Chapter 4: Technology Market Mix and Cost Estimates for Small SI Engines and Related Equipment

This chapter determines the variable costs and fixed costs per engine family modified in each class. This chapter also presents a "schedule" for how these engine modifications are phased-in (e.g. 100% in 2001 for Class I). These costs are costs to manufacture.

The Clean Air Act Amendments of 1990 section 213(a)(3) require that EPA must consider cost in determining whether proposed standards achieve the greatest degree of emission reduction. This Chapter and Appendix C present 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[6] percentage estimates for pre-Phase 2 (Phase 1) and Phase 2 engines must

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6 Market mix is the percentage of engines of specific engine design sold in the marketplace (ex: 4-stroke SV and 4-stroke OHV) compared to others in the same Class.

first be assessed. This is done by determining the Phase 1 engine market mix from confidential estimates provided by manufacturers as part of their 1997 (or 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 proposed rulemaking. A description of the methodologies and resultant market mixes for these estimates are described in 4.1. Engine Technology Market Mix Estimates.

Many of the emission reduction technologies assumed feasible for this rule consist of internal engine design changes. As a result, many technologies require changes in manufacturer production including tooling and die design. 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 SV to 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 an OHV line which were not in place for assembly of a side valve line. Variable hardware and production costs are determined by estimating variable costs for each emission reduction technology and applying those costs to 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 4.2. 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 proposed 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 are presented in 4.3. 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 required to meet the Phase 2 proposed standards. A discussion of equipment impacts is presented in 4.4 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 improve the quality of Phase 2 engines in ways which should directly benefit the consumer but information was insufficient to quantify these benefits.

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., side valve, overhead valve, 2-stroke, etc.) per class (i.e., Classes I-V). Market mixes are determined for the 1997 (or 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 only those engine families and production volumes certified to EPA's Phase 1 standard. This does not include engine families and related production volumes that are certified for CARB's Tier I standard for those are covered by CARB. A summary of results are in Tables 4-01 to 4-04 with manufacturer specific details and emission data in Appendix B Manufacturer and Product Summary.

4.1.1. Phase 1 Market Mix

The most accurate and uptodate information source on engine families and manufacturers in the marketplace today is the EPA Phase 1 engine certification list. The list, as of September 1, 1997, was utilized to estimate the number of engine families per engine design and technology for Classes I-V[7] 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.

[7] While Class V engines will do not have to be certified until January 1, 1998 for the Phase 1 rulemaking, review of the current database shows that a large number of engines are certified. This analysis will be updated for the final rule to include all Phase I engine families. In addition, there are special cases in which engines do not have to meet the Phase 1 standards. These include engines mainly utilized in wintertime equipment, such as snowblowers, that only have to meet the CO standard. Two- stroke Class I engines are under a special program to be phased-out over a period of years and need only meet the handheld standards.

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

CLASS	SV	OHV	SV w/ cat	OHV w/ cat*	TBI on OHV	2-stroke	2-stroke w/cat	TOTAL
I	18	37	--	--	--	2	--	57
II***	23	85	2	5	2	--	--	117
III	--	--	--	--	--	4	--	4
IV	--	3	--	--	--	132	3	138
V	--	--	--	--	--	22	--	22
TOTAL	41	125	2	5	2	160	3	338

* These engines include propane engines that are installed in equipment used indoors and must work to allow facilities to meet OSHA time measured safety levels for CO.

*** There is one OHV engine with EGR used on a utility vehicle.

Table 4-02
Assumed Phase 1 Sales per Class and Technology Type
Phase 1 Database as of September 1, 1997

CLASS	SV	OHV	SV w/ cat	OHV w/cat	TBI on OHV	2-stroke	2-stroke w/cat	TOTAL
I	7,291,469	914,980	--	--	--	conf**	--	8,206,449+ conf
II	1,651,966	1,307,605	conf	3,125	conf	--	--	2,964,884
III	--	--	--	--	--	715,406	--	715,406
IV	--	conf	--	--	--	7,986,641	conf	8,179,067
V	--	--	--	--	--	190150*	--	190,150
TOTAL	8,945,123	2,222,585+	conf	3,125	conf	8,872,197	conf	

* This number does not include the number of engines that are used in snowblowers that do not have to meet the HC+NOx standards. Also, it is expected that there will be additional engines certified to the Phase I standard by January 1, 1998 and thereby this number will increase. It is expected that the percentage needing improvement will remain about the same.
** Some of the blocks state "conf" this is done to honor the confidentiality if only one or two companies contribute to the total number of engine families in that block.

4.1.2. Phase 2 Market Mix

To determine the Phase 2 market mix, information was collected on potential emission reduction technologies and then the likely percentage usages of such technologies, as required by the Phase 1 engines, were estimated.

