis included the EPA Phase 1 Certification database, the Power Systems Research OELINK (PSR) database, and the Dun & Bradstreet Market Identifiers Online (D&B) database.

The ICF cost study relied on the PSR database for engine and sales data, and incorporated the results of an engineering analysis that was performed to analyze the costs of compliance with the Phase 2 emission standards. This analysis also relies on the latter study and on the PSR and D&B databases for data on handheld engine and equipment manufacturers. This information has been supplemented with information received from engine and equipment manufacturers, trade associations and from engine and equipment manufacturer websites.

To evaluate the impacts of the final rule on small entities, an economic measure known as the "sales test" was used, which measures compliance costs as a function of sales revenue. After determining the costs of compliance to the manufacturers, these costs are annualized and expressed as a percentage of annual sales revenue. EPA's guidance for this is based on the percentage of small entities that are affected by costs of compliance amounting to varying percentages of sales. Although there are a number of specific scenarios, the guidance provides that if any number of small entities are affected by less than one percent of their sales income, or if fewer than 100 small entities are affected by more than one percent of their annual sales income, this does not amount to a "substantial number" of small entities.

The Small Business Administration defines small business by category of business using Standard Industrial Classification (SIC) codes, and in the case of manufacturing, generally defines small business as a business having 500 employees or less. However, for engine manufacturers (SIC code 3519) the cutoff is 1,000 employees. Table 8-01 shows the range of primary SIC codes listed for the engine and equipment manufacturers identified, and the corresponding SBA small business cutoff, based on number of employees.

Table 8-01
Small Business Engine and Equipment Manufacturer Definitions

SIC Code	Applicable	Title	Employees
3519	Engine	Internal Combustion Engines	1,000
3523	Equipment	Farm Machinery & Equipment	500
3524	Equipment	Lawn & Garden Equipment	500
3531	Equipment	Construction Machinery	750
3561	Equipment	Pumps and Pumping Equipment	500
3621	Equipment	Motors and Generators	500

8.2 Impact on Engine Manufacturers.

8.2.1 Small Business Engine Manufacturer Impacts

8.2.1.1. Identification of Manufacturers -- The PSR database shows that there are 22 primary handheld engine and equipment manufacturers. D&B financial data were available for 20 of the 22. One of the remaining two appears to be a large multinational firm which markets on five continents, and must be assumed to be large. The other will be assumed to be small for purposes of this analysis. Under these assumptions, 17 of the 22 are large businesses, many of which also manufacture nonhandheld engines. These firms account for almost 99 percent of the total estimated handheld engine production. Five are small entities, all of which are also equipment manufacturers. Two of the five account for more than eighty percent of the total estimated production for these small business entities. At least one of the small firms also manufactures nonhandheld equipment. The Draft RIA stated that there were six engine manufacturers that were small entities, however subsequent information regarding the resources of the parent company of one of these has revealed that it is in fact a large manufacturer, according to the SBA guidelines.

8.2.2 Expected Technologies/Costs

The cost of compliance for handheld engines depends on technology employed by engine manufacturers to meet the emission standards, as well as on the standards themselves. Handheld manufacturers employ a much higher percentage of two-stroke cycle engines than nonhandheld manufacturers, which could increase the difficulty of compliance with the relatively more stringent standards being finalized today. As noted in Chapter 3, EPA expects that most handheld manufacturers will meet the new standards using improved two-stroke technologies such as compression wave or stratified scavenging technologies, in most cases with the addition of a catalyst. Such improved two-stroke technologies are under development to meet the California Phase 2 standards, and catalyst technology has already been in use on some handheld engines to meet the EPA Phase 1 standards. The Agency estimates that costs for these technologies will range from about $23 per engine in Class III, $20 per engine in Class IV, and $55 per engine in Class V, depending on the type of technology and engine family production volume. These figures include catalyst cost of $6.15 to $7.29 per engine for Class III and IV engines.

Some handheld manufacturers may elect to convert to four-stroke cycle engines. Two mini-four-stroke engines have recently appeared on the market, and a third is under development. Although EPA expects that significant numbers of four-stroke engines will be used in meeting the Phase 2 standards, the agency feels that it is unlikely that the five small-volume manufacturers will be included in this group. Should one of them choose this strategy, EPA estimates that the cost of converting a handheld engine two-stroke family to four-stroke would be approximately $15 per engine plus any licensing costs involved, for the likely production levels (based on the ICF cost study and other information that has come to the attention of the agency). Also, as noted in Chapter 3, EPA has also become aware of other engine technology developments in the area of ignition and induction improvements that may assist two-stroke engines in meeting the Phase 2 standards.

8.2.3 Expected Impact on Small Business Entities

To estimate impacts on engine manufacturers, specific compliance costs were developed for each engine class, based on the type of engine modifications needed and the level of engine production. Table 8-02 summarizes these costs. The individual annualized compliance costs were then estimated for each small ultimate parent company identified. A more detailed technology analysis is available Chapters 3 and 4, and in Appendix E.

Table 8-02
Engine Modifications and Associated Costs

Engine Class	Engine Modification	Fixed Cost	Variable Cost Per Engine
III	Compression wave technology*	$688,000	$22.43
IV	Compression wave technology* Stratified scavenge technology*	$300,000-$688,000 $691,000	$27.56
V	Compression wave technology	$300,000	$23.00

* With catalyst. Catalyst cost is included in totals.

8.2.4 Sales Test for Engine Manufacturers

A compliance cost-to-sales ratio was calculated for each small ultimate parent company for which D&B data were available. D&B data were available for four of the five small handheld engine manufacturers. These manufacturers will likely achieve compliance with the new standards through improvements to their existing engines, with the addition of catalysts in Classes III and IV. Under this scenario, the annualized costs of compliance for the two largest firms, which account for 83 percent of the production for small business entities, amounted to less than one percent and between two and three percent of sales, respectively. The costs of compliance for two of the three smallest firms were calculated at one and 12 percent of sales, respectively. Since D&B data were not available for the third manufacturer, it was not possible to calculate a compliance cost in terms of percent of sales. However, this manufacturer has already certified to California Phase 2 emission standards. EPA's analysis indicates that all three of these smallest companies will qualify for the small-volume manufacturer flexibilities being finalized in today's rulemaking. Compliance with the final standards therefore does not appear to represent a "significant burden on a substantial number" of small entities.

8.2.5 Flexibilities Case

EPA is finalizing a number of small-volume flexibilities which can ease the burden of compliance on the smallest entities. There are three major small-volume flexibilities being offered to benefit the small engine manufacturers and small volume engine families. The flexibilities for small volume engine manufacturers and small volume engine families are summarized in Table 8-03. Small-volume engine manufacturers are defined as those manufacturers which produce less than 25,000 units per year for handheld applications. Small-volume engine families are defined as families consisting of less than 5,000 units for handheld model lines.

Table 8-03
Summary of the Flexibilities for Small Volume Engine Manufacturers and Engine Families

Sector	Cutoff	Flexibility
Small Volume Handheld Engine Manufacturer	25,000	1. Allowed to produce "Phase 1" engines until 3 years after Phase 2 standards are fully implemented (i.e., through the 2008 MY for Classes III and IV and through the 2010 MY for Class V). The engines will be excluded from ABT until they are certified under the Phase 2 program. 2. Can certify using assigned deterioration factors. 3. Can opt out of PLT; SEA would be applicable.
Small Volume Handheld Engine Family	5,000	They are the same as small-volume engine manufacturer flexibilities noted above.

As noted above, all three of the smallest small-volume manufacturers could take advantage of the small-volume manufacturer flexibility. In addition, the two larger small-entity engine manufacturers could take advantage of the small engine family flexibilities for more than half of their engine families. This would allow a more orderly transition to the new emission standards and minimize the financial burden on these manufacturers. As a result, only one small-entity engine manufacturer would be impacted by more than one percent of sales.