4.1.2.1. Potential Emission Reduction Technologies --

Potential emission reduction technologies were based on information provided in a work assignment with SwRI ((Ref. 1))[8]. SwRI compared the characteristics

[8] EPA had analyzed a number of emission reduction technologies - both proven and pre-prototype (see Regulatory Negotiation Exhaust and Fuel

of engines that were below the Phase 2 standards to those engines that were above the Phase 2 standards and provided a list of characteristics/technologies of low emitting engines. EPA supplemented this analysis with some additional Phase 2 technologies and compiled a composite list, see Table 4-03.

Table 4-03
Potential Emission Reduction Technologies

ENGINE TECHNOLOGY	POTENTIAL TECHNOLOGIES
4 stroke	-OHV technology -Improved induction systems and combustion chamber design -Carburetor enleanment and improved engine cooling -Improved tolerances for carburetor with more precise air/fuel control and reduced part to part variability -Optimized ignition timing -Flex head valves, improved cylinder structural integrity, modified valve placement -Intake valve stem seals -Design improvements that reduce cylinder distortion -Reduced manufacturing tolerances -Use of piston oil control ring

Systems Technology Subgroup Reports [(2)(3)]. Cost, durability and production ready condition were major factors in determining feasible emission reduction technologies for these engines.

2 stroke	-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 -Catalysts in select products, along with other engine and carburetor modifications -Stratified scavenging -4 Stroke engine design

SOURCE: SwRI report and other known technologies

This cost analysis uses a portion of these technologies per engine design (ex: SV, OHV) per engine class. This is based on a comparison of deteriorated emission data, based on the EPA Phase 1 certification database and deterioration factors presented in Chapter 3, to the proposed Phase 2 standards, see Table 4-04. The following describes the rational behind the estimation of use of these technologies by engine Class and engine technology. 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.

4.1.2.1.1. Class I -- The majority of engines in Class I are produced for the low cost consumer market and are of side valve design (88% SV). Many internal engine design improvements, such as material selection, enleanment, and valve placement, have been made on a large portion of these engines in order to meet the Phase 1 new engine emission regulations. To meet the standards in this proposed Phase 2 regulation, EPA estimates that Class I SV engines will use technologies to reduce new engine out emissions and increase emissions durability. Improvements to the carburetor, combustion chamber and intake will reduce new engine emissions while oil control rings and valve stem seals will improve emissions durability by lowering combustion chamber deposits from the seepage of oil.

EPA estimates that Class I OHV engines will require no improvements due to the fact that Phase 1 certification data shows that deteriorated Class I OHV engines are already below the Phase 2 standard. Industry may choose to improve Class I OHV engines to obtain more credits to offset SV engines that are above the Phase 2 standard; however, this is not required.

4.1.2.1.2. Class II -- Class II engines are nearly equal in number of engine population of four-stroke side valve and overhead valve designs. The emission level and useful life requirements for Class II engines to meet the in-use emission standards of this rule are more rigorous than for Class I engines. It is expected that a number of Class II SV engines will convert to a clean durable OHV emission performance technology. While the majority of SV engine families are expected to convert to OHV, it is acknowledged that there are durable side valve engines in this class, particularly those geared towards commercial applications.

Current OHV engines will be improved by lowering new engine levels and improved emission durability. Improvements in combustion chamber design and intake system will allow the engines to run more efficiently and thereby lower new engine emissions. Improvements in emission durability will be achieved by refinement of piston profile and improved piston ring specifications to reduce oil seepage into the combustion chamber.

4.1.2.1.3. Handheld -- The HC+NOx in-use emission standards for Phase 2 are 30% below the new engine standards for Phase 1. To comply with the emission standards, manufacturers will have to incorporate a number of engine changes.

Improved scavenging includes better designed combustion chambers and transfer ports. The chambers are generally more spherical in shape and employ a squish area. The improved combustion chamber design will also promote more complete combustion. The size and angle of the transfer ports may be optimized to direct intake charge flow so as to reduce scavenging losses. EPA also assumes that leaner calibrations will be used to reduce HC emissions with requisite improved engine cooling. This is based on considerations that as engines are enleaned there is less fuel available to cool the engine and therefore additional cooling must be found in order to assure correct engine operation. Additional cooling will be achieved through redesigning of existing material in the engine to provide increased surface area in engine head and block and engine fan. Changes are also expected in the current carburetion design to achieve the leaner calibrations. Manufacturing tolerance improvements are also expected to lower emissions as improvements may include tighter fits with the piston rings and cylinder bore, or reduced variability in the positioning of the transfer port openings as related to piston travel.

Other engine technologies currently used in Class IV include catalyst and four stroke OHV design. One handheld engine/equipment manufacturer has introduced several engine families with unique catalyst technology. Several other engine/equipment manufacturers have certified handheld four stroke engines. Calculation of assumed in-use levels from these technologies

(1.30 and 2.0 for catalyst and four stroke, respectively) shows that the Phase 1 standards do not require the use of these technologies for emission control, nor will the proposed Phase 2 standards.