8.3 Impact on Equipment Manufacturers

8.3.1 Number of Small Manufacturers

With few exceptions, handheld equipment manufacturers are typically also the engine manufacturers. The first exception to this rule consists of the small auger manufacturers. These manufacturers rely upon the engines being produced in the marketplace. Since publication of the January 1998 NPRM, six such auger manufacturers have been brought to the agency's attention. The other exception is handheld equipment made by nonhandheld manufacturers. EPA has identified an additional six manufacturers, including four lawn and garden and two paving equipment producers. Total production for these twelve manufacturers is on the order of 65,000 units per year, out of a total handheld production of over ten million pieces of equipment. Production for these manufacturers is limited to Class IV and V equipment, with two of them manufacturing only Class IV equipment, seven manufacturing only Class V equipment, and the remainder manufacturing both Class IV and V. In addition to the twelve small businesses, EPA has also identified two equipment-only manufacturers that are not small entities.

8.3.2 Impact on Equipment Manufacturers

Because handheld equipment manufacturers are also often the engine manufacturers and because of the relatively low number of handheld equipment lines, EPA estimates that the impact on equipment manufacturers will be minimal. The handheld manufacturers will be afforded ample lead time by the effective dates for the new standards, so that necessary engine changes can be phased in together with normal equipment changes. Auger manufacturers and other relatively low-volume manufacturers who do not also manufacture their own engines fear a potential lack of availability of engines. Because of their relatively low production levels, the auger manufacturers have expressed concerns that engine manufacturers would be reluctant to make the necessary investment to develop compliant engines suitable for their particular applications. Some have also expressed concerns that the power characteristics of a four-stroke engine may not be suitable for the requirements of their particular applications. However, again, EPA is providing flexibilities that should address these concerns and allow these relatively few entities to continue production of their products.

8.3.3 Possibility of Cost Passthrough

Some manufacturers have expressed concerns that catalyst or other advanced technologies will necessitate price increases that will diminish the demand for their products. However, EPA believes that the need for the products will likely remain, regardless of cost increases--lawns will need care, construction will need to go on, etc. Then too, across-the-board increases for SI engines will ultimately impact all equipment manufacturers equally so that no manufacturer should gain a substantial competitive advantage. Individual small business equipment manufacturers have informed EPA of the likelihood they would pass most, if not all, additional costs on to consumers. Many of these small equipment manufacturers appear to cater to niche markets, which provides an even better opportunity for partial or full cost passthrough.

8.4 Estimation of Impacts on Small-Volume Equipment Manufacturers:

8.4.1 Base Case--No Flexibilities

For the final standards, EPA calculated only the sales impact on the handheld equipment manufacturers that were classified as small business entities. Cost estimates were calculated per equipment model for each manufacturer. Each equipment model is assumed to correspond to an application with a specific horsepower rating. To calculate an annualized cost of compliance for each manufacturer, the fixed costs per model were multiplied by the number of equipment models produced by that manufacturer. The fixed costs for each model were then annualized using a seven percent annual cost of capital over a ten year period. The variable costs per unit were multiplied by the number of units produced annually, yielding total annual variable costs. These costs were then added to the annualized fixed costs to calculate the total annual cost per manufacturer. The results were compared to total value of sales for the manufacturer to determine the costs as a percentage of sales. The base case depicts a worst-case scenario, in which none of the small-business equipment manufacturers take advantage of the flexibilities provided for small-volume manufacturers or small-volume equipment lines.

Because there were relatively few manufacturers identified, and because of their low number of models, the analysis concluded that the new standards would pose a minimal impact on these small businesses. An analysis of the D&B data for the twelve equipment-only manufacturers indicates that seven of the equipment manufacturers would be impacted by less than one percent of sales, four would be impacted by between one and two percent of sales, and only one would incur costs amounting to between two and three percent of annual sales. However, the possibility remains that engine manufacturers may cease to produce engines suitable for the low-volume auger and other applications. EPA is therefore providing flexibilities for small equipment manufacturers and model lines in an attempt to mitigate this possibility.

8.4.2 Flexibilities Case

EPA is finalizing a number of small-volume flexibilities which can ease the burden of compliance on these smallest entities. It should be emphasized that the flexibilities being adopted for small-volume equipment manufacturers and small-volume equipment model models are for equipment manufacturers only, and cannot be used by engine manufacturers who also manufacture equipment. (The flexibilities being adopted for small volume engine manufacturers and small volume engine families were described earlier in section 8.2.5.) These small-volume equipment manufacturer and small-volume model flexibilities are summarized in Table 8-04. Small-volume equipment manufacturers are defined as those manufacturers who produce less than 25,000 units per year for handheld applications. Small-volume equipment models are defined as model lines consisting of less than 5,000 units for handheld model lines. Engine manufacturers will be allowed to continue production of the engines necessary to satisfy the demand from small volume equipment manufacturers and small volume equipment models.

Table 8-04
Summary of the Final Rulemaking Flexibilities

Sector	Cutoff	Flexibility
Small Volume Handheld Equipment Manufacturer	25,000	May continue using Phase 1 compliant engines through the third year after the last applicable phase-in date of the final Phase 2 standards if the equipment manufacturer is unable to find a suitable Phase 2 engine before then (i.e., through the 2008 MY for Classes III and IV and through the 2010 MY for Class V).
Small Volume Handheld Equipment Model	5,000	May continue to use Phase 1 compliant engines throughout the time period the Phase 2 regulation is in effect if no suitable Phase 2 engine is available and the equipment is in production at the time these Phase 2 rules begin to be implemented. If the equipment is "significantly modified" then this exemption ends, since design accommodations could be made during such a modification to accept an engine meeting Phase 2 standards.
Any Equipment Manufacturer	Any	Any equipment manufacturer, regardless of size, for any of its applications, regardless of size, may continue using a Phase 1 engine for up to one more year beyond the last phase-in of the final standard for that engine class if the requirement to otherwise use a Phase 2 compliant engine will cause substantial financial hardship.

All but one of the 12 small equipment manufacturers will be able to take advantage of the small- volume manufacturer flexibilities. However, the one small entity equipment manufacturer that would not be able to utilize this flexibility would be impacted less than one percent of sales by the new standards. This manufacturer would also qualify for the small-volume equipment model flexibility for half of its product lines, with a corresponding reduction in the cost impact on that producer. The 11 other small manufacturers could also qualify for the small equipment model flexibility for all but three of their product lines, should they choose to take that route. These flexibilities should help address the concerns expressed by the handheld auger manufacturers about the potential lack of engines. The equipment flexibilities would at least enable continued production of the engines that are currently utilized for these applications. The recent advances in two-stroke technology may also preclude the necessity for conversion to four-stroke engines, which could also address many of their concerns about the unsuitability of such engines for certain applications.

8.5 Conclusions

Analysis of the current data shows that the majority of engine and equipment manufacturing firms (representing almost 99 percent of handheld production) are not small business entities. Of those that are, only three small engine manufacturers and five small equipment manufacturers would be impacted by more than one percent of sales, even without taking advantage of the flexibilities provided. If the small manufacturers do take advantage of the flexibilities offered, only one engine producer would be affected by more than one percent of sales, and none of the equipment manufacturers would be affected by more than one percent. Moreover, there are other mitigating factors which could enter into the cost equation. The inclusion of additional flexibilities, which will benefit both small engine and equipment businesses, will further reduce possible adverse impacts. For example, it is possible for some of the companies to be in a state of poor financial health, which would increase the compliance burden placed on them. EPA will therefore allow handheld manufacturers to use the hardship provision that was adopted in the Phase 2 small nonhandheld SI final rulemaking, which provides additional relief to companies undergoing severe financial distress.