Table 4-04
ASSUMED TECHNOLOGY IMPROVEMENTS FOR THIS ANALYSIS

CLASS	ENGINE DESIGN	ASSUMED TECHNOLOGIES
I	4 stroke - SV	Carburetor Improvements Combustion Chamber Improvements and Intake System Improved Oil Consumption (piston/valve guides)
	4 stroke - OHV	None necessary
	2 stroke	None necessary (engines being phased out through Phase 1 process)
II	4 stroke - SV	Conversion to Clean OHV
	4 stroke - OHV	Piston and Piston Ring Improvements Improved Combustion and Intake System
III-V	2-stroke	Carburetor Improvements Improved Scavenging and Combustion Chamber Design Manufacturing Tolerance Improvements

4.1.2.2. Engine Families Selected for Emission Improvement -- The Phase 1 certification database was utilized in the analysis to determine the number of engine families and corresponding production volume that would need to incorporate emission or emission durability improvements[9]. Different

[9] The database contains several entrees 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.

certification programs are being proposed for handheld and nonhandheld engine families and therefore this analysis looks at each group separately, see Sections 4.1.2.2.1. and 4.1.2.2.2. Refer to Tables B-02 through B-06 in Appendix B for specific emission data per engine manufacturer per engine family. Note also that the analysis for this document assumes that all engines that are assumed to require emission reduction technology, per class and engine design, will utilize the same set of technologies (see Tables 4-08 and 4-11).

4.1.2.2.1. Nonhandheld -- The standards for nonhandheld Class I and Class II engines are fully implemented in 2001. The emission standards are fully implemented in the year 2001 for Class I engines, however are phased-in for Class II engines through 2005. The following paragraphs describe the methodology used to analyze the data for engines in Classes I and II.

The Phase 2 standard is an in-use standard, and therefore the Phase 1 new engine certification data must be adjusted to account for aging. For Class I engines, deterioration factors of 1.4 for overhead valve engines, 1.9 for side valve engines and 1.6 for propane engines with a catalyst[10] were used (see Chapter 3 for the basis of these values). The Averaging, Banking, and Trading (ABT) equation was then applied to each engine manufacturer's set of engine

[10] SAE 932445 presents test results on a Class II propane engine with air/fuel ratio control and 3-way catalyst. Results show 1.6 deterioration of HC+NOx at 300 hours and 1.8 deterioration of HC+NOx at 500 hours. It is assumed that all propane engines certified to Phase 1 that have extremely low CO emissions will utilize such a system for they are marketed for indoor use.

families[11]. The ABT calculation is (Standard-FEL)*Power(Maximum Modal)*Useful Life*Load Factor *Sales. The standard used in the calculation was the Phase 2 standard minus a 10% compliance margin to account for production variability (22.5 g/kWh)[12]. If a manufacturer's resultant ABT calculation was positive (ie: needed credits), then it was assumed that the manufacturer would focus on improving the engine families that produced the greatest need for credits such that it would receive the largest benefit for the improvements to the engine family. In making this determination, families were ranked according to the combination of emission level and sales volume such that the highest ranked family would provide the greatest assumed emission benefit when modified to comply with the emission standard. The chosen engine family was assumed to just meet the standard, minus compliance margin, of 22.5 g/kWh and the manufacturer's sales weighted emission average was recalculated[13]. This was done for as many engine families as necessary until the engine manufacturer's ABT calculation was below zero. The expected technologies for these engines include internal improvements to existing engine families and therefore the Phase 2 market mix for Class I is assumed to be the

11 This ABT program allows engine manufacturers some flexibility as they optimize their choice of engine families to meet or exceed the Phase 2 standard. It is available only to nonhandheld engine families.

12 It is assumed that engine manufacturers will allow some room for flexibility such that changes in emission results, production variability and actual sales, etc. will not result in a noncompliance.

13 This is a conservative assumption since application of these technologies would be expected to result in emission levels somewhat below 22.5 g/kWh thus questioning greater emission benefit than assumed by this calculation.

same as Phase 1.

The standard for nonhandheld Class II engines is also a sales weighted average standard; however the standard is sequentially tightened over a phase-in period from 2001-2005. The analysis was performed in the same manner as for Class I engines for each implementation year; however the deterioration factor applied to SV engines in this class was 1.6, OHV's remained at 1.4 (see Chapter 3 for the basis of these values) and 1.8 for propane engines with a catalyst. The market mix for these engines is expected to change as SV engine families are converted to OHV engine families during the phase-in. This analysis assumes that all SV engine families that are converted to OHV do result in a new engine family and that existing OHV production does not fulfill the need of the discontinued SV engine families. Class II engines also include SV and OHV engines that utilize catalysts, OHV engines that use Throttle Body Injection and EGR. Based on review of the Phase 1 certification database of emission data, it is assumed that only one of the OHV engines with a catalyst will need slight emission improvement. It is assumed that the same engine improvements as for improved OHV engines will be utilized.