8.6 Outreach Activities

In addition to the comments received on the original January 1998 NPRM and the July 1999 SNPRM, EPA has made other outreach efforts. A number of small businesses were contacted to determine the impact of the more stringent standards for handheld engines. In addition, EPA has been in almost constant contact with engine producers, including the small entities, at their own request or at the request of trade associations. Many of these firms who have provided input to the process believe that sufficient lead time can alleviate some of the problems associated with a transition to the advanced technologies expected under the Phase 2 regulations. Additional lead time allows for a more orderly transition to this advanced technology when other changes are made.

Chapter 8 References

1. "Small Business Impact Analysis of New Emission Standards for Small Spark-Ignition Nonroad Engines and Equipment," prepared for EPA by ICF Incorporated under EPA Contract 68-C5-0010, August 1998, available in Docket A-96-55.

2. "Cost Study for Small Engine Emission Regulations," prepared for EPA by ICF Incorporated under EPA Contract 68-C5-0010, October, 1996, available in Docket A-96-55.

Chapter 9: Useful Life and Flexibility Supporting Data

9.1 Information on Useful Life

This chapter contains information used by the Agency in the development of the useful life categories for Phase 2 small engines for handheld (Classes III through V), Class I-A and Class I-B.

During the development of the Phase 2 program, and during the development of the Phase 1 regulation, EPA was aware that the nonroad SI category of engines and equipment was comprised of a wide variety of equipment with a wide range of usage patterns. Handheld engines are designed for many different types of applications, with each application having specific design criteria. Within each application are a number of markets with different target life expectancies. The most obvious example of these differences is the distinction between commercial (or professional) operators and residential (or home) operators. In general, commercial operators expect to accumulate high numbers of hours on equipment on an annual basis, such as commercial lawn-care companies or rental companies, while a residential operator expects to accumulate a relatively low number of hours on an annual basis, such as a residential chain saw owner. Several organizations have investigated the issues related to average life and annual use of equipment powered by Small SI engines, including industry organizations, CARB, and the EPA. A brief summary of several of these reports is presented in the remainder of this Chapter.

9.1.1 Handheld Useful Life Estimates from PPEMA

In 1990 the Portable Power Equipment Manufacturers Association (PP EMA) contracted for a report which contained estimates on useful life periods for two-stroke powered handheld equipment.(Ref. 1) A summary of the information contained in the report on two-stroke powered handheld equipment usage is presented in Table 9-01.

Table 9-01
Summary of Information on Useful Life
Available from Heiden Associates Report, July, 1990

Equipment Type	Con. Average Annual Use (hours)	Prof. Average Annual Use (hours)	Con. User Expected Life Estimates (years)	Prof. User Expected Life Estimates (years)	% of Equipment Purchased by Prof. Users	Con. User Expected Life Estimates (hours)	Prof. User Expected Life Estimates (hours)
Chain saws	7	405	8	1	25%	56	405
Trimmers & Brushcutters	10	170	6	1.5	16%	60	255
Hand Blowers	9	197	6.67	2	5%	60	394
Back Blowers	12	293	6.67	1.83	95%	80	536
Cut Off Saws	N/A	113		2	100%	N/A	226
Hedge Trimmers	7	75	7.5	3	79%	53	225

(Con. = consumer user, Prof. = professional user)

This report clearly demonstrates the large disparity between consumer and professional use, with consumer equipment expected life estimates range from 53 to 80 hours, and professional equipment expected life estimates range from 225 to 536 hours.

9.1.2 Handheld Useful Life Estimates from CARB

In 1990, the California Air Resources Board (CARB) contracted for a report from Booz, Allen and Hamilton which included estimates of usage rates and life spans for several categories of nonroad equipment powered by small engines(Ref. 2). A summary of the information contained in the report pertaining to handheld applications is presented in Table 9-02.

This report also indicates there is a large disparity in average life-span between equipment used by residential and commercial applications. Residential equipment implied average lifespan estimates range from 35 to 127 hours, and commercial equipment implied average lifespan estimates range from 274 to 784 hours.

9.1.3 Small Engine Equipment Usage Estimates used by EPA

The Agency has also developed estimates related to average annual use and equipment survival, many of these estimates are based on the usage information in the previously cited reports. These estimates were presented in the Small Engine Phase 1 Regulatory Support Document.(Ref. 3) The Phase 1 RSD includes Agency estimates of: average annual sales by equipment type, percentage splits between residential and consumer equipment, average annual use by equipment, B-50 (number of years after which 50 percent of the equipment have failed), and sales splits by equipment between each of the five engine classes. Figures 9-01 through 9-03 are a series of bar graphs summarizing the Agency's information regarding engine classes and hours of use.

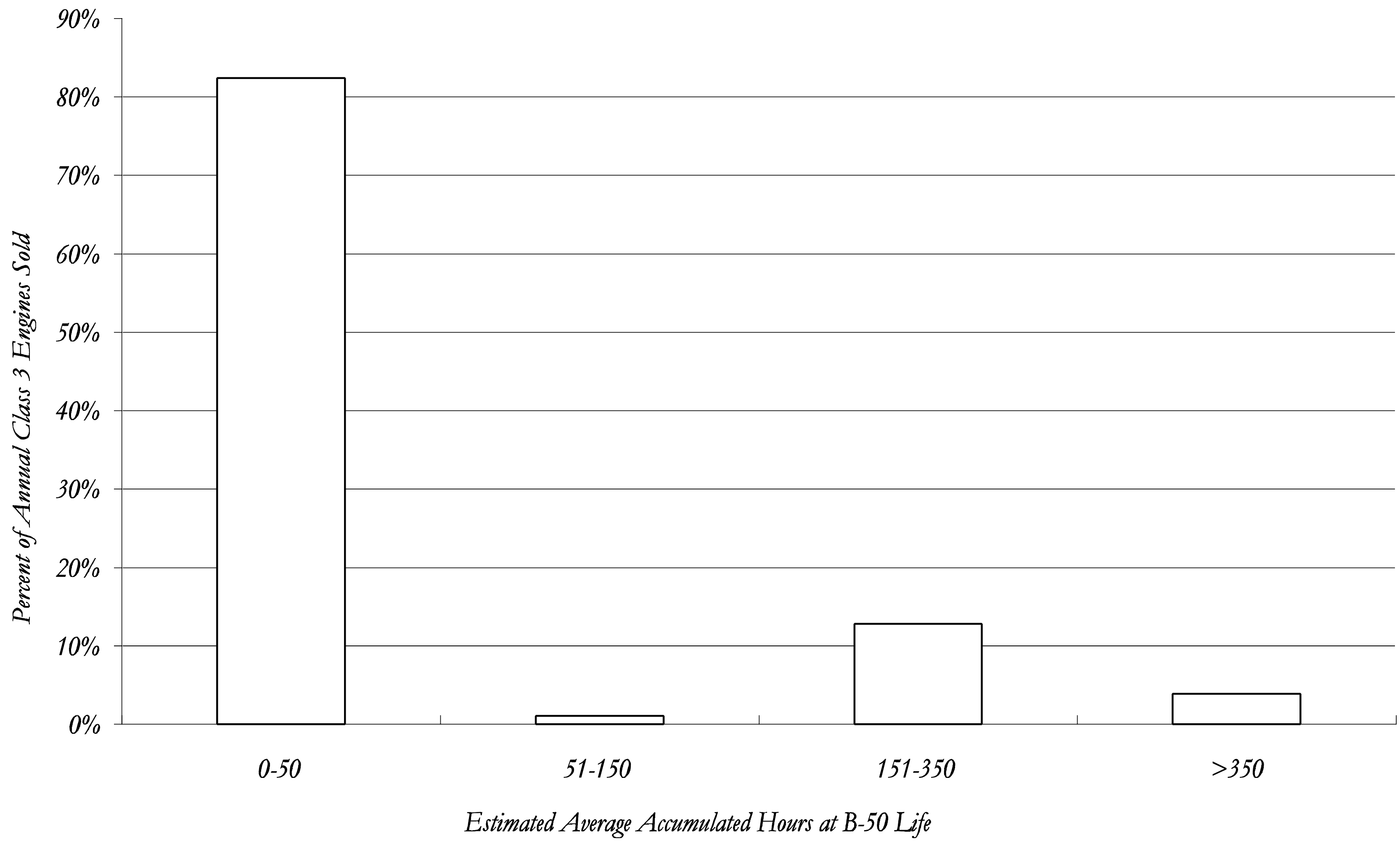

Figure 9-01: Summay of EPA Class 3 Engines Useful Life Estimates

Table 9-02
Summary of Information on Useful Life
Available from Booz, Allen & Hamilton Report, Nov. 1990

Product Category	% of Total Sales, Home Use	% of Total Sales, Commercial Use	Res. Implied Avg. Lifespan (years)	Com. Implied Avg. Lifespan (years)	Res. Annual Hrs Use per Year	Com. Annual Hrs Use per Year	Res. Implied Avg. Lifespan (hours)	Com. Implied Avg. Lifespan (hours)
Tillers	60%	40%	7.04	5.41	18	72	127	390
Snowthrowers	90%	10%	5.41	5.41	10	60	54	325
General Utility	25%	75%	7.04	2.85	5	96	35	274
Two-stroke blowers/ vacuums	85%	15%	5.21	2.85	10	170	52	485
Two-stroke edgers/ trimmers	85%	15%	5.21	2.85	10	275	52	784
Chain saws	75%	25%	5.21	1.33	7	405	36	539

(Res. = residential user, Com. = commercial user)

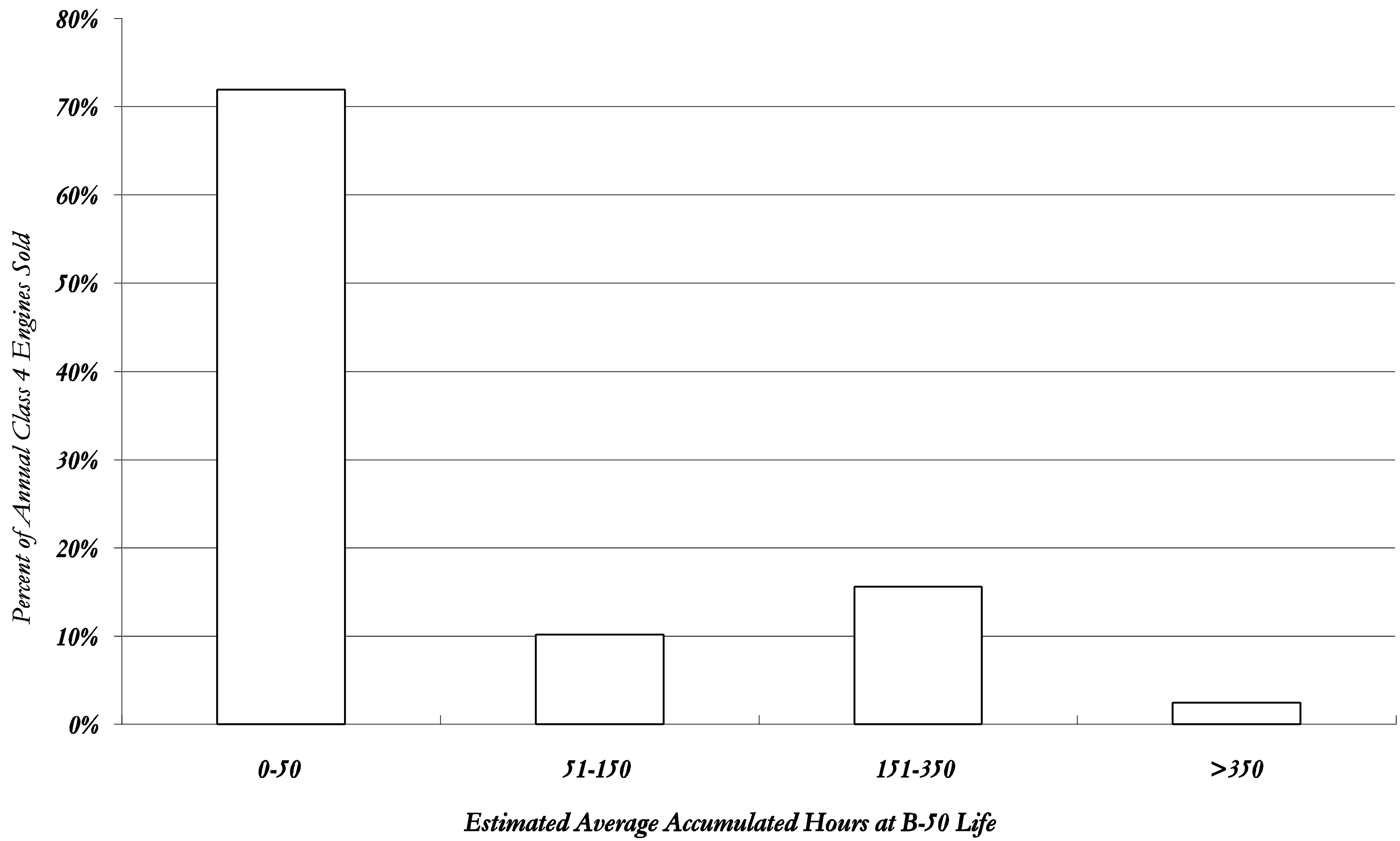

Figure 9-02: Summary of EPA Class 4 Engines Useful Life Estimates

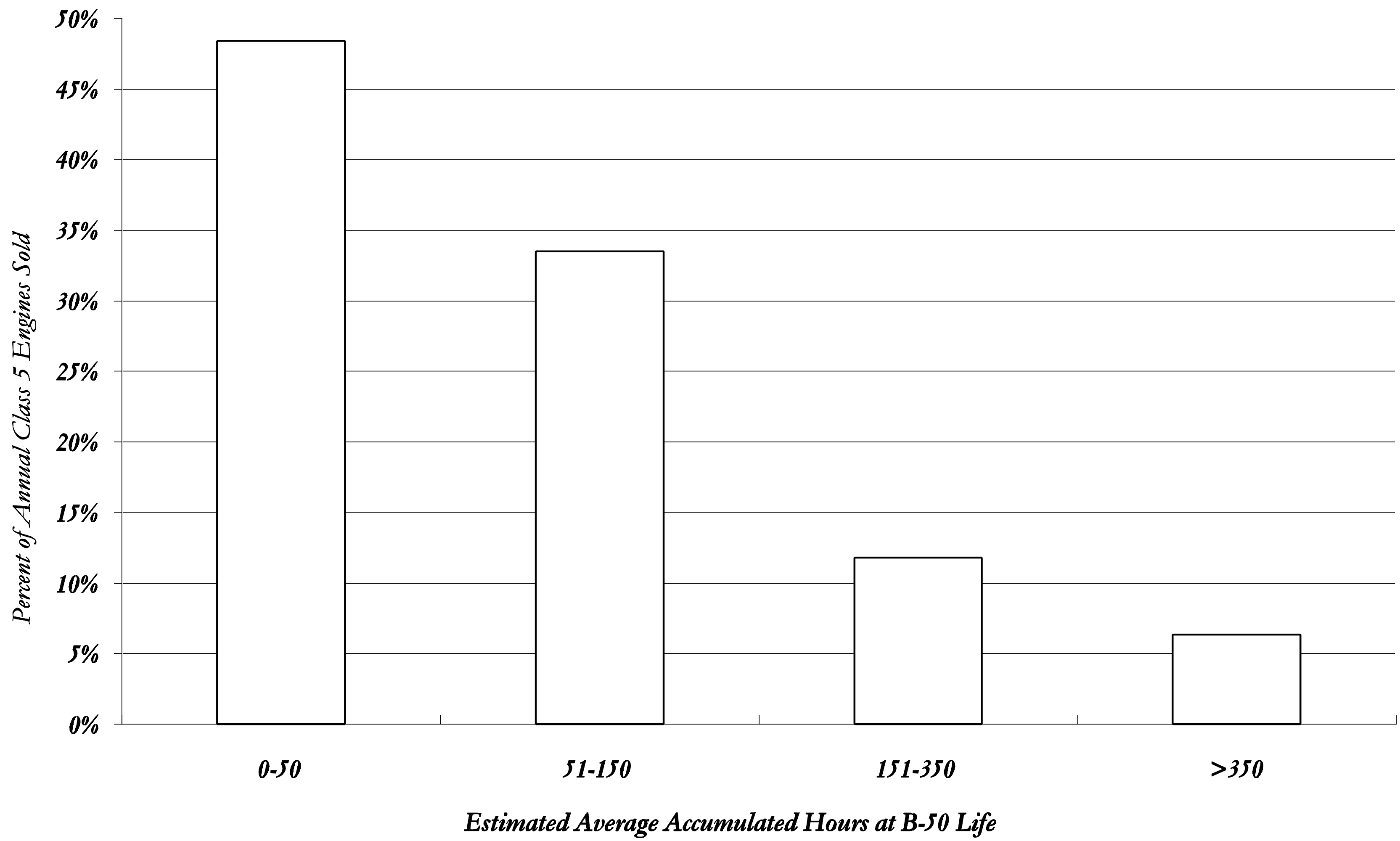

Figure 9-03: Summay of EPA Class 5 Engines Useful Life Estimates

Figures 9-01 thru 9-03 make it clear that small engines can accumulate vastly different hours of use over the life of the equipment. Manufacturers are able to design and build engines for various design lives which fit the type of equipment the engine is likely to be produced for.

9.1.4 Phase 2 Useful Life Categories

EPA is adopting several useful life categories for handheld engines (Classes III through V), presented in Table 9-03. Based on the data presented in Sections 9.1.1 thru 9.1.4 the Agency believes these useful lives are appropriate for regulatory purposes.

Table 9-03
Regulatory Useful Life Values for Small SI
Handheld Engines (Classes III through V)

Category	A	B	C
Useful Life (hours)	300	125	50

The Agency believes multiple useful life categories are appropriate considering the wide range of useful life values for Small SI engines. At the same time, the Agency would like to keep the number of useful life categories small to avoid confusion among consumers. The Agency believes the three categories for handheld engines fulfils the goal of having a small number of useful life categories, and at the same time, adequately covering the useful lives experienced by engines in actual use.

For Class I-A engine families, the useful lives are the same as for Classes III through V since Class I-A families are just an extension of these engines to nonhandheld applications. Class I-B engine families will utilize Class I useful life categories (125, 250, 500) since the majority of engine families that will certify to this Class are already certified to Class I Phase 1 standards.

9.2 Background for Choice of Small-Volume and Small-Family Cutoffs

The Phase 2 rulemaking for handheld engines contains a number of flexibilities for small-volume engine and equipment manufacturers as well as small-volume engine families and equipment models. (The actual flexibilities are summarized in Table 9-04 at the end of this chapter.) This section describes the methodology utilized to develop these estimates. The main sources for this analysis include the September 1998 EPA Phase 1 certification database (engine/equipment manufacturers) and Power Systems Research 1996 OE LINK database (independent equipment manufacturers) along with the results from EPA's work to analyze the impact on small businesses which can be found in Chapter 8.

9.2.1 Small-Volume Handheld Engine Manufacturers

The work performed to determine the impacts on small businesses, as described in Chapter 8 of this RIA, utilized the SBA definition of 1000 employees as a cutoff for small-volume engine manufacturers. Application of this definition to the range of engine manufacturers in this industry resulted in identification of 6 small engine manufacturers. Only 5 of these companies were able to be analyzed, since both financial and estimated production information are necessary for the analysis. An overview of the companies showed that they varied greatly in income and production volumes. Two of the five companies were clearly small with low number of employees and annual revenue. Due to production volume and number of engine families produced, the sixth company could reasonably be assumed to be small as well. However, three of the companies produced 75,000 to 700,000 engines and had very high annual incomes. The high annual income and the high volume of engine production of some companies raised doubt regarding the use of the SBA definition for developing small-volume manufacturer cutoffs. EPA therefore consulted the Phase 1 certification database for its basis of a new definition of small-volume engine manufacturer.