Table 4-05 contains the resultant assumed phase-in of engine families per class per phase-in year, if applicable, and the corresponding technology change[14]. Table 4-06 contains the resultant number of engines that correspond to those engine families being improved. The purpose of this table is to show that, for example, while only 4 engine families are being improved in Class I,

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[14] A special provision for small engine families of SV design exists for this rulemaking. The provision is that Class II engine families under 1000 engines are allowed to meet a higher standard of 24 g/kWh. This analysis found two small SV engine families.

they account for 52% of the engine production in this class. Table 4-07 shows the resultant assumed Phase 2 market mix for Class II engines.

4.1.2.2.2. Handheld -- The standards for handheld engines are phased-in over four years (2002-2005) with each year requiring that more of the annual production meet the Phase 2 standards. The Phase 1 certification new engine emission data was adjusted by a deterioration factor (1.0 for 2-stroke engines (see Chapter 5), 2.0 for 4-stroke engines (see Chapter 3) and 1.3 for 2-stroke engines with a catalyst[15] to determine the in-use emission rates. The emission rates for each engine family in each class were then compared to the corresponding emission standard (minus a 10% compliance margin to account for production variability). This analysis assumes that the manufacturers will choose the highest volume engine families to meet the Phase 2 standards in the early years, thereby leaving additional time for the many lower volume engine families. Table 4-05 shows the assumed engine family phase-in for the years 2002-2005. Table 4-06 shows the resultant engine production that are represented by the number of engine families in Table 4-05. Handheld engine families are assumed to meet the standards with improvements in 2 stroke design and therefore, the market mix for Phase 2 is assumed to remain the same as in Phase 1.

15 Based on data in SAE 941807 that tested a catalyst on a 4-stroke engine. Catalyst deterioration results were based on exhaust in and out of the catalyst - therefore assumed applicable to 2 stroke engine.

Table 4-05
ASSUMED PHASE-IN SCHEDULE OF ENGINE FAMILY CHANGES
(Number of Engine Families)

CLASS	Specific Technology Change	2001	2002	2003	2004	2005
I	Improved SV	4	na	na	na	na
II	Improved OHV	2	2	4	6	29
	SV to OHV	2	0	1	2	7
III	Improved 2-stroke	na	2	--	--	2
IV		na	17	6	19	76
V		na	9	0	5	6

Note that not all engine families need improvement, therefore the numbers in this table do not add up to the numbers in Table 4-01.

Table 4-06
Production Volume (and % of Total) Represented by Engine Families

CLASS	Specific Technology Change	2005	
		# of Engines	% Within Class
I	Improved SV	3,756,696	52%
II	Improved OHV	899,387	69%
	SV to OHV	1,354,024	82%
III	Improved 2-stroke	715,406	100%
IV		8,085,641	96%
V		190,150	100%*

Table 4-07
Phase 2 Technology Mix - Class II
Engine Families and Sales per Technology Type

CLASS	SV	OHV	SV w/ cat	OHV w/ cat*	TBI	2-stroke	2-stroke w/cat	TOTAL
Engine Families	10*	97	3	5	2	--	--	117
Sales	306,463	2,658,421	conf	3,125	conf	--	--	2,964,884

SV families <1000 units, those that are geared solelly to snowblowers, and several others remain unchanged.

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 from the cost report from ICF and EF&EE [4] for the variable hardware cost and production cost for each emission

reduction technology per class and engine design (see Tables 4-09 and 4-10).

Costs that were not included in the analysis include the additional letter on the certification label to indicate useful life category and updated service manuals (writers, documentation) and seminars for dealers and training for technicians for they were assumed to be negligible. It is expected that the later changes can be incorporated during the phase-in years and prior to the phase-in years as these activities take place due to ongoing manufacturer model changes. In addition, all of the technologies being estimated for this rule are currently being utilized in engine families and therefore are not new to the technicians or dealers. EPA expects to update the sales and technology changes estimates using the EPA Phase I certification database after the Phase I implementation date of January 1, 1998 by which time all Class V engines are to be certified (all other engines were to be certified by September 1, 1997).

4.2.1. Nonhandheld Engines

Table 4-8 lists the assumed variable hardware and production costs for each technology per engine class and engine design. These costs are based on the cost study by ICF and EF&EE(4).

The ICF and EF&EE cost study provided estimates for several production model volumes. This analysis uses only one production volume estimate for all engine families per class per engine design. This was determined by choosing the production volume estimate that best represents the sales estimates presented in the Phase 1 certification database sales estimates.