EPA reviewed the September 1998 Phase 1 certification database for the range of engine manufacturers and their estimated annual production. EPA observed that there is a range of volumes among the engine manufacturers for the handheld industry. The total projected sales numbers are seen to be less than 25,000 for 6, 25,000 -35,000 for 2 engine manufacturers and greater than 50,000 for the remaining handheld engine manufacturers. Based on this, the selected production cutoff is listed in Table 9-04.

Table 9-04
Production Cutoffs for Small-Volume Engine Manufacturer

Handheld Engines	25,000 units

Application of these cutoffs to the September 1998 EPA Phase 1 database show that the handheld definition will include 14 percent of the companies, but only 0.3 percent of the total engine production.

9.2.2 Small-Volume Engine Family

Data utilized to determine small-volume engine families for the handheld sections of this industry were from the EPA Phase I certification database.

The small-volume engine family cutoff for handheld engines is presented in Table 9-05. A value of 5,000 is being adopted for handheld engine families, which is the same as nonhandheld, as requested by EMA and PPEMA in comments to the January 1998 NPRM.

Table 9-05
Small-Volume Engine Family Definition

Handheld Engines	5,000

The result is that approximately 45 percent of total number of engine families in the handheld industry could be considered small-volume engine families. While this may seem like a large number of families, when one compares the number of engines represented by these families and the total number of engines, only 1.74 percent of the annual production of Small SI engines will be included in this definition.

Overall, the total engine production that will fall under the two definitions of small-volume engine family and small-volume engine manufacturer amounts to only 1.77 percent of the total production for the handheld industry as a whole.

9.2.3 Small-Volume Equipment Manufacturer

The 1996 Power Systems Research EO LINK database and information from various equipment manufacturer associations and equipment manufacturer websites were utilized to determine the cutoffs for small-volume equipment manufacturers (NOTE: This flexibility applies for equipment manufacturers that do not make their own engines). Table 9-06 contains the cut off for small-volume equipment manufacturers.

For handheld equipment manufacturers, the cutoff is 25,000 units, which is the same as the small-volume engine manufacturer. The basis for this is that a review of the small-volume equipment manufacturers (of which there are only 11), show this to be a reasonable cutoff in order to provide manufacturers the flexibilities to change their production to use Phase 2 certified engines. This provision affects 79 percent of the equipment manufacturers identified in the PSR database or elsewhere as producing equipment with handheld engines. However, these small-volume equipment companies utilize only about 0.3 percent of the total number of engines produced each year.

Table 9-06
Small-Volume Equipment Manufacturer Cutoff

Handheld Units	25,000

9.2.4 Small-Volume Equipment Model

The cutoff for small-volume handheld equipment model (in which the equipment manufacturer does not make engines as well) is presented in Table 9-07 and is 5,000 units/model. The cutoff has been raised in response to comments on the July 1999 SNPRM. This flexibility is expected to affect only one, or possibly two, manufacturers that would not also be considered small-volume equipment manufacturers. Production data were not available for one large multinational firm which markets on five continents, advertising itself as one of the largest lawn and garden equipment manufacturers in Europe, and it will thus be considered a large volume equipment manufacturer. However, even if all eight of this manufacturer's product lines were to qualify for small-volume equipment model flexibilities, the resultant percentage of equipment being allowed to utilize a Phase 1 engine would be a minuscule portion of the total annual engine/equipment production.

There are a number of factors that will influence whether this definition is put to use by equipment manufacturers. These include (1) the distribution system for engines and equipment is complex and all engine families may meet the standards in order to have a nationwide engine program, (2) the inability for engine manufacturers to pick who gets a "lower price engine" over others, and (3) market pressure for a Phase 2 certified engine may result in less use of this flexibility.

Table 9-07
Small-Volume Equipment Model Cutoff

Handheld Units	5,000

Table 9-08 summarizes the flexibilities included in the final rule. The flexibilities are for handheld engine manufacturers and engine families only unless otherwise specified. Also, the equipment manufacturer flexibilities are for those independent equipment manufacturers who do not make engines for their own equipment.

Table 9-08
Summary of the Final Rulemaking Flexibilities

Sector	Cutoff	Flexibility
Small Volume Handheld Engine Manufacturer	25,000	1. Allowed to produce "Phase 1" engines until 3 years after Phase 2 standards are fully implemented (i.e., through the 2008 MY for Classes III and IV and through the 2010 MY for Class V). The engines will be excluded from ABT until they are certified under the Phase 2 program. 2. Can certify using assigned deterioration factors. 3. Can opt out of PLT; SEA would be applicable.
Small Volume Engine Manufacturer for Classes IA and IB	10,000	May elect to not participate in the PLT program, however, the SEA program will still be applicable.
Small Volume Handheld Engine Family	5,000	They are the same as small-volume engine manufacturer flexibilities noted above.
Small Volume Engine Family for Classes IA and IB	5,000	May elect to not participate in the PLT program, however, the SEA program will still be applicable.
Small Volume Handheld Equipment Manufacturer	25,000	May continue using Phase 1 compliant engines through the third year after the last applicable phase-in date of the final Phase 2 standards if the equipment manufacturer is unable to find a suitable Phase 2 engine before then (i.e., through the 2008 MY for Classes III and IV and through the 2010 MY for Class V).
Small Volume Handheld Equipment Model	5,000	May continue to use Phase 1 compliant engines throughout the time period the Phase 2 regulation is in effect if no suitable Phase 2 engine is available and the equipment is in production at the time these Phase 2 rules begin to be implemented. If the equipment is "significantly modified" then this exemption ends, since design accommodations could be made during such a modification to accept an engine meeting Phase 2 standards.
Any Equipment Manufacturer	Any	Any equipment manufacturer, regardless of size, for any of its applications, regardless of size, may continue using a Phase 1 engine for up to one more year beyond the last phase-in of the final standard for that engine class if the requirement to otherwise use a Phase 2 compliant engine will cause substantial financial hardship.

Chapter 9 References

1. "A 1989 California Baseline Emissions Inventory for Total Hydrocarbon & Carbon Monoxide Emissions from Portable Two-Stroke Power Equipment", prepared by Heiden Associates, Inc, for the Portable Power Equipment Manufacturers Association, July 24, 1990. This report is available in Docket Item II-D-14.

2. "Utility Engine Emission Report", prepared by Booz, Allen & Hamilton Inc., for the California Air Resources Board, November 20, 1990. This report is available in Docket Item II-I-02.

3. "Regulatory Support Document, Control of Air Pollution, Emission Standards for New Nonroad Spark-Ignition Engines at or Below 19 kiloWatts" US EPA, May 1995, EPA Air Docket A-93-25, Docket Item V-B-1.

APPENDIX A

APPENDIX A: INDUSTRY CHARACTERIZATION

This Appendix discusses the structure of the industries producing engines and equipment affected by this rulemaking.   The industry characterization presented here is taken from a report prepared under a contract work assignment for EPA by Jack Faucett Associates.(Ref. 1) The purpose of the work assignment was to prepare a report describing and analyzing the market structure, conduct, and performance of the small nonroad engine and equipment industry and to assess the technologies represented by the most common engines and equipment. The following descriptions are excerpted from that report. Some sections which are excerpted are specific to the Lawn and Garden Equipment Standard Industrial Code (SIC) 3524, although 11 SIC code categories were analyzed in the report. The reason this section is focusing on the lawn and garden equipment category is that most of the engines and equipment covered by this regulation are in that category. (Note that this summary is from the time of the Jack Faucett Associates report (December 1992) and has not been updated. Most information is still relevant, however company specific information is outdated.)

> [The small nonroad engine market is best described as a chain of industries that: convert raw materials into components, engines, and equipment; distribute the final product to end users; and, provide service and parts as required. The establishment of regulation or alternative-market based regulatory approaches will impact this chain of industries in a variety of ways. The structure of this chain, and the characteristics of the industries that comprise it, will influence how successful alternative control strategies will be in practice.
>
> Figure 1 provides a schematic of the relationships and flow of goods for engine manufacturers. To begin the process, raw materials and components are purchased from suppliers. Necessary raw materials include the steel and aluminum required to manufacture engine parts. The amounts and types of purchased components will vary from one manufacturer to another. Some engine manufacturers make their own parts, others purchase components. Die-cast molds are used to forge parts. The finished parts and components are assembled into engines on an assembly line.
>
> Complete engines are sent to one of three places: equipment manufacturers, distributors, or export markets. A great deal of engines are sold directly to equipment manufacturers. In cases where engine manufacturers are vertically integrated, these sales would be recorded as intra-company transfers. Direct sales to equipment manufacturers is particularly common for high volume consumer equipment and for technically demanding equipment for the commercial market. The large volume engine manufacturers such as Briggs & Stratton and Tecumseh sell directly to mass merchandiser equipment manufacturers such as Murray Ohio Manufacturing and American Yard Products.

Price and economies of scale[51] are the primary factors of competition for engine sales to mass merchandisers. For direct sales to equipment manufacturers producing mid-range and premium priced equipment, engineering and design cooperation is essential. In these cases, the engine manufacturers also work closely with the equipment manufacturers to develop superior products.

For smaller equipment manufacturers, or for some of the cases where there is no need for technical cooperation, it is usually not cost-effective for the engine manufacturer to sell engines directly to the equipment manufacturer. In those cases, engine manufacturers often ship engines to independent wholesale distributors. As independent businesses, these distributors carry engines from multiple manufacturers. The distributors then sell the engines to original equipment manufacturers (OEM's) to be installed as product components. Distributors also sell "loose" engines as replacement parts. Large-scale end-users and dealers/retailers who provide service on used equipment are the most frequent purchasers of replacement engines. Engines not sold to equipment manufacturers or domestic distributors are shipped as exports.

In every segment of the utility industry, equipment manufacturers must decide whether to use "two-tiered" distribution channels or to interface directly with their dealer network. In a two-tiered distribution system, an independent wholesale distributor acts as an interface between the equipment manufacturers and the dealer network. Distributors add value by providing service to both the equipment manufacturers and the dealer network. Distributors remove a great deal of the inventory burden from dealers. Because dealers generally do not have the facilities or financial strength to maintain large inventories, they must frequently order parts for repair. Successful distributors can usually provide parts within 24 hours. In the absence of a distributor, parts must be shipped from the equipment manufacturers by package delivery services (such as UPS). This can take several days or more, depending on manufacturer location and the availability of the part. Furthermore, because many dealerships are small businesses, they often rely on their distributors for bookkeeping and general business support. Enhanced service provided by the distributors improves the reputation of the equipment manufacturers. Also, distributors provide market information to manufacturers because they are closer to the consumers and are often able to identify emerging trends faster than the manufacturers themselves.

Despite the added value that distributors provide for both dealers and manufacturers, they are declining in numbers and importance. This shift is generally attributed to the ever increasing price competition in the consumer marketplace. The value added by distributors must be offset by the profit margin required by the additional tier in the distribution chain. Although distributors will

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[51] An economy of scale is said to exist when larger output is associated with lower average cost.

remain important, particularly for premium line equipment, their impact on the market is projected to decline.