Several adjustments were made to the nonhandheld estimates in the ICF and EF&EE study. The first cost estimate modified was the improvement in piston and piston ring improvement for a Class I SV engine. ICF assumed that the engine manufacturers would need to produce a better quality piston in order to reduce oil loss into the combustion chamber. The better quality piston would be a piston produced by permanent mold casting rather than a die-casting. EPA assumed that this expense will not be necessary due to the expectation that manufacturers will utilize the technologies of improved carburetion and combustion chamber design to reduce new engine out emissions rather than incorporate this expense for reduced in-use emission deterioration. The second cost estimate modified was the variable cost for the conversion of a Class II SV to an OHV engine design. ICF had assumed specific time criteria to manufacturer rocker arms, rocker covers, push rod guides, push rod and cylinder head and cylinder at 1, 1, 1, 1.5 and 3 minutes respectively per piece. These times are considered very long in consideration of the likelihood that many pieces are manufactured at a time. As a result, the times for manufacturer of these pieces were changed to 0.1, 0.1, 0.1, 0.15 and 0.5 minutes respectively. This decreased the variable cost for a Class II SV to OHV engine to 8.59 from 12.88.

Table 4-08
Estimated Variable Hardware Costs for Technology Changes

CLASS	ENGINE DESIGN	SPECIFIC TECHNOLOGY	HARDWARE VARIABLE ($)	PRODUCTION VARIABLE($)	TOTAL VARIABLE
I	SV	Carburetor Improvements	$0.00	$0.00	$0.00
		Combustion Chamber Improvements and Intake System	$0.00	$0.00	$0.00
		Improved oil consumption (piston/valve guides)	$0.80	$0.18	$0.98
II	OHV	Piston and Piston rings improvement	$2.25	$0.00	$2.25
		Improved Combustion and Intake System	$0.00	$0.00	$0.00
	SV to OHV	Additional parts in OHV, assembly	$7.54	$1.05	$8.59

Source: ICF and EF&EE cost study [4]
NOTE: Technology changes with $0.00 indicate that there is no variable cost assumed for this technology.

The ICF and EF&EE report addresses possible developments to reduce incremental conversion costs to convert Class II SV engine families to OHV design. Such actions include the redesign and re-engineering of production processes to take advantage of improvements in manufacturing techniques. The report states that "Many existing SV engine designs are quite old and incorporate old manufacturing technology. By redesigning the engine (ie: fewer parts) and its production processes, manufacturers might be able to achieve significant savings in production costs". The report continues to state that "advances in material minimization or the use of lighter and cheaper materials could reduce costs further". While this analysis does not assume any decreases in cost due to these factors, this cost analysis does include decreases in variable costs due to the learning curve effect. This analysis accounts for this by assuming that variable costs for this technology change decrease to 80% of the original estimate in 2007 and then another 20% (or 64% of the original cost estimate) in 2010. See appendix C for the basis of this learning curve effect.

4.2.2. Handheld Engines (Classes III, IV and V)

Table 4-09 lists the assumed variable hardware and production costs for each technology per engine class and engine design used in this analysis. The ICF cost analysis was also used for the basis of these cost estimates.

Table 4-9
Estimated Variable Hardware Costs for Technology Changes to 2-Stroke Engines

CLASS	SPECIFIC TECHNOLOGY	HARDWARE VARIABLE ($)	PRODUCTION VARIABLE($)	TOTAL VARIABLE ($)
III-V	Carburetor Improvements	$0.00	$0.00	$0.00
	Improved Scavenging and Combustion Chamber Design	$0.00	$0.00	$0.00
	Manufacturing Tolerance Improvements	$0.00	$0.00	$0.00

Source: ICF and EF&EE Cost Study to EPA [(4)].
NOTE: Technology changes with $0.00 indicate that there is no variable cost assumed for this technology.

4.3. Fixed Production and Research and Development Cost Estimates per Engine Class

Many of the technology changes 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 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. Many small engine manufacturers have already begun research and development activities to address emission reductions on a portion of their production, in anticipation of emission levels as Tier II requirements by the California Air Resources Board (CARB). EPA has not removed any costs for manufacturers to meet CARB Tier II since it is not yet finalized. If EPA were to remove any costs associated with CARB Tier II, the research and development costs for engines used in CARB's preempted farm and construction applications (includes most Class V engines) would still be applied to the federal rule.