The distribution system for lawn and garden equipment manufacturers is probably the most diverse and complex in the utility market. This is primarily due to the different needs of the commercial and consumer markets. The bulk of all lawn and garden unit sales go to consumer end-users.[52] However, commercial customers represent too large a market to ignore, and some equipment manufacturers and members of the distribution chain focus strictly on the commercial business. Balancing the commercial customers need for performance and service with the consumer customers need for a low price is the challenge facing manufacturers and the distribution channels they have developed.

Figure 2 provides a schematic of the relationships and flow of goods from the viewpoint of the lawn and garden equipment manufacturers. These manufacturers design and manufacture their own parts and/or purchase components. The finished parts and components are assembled into end-user equipment. Finished goods are sent to one of three places: wholesale distribution dealers or other retail establishments, or shipped for export.

Some manufacturers use a direct (i.e., one-tier rather than two-tier) distribution system, dealing directly with dealers or other retail establishments. The larger the manufacturers and the larger the retail unit, the more likely that this link will be direct. Mass merchandiser manufacturers deal directly with mass merchant and discount retail outlets. Some manufacturers deal directly with all types of retail outlets. The trend towards direct distribution is expected to continue, as is the trend towards the mass merchandisers. These trends serve to keep prices low, foster price based competition, and put a squeeze on distributors and local dealers. The average service dealer makes $100,000 to $250,000 in sales per year. There are 300 dealers that bring in over $1,000,000 in revenues annually. There are also a great many dealers that have less than $100,000 annual revenues. Dealers are extremely dependent on service revenue to stay in business. Approximately 50 percent of the average dealers revenues are realized through parts and repair work.[53]

As emission requirements force small nonroad engines to be more complex, more will be expected of small engine technicians. The situation is similar to automobile dealers who must perform vehicle emission compliance work. Jeff Voelz, Marketing Director at Onan Corporation, noted that, “dealers

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[52] For example, OPEI estimates that 90 percent of walk behind lawnmower sales go to the residential market.

[53] North American Equipment Dealers Association.

will have to get savvy and understand that this is their future."[54] As in the automotive industry, emission control advances are likely to reduce the user's maintenance abilities and require an increase in small engine technician skills.

Although two-tier distribution is declining, it is still an important feature of the distribution network. According to a survey of its members, OPEI found that 41.4 percent of shipments were distributed through wholesale distributors in 1988. Many manufacturers use two-tier distribution for virtually every type of retail establishment, although distributors are generally bypassed when shipments go to mass merchandisers and discounters. Because of fierce price based competition, the pressure is on distributors to prove their ability to add value in order to maintain their volumes of business in the future.

Most manufacturers choose to focus on either the consumer or commercial market. These factors, in turn, influence their choice of distribution channels. Manufacturers that focus strictly on the consumer market, especially at lower end prices, generally retail exclusively through mass merchandisers. Manufacturers that focus strictly on the commercial market, generally rely exclusively on dealers. Mid-range manufacturers and other manufacturers that wish to compete at the commercial or top-end consumer market and the low-end consumer market face a difficult choice. It is tempting to use both mass merchandisers (for sales volume) and dealers (for value added service). However, this creates tremendous conflict within the channels, particularly for the dealers. The dealers cannot match mass merchandisers on price, and frequently end up as repair shops, merely servicing the equipment that they can no longer sell. The solution to this situation that has been most successful is to sell separate lines of products, restricting the mass merchandisers from selling the higher quality product lines. McCullough has been able to do this successfully. Toro tried to do this, but eventually withdrew from mass merchandiser outlets. Toro is now trying the mass merchandisers again with its Lawnboy subsidiary.

This discussion of lawn and garden manufacturer distribution channels primarily addresses nonhandheld equipment manufacturers, although, in general, it applies to handheld equipment manufacturers as well. There are, however, some unique facets of the handheld manufacturers distribution networks that have not been previously addressed. The major difference is that the handheld manufacturers all make their own engines. This changes the mixture of raw materials and components they purchase as well as their manufacturing and design processes. A separate engine market would not suffice for handheld manufacturers because of the size, performance, and design restrictions placed on their products by the unique end-user requirements for handheld equipment.

There are only a handful of nonhandheld equipment manufacturers that are

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[54] Phone conversation on June 8, 1992.

vertically integrated. Kubota is an example of a major manufacturer of both engines and equipment.(Ref. 2)

The Lawn and Garden Equipment Industry (SIC 3524) accounted for 0.11 percent of GDP in 1990.... Constant dollar shipments have increased sharply, with a 33.1 percent increase from 1984 to 1990.... [R]oughly the same number of companies were responsible for the increased out, indicating that new firms entering the industry may not have been responsible for higher output. Value added as a percent of output for the industry in 1990 was 40.9 percent, roughly the same as the internal combustion engine industry.

This industry does not seem to be capital intensive, as assets were only 18.8 percent of output in 1990, less than the corresponding percentage for All Manufacturing Industries.... In addition, capital turnover rates are 15.6 years, slightly above the average for All Manufacturing Industries. As a result, should regulation result in new purchases of capital, the industry may not have as much difficulty as other industries in adapting to regulatory actions.

Concentration in this industry is high, as the 8 largest companies control 71 percent of the market. These companies may have the ability to influence the price of their products. Yet the industry does not seem to have excess capacity, with a capacity utilization rate of 73 percent. This figure is slightly less than the 76 percent rate for All Manufacturing Industries....

Because the Statistics of Income Classification code relevant to the Farm Machinery and Equipment industry includes both 4-digit SIC codes 3523 and 3524, the profitability analysis for the Farm Machinery and Equipment industry also applies to the Lawn and Garden Equipment industry. For 1988, profitability for this industry seemed quite good, with the average return on equity up to 17.9 percent, a 14.1 percent increase from 1990. The average debt to asset ratio, however, is among the higher of the seven minor industries considered... at 42 percent.

Constant dollar shipments are expected to grow at an annual rate of 2 percent over the next 5 years for the Lawn and Garden Equipment industry. The U.S. Industrial Outlook attributes this increase to several factors, first among them are demographic changes in the U.S. population. In particular, the fastest growing age group, 44-54, will be near their maximum earning potential, which should result in larger expenditures on lawn and garden equipment. The report also notes that many of these consumers will be more inclined to upgrade their current properties, which may entail landscaping. The removal of trade barriers in Mexico and Canada as a result of the North American Free Trade Agreement (NAFTA) should give companies in the three North American countries the opportunity to expand their exports. In addition, the report mentions that possible environmental standards may have an impact on sales, but the report does not give a clear indication of whether or not these regulations will cause sales to increase or decrease.(Ref. 3)

[M]any of the eleven 4-digit SIC industries encompassing the small nonroad engine and equipment industry are characterized by significant value added, fairly high concentration, growth in the value of shipments, capital intense production processes, high capital turnover, and relatively efficient capacity utilization. These basic industry trends determine the competitive nature of the industry and condition the interactions of the firms that form these industries with suppliers, consumers and each other.(Ref. 4)

[The competitive features of the small nonroad engine and equipment industry have been reviewed. These features include: channels of product distribution, the levels of vertical and horizontal integration across engine and equipment manufacturers supplying the nonroad engine and equipment industry, the types and extent of barriers to entry that may exist in this industry, the degree of market power inherent in the nonroad engine and equipment industry at various levels of producer interactions, the availability and importance of substitute power sources for these engines, the global competitive position of U.S. firms in this industry, and characteristics of end-users which drive the demand for the various products that are sold in the small nonroad equipment industry. Such a comprehensive description of this industry's competitive features has revealed various interesting results which should be summarized.

First, the level of vertical integration in the small nonroad engine and equipment industry appears to be rather small. Where present, vertical integration is concentrated in three areas of the industry: foreign lawn and garden engine and equipment manufacturers, foreign recreational engine and equipment manufacturers, and handheld lawn and garden engine and equipment manufacturers. For example, Honda produces both the engine and equipment components of their lawn and garden products... In fact, most of the vertically integrated companies are foreign companies.

Horizontal integration, on the other hand, is common among engine manufacturers in the small nonroad engine and equipment industry. This follows directly from the fact that a single engine design is often used in many small nonroad equipment applications.... [T]ecumseh and Briggs & Stratton engines, for example, are employed by various types of equipment including lawn and garden equipment, light commercial and industrial equipment, light agricultural equipment, and others.

Second, advertising and product differentiation, economies of scale, and large capital requirements appear to be the only forms of barriers to entry that <u>may</u> characterize the small nonroad engine and equipment industry. However, the effectiveness of these phenomena is difficult to assess. Nevertheless, advertising plays an important role in the lawn and garden equipment industry, as shown by its relatively high advertising intensity ratio. Similarly, product differentiation is important in this market as evidenced by the large number of brands and product models that are offered for different equipment types, such as lawnmowers or chainsaws...

Economies of scale and large capital requirements, on the other hand, are likely to be more important at the engine manufacturing level of the industry, since this level is capital intensive and characterized by few dominant sellers....

...[O]ne general characteristic of the industries that comprise the small nonroad engine and equipment industry is high levels of seller concentration. Empirically, high seller concentration has been shown to perpetuate product pricing that is above the marginal cost of the products production.(Ref. 5)... [R]esults that are characterized by this pricing outcome are economically inefficient, and display the market power, of at least the market leaders, in the industry. However, although the small nonroad engine and equipment industry is generally characterized by seller concentration,... the various relationships between the economic agents operating in this industry are not characterized by significant levels of market power. Much of the reasoning behind this conclusion centers on the concept of contestable markets... The fact that the small nonroad engine and equipment industry is not characterized by market power implies that if regulatory actions increase the production costs of the firms producing in this industry, then these incremental costs will likely be passed on to consumers, or end-users, in the form of higher prices. Moreover, the likelihood that market power is not prevalent in the small nonroad engine and equipment industry implies that economic profits are not being accrued in the long run. This in turn suggests that entry into the market is relatively free. Although some aspects of barriers to entry may exist (such as product differentiation, advertising, and economies of scale), their effectiveness at deterring entry is not necessarily evident.

Fourth, the prevalence of substitute power sources and equipment that displace equipment powered by internal combustion engines is most evident in the lawn and garden equipment market where electrically powered machines have been common for many years. However, the sale of electrified lawn and garden equipment is hampered by various factors. For example, the long extension cords necessary for the operation of electrified equipment are cumbersome, while electrified lawn and garden equipment are generally not a viable option for commercial users. However, use of battery packs could potentially resolve some of the detrimental user oriented externalities associated with electrically powered lawn and garden equipment (Ref. 6).

Appendix A References

1. Jack Faucett Associates, *Small Nonroad Engine and Equipment Industry Study*, JACKFAU-92-413-14, December 1992

2. ibid, pages 68-76

3. ibid, pages 57-58

4. ibid, p. 67

5. Curry, B., George, K.D., *Industrial Concentration: A Survey*, The Journal of Industrial Economics, March 1983

6. Jack Faucett Associates, *Small Nonroad Engine and Equipment Industry Study*, JACKFAU-92-413-14, December 1992, p. 123-126.

NOTE: Graphs not included in this electronic version

Appendix B: Manufacturer and Product Summary

B.1. Introduction

This appendix summarizes information on the equipment related to the category of engines regulated, nonroad handheld spark-ignited engines 19 kW or less. This appendix summarizes the engine manufacturers and their products, the technology used on these engines, and estimates the amount of these engines consumed in the United States.

B.2. Engine Manufacturer Summary

There are a wide variety of engine manufacturers producing engine products which will be regulated. Data on the manufacturers and their products is provided from EPA's Phase 1 certification database[55].

B.2.1. Listing of Known Engine Manufacturers

EPA has generated a listing of engine manufacturers from the September 1998 EPA Phase 1 certification database. It appears that there are 22 manufacturers which produce two-stroke engine families and three manufacturers which produce four-stroke engine families.

B.2.2. Listing of Known Engine Models per Manufacturer

The EPA Phase 1 database contains the most extensive listing of information at the engine model level. The data in this section is excerpted from this database. Presented in Table B-01 are the number of engine models per manufacturer and the estimated number of engine models in each standard category.

B.2.2.1. Number of Engine Models- Table B-01 shows that there are 186 engine models in Classes III through V. There are nine manufacturers of handheld engines who produce less than five engine models. The more engine models a manufacturer produces does not correlate to overall more engine sales. Some engine manufacturers are specialized and serve a number of specialty markets.

B.2.2.2. Engine Family and Emissions Per Engine Family Per Class – Tables B-02 through B-04 contain information per engine family per manufacturer on engine family, new engine emissions (HC, NOx, CO), emission control technology, major applications and displacement.

Since the Phase 2 regulation is an in-use set of standards, the new engine values from the September 1998 Phase 1 certification database have been deteriorated to compare to the new engine standard. Deterioration factors were taken from data submitted by industry and EPA's own analysis. Table B-05 lists the deterioration factors applied to the corresponding engine families.

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[55] All engine models for production in the 1997 model year were to be certified by September 1, 1997. The only exception are those models that are exempt from CARB's Tier 1 program (Class V engines) which have until January 1, 1998.

Table B-05
Deterioration Factors

Engine Class	III	IV	V
	HC/NOx	HC+NOx or HC/NOx	HC/NOx
four-stroke OHV	--	1.5	--
two-stroke	1.1/1.0	1.1/1.0	1.1/1.0
two-stroke w/ Catalyst	--	1.3	--

B.3. Estimate of Historical and Future Equipment Consumption (Sales)

Information on the estimate of historical sales is summarized in this section. Historical data came from EPA's analysis of the information from the PSR database as well as information from Outdoor Power Equipment Institute (OPEI), the Portable Power Equipment Manufacturers Association (PPEMA), and a study done for the California Air Resources Board by Booz, Allen, Hamilton (BAH). Data presented in this section show the estimates of historical consumption from these sources. This information was used in EPA's check of the 1996 population estimates being used in the NONROAD model. The information on future equipment consumption is described in Chapter 6.

Table B-01
Engine Manufacturers and Engine Families Per Class and Engine Type
September 1998 EPA Phase 1 Certification Database

MANUFACTURER	HANDHELD					TOTAL
	III 2-S	IV 4-S	IV 2-S	V 2-S	V 4-S	
Emak s.p.a.			4	4		8
Fuji Heavy Industries, Ltd.			1	4	1	6
Fuji Robin Industries	1		2	1		4
Honda		2			2	4
Husqvarna AB			11	16		27
Ishikawajima Shibaura Machinery Co.			4			4
John Deere Consumer Products, Inc.	1		8	2		11
Kawasaki	1		7			8
Kioritz			8			8
Kioritz-Echo			10			10
Komatsu-Zenoah			7	1		8
Makita USA, Inc.			7	8		15
Maruyama US Inc.			7			7
Mitsubishi Engine North America, Inc or Mitsubishi Motors Corporation			2			2
Poulan	3		10	1		14
Ryobi		1	3			4
Shin-Daiwa Kogyo Co. Ltd			13			13
Solo Incorporated			1	1		2
Stihl			12	11		23
Tanaka Kogyo Co. Ltd	2		1			3
Tecumseh			1	3		4
Wacker-Werke GmbH&Co KG.				1		1
TOTALS	8	3	119	53		186

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F