4.3.1. Nonhandheld

Review and analysis of EPA Phase 1 certification database indicate that Class I engines will require R&D for a limited number of existing engine families, see Table 4-04. The technologies are already known for increasing emission durability based on the fact that Class II engines, geared toward commercial markets, have incorporate such technology. The report by ICF and EF&EE contain estimates for several sizes of engine families, 1.2 million, 200,000 and 35,000. The estimated sizes of engine families is mostly used by ICF and EF&EE to calculate fixed cost/engine for their report. This analysis uses Phase 1 engine family production data which varies from engine family to engine family and therefore the cost estimates are not influenced very much by the choice of engine family size in the ICF and EF&EE report. In cases in which it did affect the base estimate (ie: more machines required for the 200,000 case versus the 35,000 case), the cost estimate for the 200,000 case was used for all Class I engine families and the 35,000 case was used for all Class II engine families as described below. This analysis amortizes all costs to 5 years whereas the ICF and EF&EE report amortizes most costs to 5 years and tooling costs to 10 years. This is a change that may be accommodated in EPA's analysis in the final rulemaking process.

For the carburetor improvements for Class I SV engines, only one cost was estimated by ICF and EF&EE due to the assumption that manufacturers use similar carburetors on the engines and would likely work with large volume production/ orders (depending whether they made their own in-house or not). The base costs for a model specific carburetor is $1,445,000. Combustion Chamber and Intake System improvements are estimated for all 3 cases and therefore the cost for the 200,000 units was utilized at $260,000 per engine family. The only difference was $25,000 for machine tool setup for the higher volume case. The same type of analysis was done for the piston ring improvements as the combustion chamber improvements. The cost estimate is $285,000 per engine family. For the details of what is included in each cost estimate, refer to the report. The technologies and fixed costs assumed for Phase 1 SV engines are listed in Table 4-10.

For Class II engines, a number of SV engine families are expected to be converted to OHV design and an even larger number of OHV families are expected to incorporate emission improvements. The same size cases for Class I are used for estimating costs for Class II engines (1.2 million, 200,000 and 35,000). For the SV engine families, analysis of the EPA Phase 1 database shows that, of the 12 SV families assumed to change, 3 would fall near the 200,000 case and 9 would fall near the 35,000 case. The only difference in the cost estimate for SV to OHV is the base estimate of new machine tools ($230k for the 200k case compared to $90k for the 35k case). This analysis assumes the costs for the 35k case across all engine families. The basis for this is that the majority of engine families fall close to this number and the fact that it is possible that some SV engine families will be discontinued and/or the production will be taken up with existing OHV production equipment.

Improvements in new engine and emission durability for OHV will also likely require some fixed costs for improved combustion chamber and intake system, and improved piston and ring design and bore smoothness. Of the 43 OHV families assumed to require emission improvements, 41 fell close to the 35,000 case while only 2 fell close to the

200,000 case[16]. Therefore, the 35,000 case was used for all engine families. Cost estimates for the changes assumed for these engines did not differ between the 200,000 and 35,000 cases for the combustion chamber redesign and intake system. The cost was $395,000 per engine family. Cost estimates for the piston, ring design and bore smoothness technologies was $310,000. The 35,000 case was $75,000 less than the 200,000 case[17].

Table 4-10
ASSUMED FIXED COSTS FOR NONHANDHELD PER MODEL($)*

CLASS	ENGINE DESIGN	TECHNOLOGY	FIXED PRODUCTION	FIXED R&D	TOTAL FIXED COSTS
I	SV	Carburetor Improvements	$1,160,000	$285,000	$1,445,000
		Combustion Chamber Improvements and Intake System	$75,000	$185,000	$260,000
		Improved Piston Rings and Valve Stem Seals	$40,000	$245,000	$285,000
		TOTAL PER SV ENGINE FAMILY			$1,990,000
II	SV	SV to OHV	$395,000	$620,000	$1,015,000
	OHV	Improved Combustion and Intake System	$110,000	$185,000	$295,000
		Improved Piston and Ring Design and Bore Smoothness	$65,000	$245,000	$310,000
		TOTAL FOR IMPROVED OHV			$605,000

16 It should be noted that 25 of the 41 engine families were less than 3,000 units and therefore one could consider whether the full changes contemplated here would be incurred by these engine families.

17 The piston improvement, from die-cast to permanent-mold casting, for a more heat tolerant (less distortion) design assumed purchasing pistons from an outside source. If an engine manufacturer produced the pistons itself, the cost may be lower.

*Per engine family as determined in this analysis.

The cost estimate for research and development cost for improved combustion chamber and intake system for Class II OHV engines has been modified from the cost estimate in the ICF and EF&EE cost study. In the report, ICF and EF&EE estimate that two engineer years would be required to carry out the research development and design work involved in improving combustion and intake systems for the OHV engines based. This is based on the assumption that engine manufacturers have more experience with SV than OHV engines. EPA's review of the Phase 1 certification database, in comparison to the Phase 2 standard, shows that majority of engine manufacturers with the OHV experience will be incorporating this technology. As a result, the cost estimate has been reduced from $200,000 to $100,000 for the engineering portion of the total research and development cost for this technology.

4.3.2. Handheld

Handheld classes III-V will require fixed costs for production and research and development. Manufacturers may incorporate improved 2 stroke ideas from those engines which already meet Phase 2 emission levels in their designs. The cost study from ICF and EF&EE was used to estimate the fixed costs per technology, see Table 4-11. The report lists cost estimates for two cases of different annual production. The two cases are 400,000 units and 90,000 units. Analysis of the EPA Phase 1 certification database shows that, of those assumed to incorporate emission improvements, the one Class III engine family, 107 of 116 Class IV engine families and all 22 Class V engine families, for a total of 139, are close to the 90,000 unit case and only 9 Class IV engine families are close to the 400,000 unit case. As a result, the cost estimates for the 90,000 unit case are used for all engine families. For improved scavenging and combustion chamber redesign, the cost estimate differed by only $25,000 for machine tool setup. The four stroke cost estimates were used for carburetor improvements, and manufacturing tolerance improvements since this report did not cost these out for two stroke engines. The four stroke cost estimate for the 35,000 case was used since the majority of engine families are near this production volume (approximately 133 out of 142 engine families) as compared to the 200,000 case. For the carburetor improvements, the cost was taken directly from the 4-stroke case at an estimate of $1.445 million per carburetor. This assumes that different carburetors are used per engine family per manufacturer. However, it is known that a number of the manufacturers use the same or very similar carburetor and therefore there is some overlap among engine manufacturers and likely within an engine manufacturers product line. The exact mix of carburetors per engine family is unknown and therefore a modification to this cost estimate has been made to reflect the real world use of carburetors on two stroke engines. The cost estimate for improved carburetors has been reduced by 50% and is applied to all of the engine families. For manufacturing tolerance improvements, the estimate for the 35,000 case compared to the other cases was dependent on the number of additional machines and quality auditing and control. Engineering and machine tool setup was the same.

Table 4-11
ASSUMED FIXED COSTS FOR HANDHELD PER MODEL($)*

CLASS	ENGINE DESIGN	TECH-NOLOGY	FIXED PRODUC-TION	FIXED R&D	TOTAL FIXED COSTS
III-V	2-Stroke	Carburetor Improvements	$1,160,000*50% carburetors	$285,000* 50% of carburetors	$722,500
		Improved Scavenging and Combustion Chamber Design	$140,000	$340,000	$480,000
		Manufacturing Tolerance Improvements	$88,000	$155,000	$243,000
		TOTAL FOR 2 STROKE ENGINE FAMILY			$1,445,500

Four stroke engines in the handheld classes will not require any changes due to their new engine emission level and deterioration compared to two stroke engines.

4.4. Equipment Cost Estimates

Small engines are utilized in a wide variety of equipment from handheld trimmers and chain saws to garden tractors and generator sets, see Table 4-12.

Table 4-12
Common Equipment Types Per Class

Class I	Class II	Class III	Class IV	Class V
mowers tiller snowblower generator	tractor mower comm turf generator snowblower pumps	trimmers	trimmer 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(5), the EPA Phase 1 certification database and the ICF cost study (4). 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 manufacturers line 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 as well as the phase-in period for incorporation of OHV class II engines, it is expected that equipment manufacturers will purchase new dies near or at the end of the useful life of their existing dies. Equipment manufacturers will likely have to work closely with engine manufacturers to ensure the availability of OHV engine designs in a reasonable time frame for equipment engineering requirements.

4.4.1. Nonhandheld Equipment

Estimates for equipment changes have been based on the estimated engine changes for Class I and Class II engines. The impact of changes in engine design for Class I engines are expected to be minimal and therefore no costs are estimated for equipment that use Class I engines. Changes for equipment using Class II SV engines are expected to range from nothing at all to extensive, depending on the particular piece of equipment and current engine usage. While it is known that a number of small production volume equipment manufacturers have converted to OHV design already, due to market forces and changes in engine manufacturer product line (2), the sales of Class II SV engines shown in Table 4-02 indicate that a lot of equipment still use SV engines. Due to the unknowns about the entire current equipment manufacturer engine usage, this analysis uses the high volume equipment producers (account for approximately 95% of the engines) from the PSR database as the basis of the costs for this rule. No costs were assumed for equipment currently using Class II OHV engines for changes to Class II OHV engines are expected to be internal changes thereby not influencing outer dimensions or operating parameters.

This analysis assumes there are no variable or fixed costs for nonhandheld equipment using Class I engines. Class I engines are expected to incorporate several internal engine design changes to reduce oil consumption. It is estimated that these changes will not influence the engines operation or outer dimensions and therefore there are no costs associated with incorporating Phase 2 Class I engines into the equipment.

Class II engines are expected to result in a number of changes for equipment that utilize SV engines. EPA's work with ICF, to analyze the impacts on small production volume equipment manufacturers(2), compiled cost information from equipment companies who have already switched from

SV to OHV engines, mainly for market competitive reasons. A summary of the costs used for this analysis is presented in Table 4-16.

Table 4-13

ESTIMATED COSTS PER EQUIPMENT APPLICATION (CLASS II)

Application[18]	Fixed Costs (per line)	Variable Costs (per Unit)	Equipment Changes
Walk Behind Lawnmowers	$0	$0	
Rear Engine Riders	$50,000	$0	mounting holes, longer control wires, modified exhaust/air filter positioning, and relocation of oil drains
Commercial Turf 12hp >12 to 16hp 16 to 25 hp	 $1,000 $600,000 $100,000	 $0 $0 $12	-mounting holes, controls, exhaust and oil drains -new injection molding die to create a redesigned plastic hood -additional baffling
Other Agricultural Equip	$100,000	$0	
Leaf Blower/Vacuum	$50,000	$0	
Tillers	$50,000	$0	Modified exhaust positioning, relocation of oil drains, and a redesigned baffle
Generator Sets	$100,000	$0	Frame or case be redesigned, developed, tooled and fabricated. Redesigned fuel tank and relocated muffler
Pumps	$50,000	$0	
Roller, Concrete Saw	$50,000	$0	
Other	$50,000	$0	

Source: ICF report [(6)]

18 No costs are assumed for modifications to snowblowers for they are not required to use engines certified to the HC+NOx standards due the special provision in the Phase 2 rulemaking.

The main reason for equipment changes is that the OHV engines are taller than SV engines due to the fact that the valve train is not on the side of the engine block but in the cylinder head. Based on the ICF report [4], some equipment will require that OHV engines be reoriented 90 degrees from the SV engine so that the cylinder is parallel to the center line of the equipment. This requires changes including mounting holes, controls, exhaust and oil drains. Lawn tractors traditionally have a hood covering over the engine and thereby the hood will need to be lengthened. A new injection molding die to create a redesigned plastic hood is assumed to be required. Other costs are similar to the rear engine rider. Lawn and garden tractors typically always have the cylinder head facing forward and have room under the hood to handle a V-twin OHV engine. Generators and pumps are usually encased in frames that hold the engine and other parts of the equipment. The taller OHV may require that the frame or case around the equipment be redesigned, developed, tooled and fabricated. The fuel tank may also need to be redesigned and possibly the muffler relocated.

4.4.2. Handheld Equipment

Estimates for equipment changes have been based on the estimated engine changes for Classes III-V engines. The majority of engine changes are expected to be internal. Handheld engines are expected to utilize technologies of improved 2-stroke (reduction of scavenging, enleanment, etc.). Augers will need to incorporate changes to the transmission box in order to accommodate modifications to the engine's speed-torque signature.

Table 4-14

COST ESTIMATES FOR HANDHELD EQUIPMENT (Classes III-V)

Application	Fixed Costs (per line)	Variable Hardware (per unit)	Variable Production (per unit)
Ice and Earth Augers	$60,000	$0	$0

Based on confidential conversations with Auger manufacturers.

4.5. Fuel Savings and Impacts on Performance

Section 213(a)(3) of the 1990 Clean Air Act Amendments 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 proposal 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 proposed 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 inputted into the nonroad small engine emission model (SEEM) to calculate the fuel savings per year for all equipment types given scrappage rates, production volume increases, engine power, engine load factor, residential or commercial usage and useful life. No assumption was used for fuel consumption as engines age over time. Additional calculations for number of barrels reduced and resultant cost savings is presented in Chapter 7 on Aggregate Costs and Economic Analysis.

4.5.1.1. Nonhandheld Equipment -- For Class I engines, EPA estimates that oil consumption technologies will be incorporated, such as improved piston rings and valve seals, in order to improve Class I engine lifetime emissions performance. It is expected that these technologies will not influence the engine's fuel consumption appreciably and thereby EPA estimates no change for Class I engines.

EPA estimates that the conversion of SV engine designs to OHV engine designs or the use of other emissions technologies to reduce new engine out emissions and emissions durability, will result in a decrease in fuel consumption. Estimates for Phase 2 engines were based on the estimated fuel consumption from Phase 1 engines found in the Phase 1 Regulatory Support Document (see Table 4-18). Tables 4-15 and 4-16 contains information found on brake specific fuel consumption of typical Class II OHV that are close to the Phase 2 standard and Class II SV engines. Industry has also submitted a limited amount of confidential BSFC information on Phase 1 engines. All of this information was considered and fuel consumption values for Phase 2 OHV and SV engines were determined, see Table 4-19. Note that the value for Class II SV engines does not change from the value used in Phase I. This is based on the fact that the SEEM, that calculates emission benefits and fuel savings, considers that all engines will become OHV engines or have OHV like characteristics (ie: emission benefits, fuel usage, etc.)

Table 4-15
Fuel Consumption of OHV Class II Engines
Close to the Phase 2 Standard

ENGINE	BSFC (g/kWh)	Reference
11 hp (HC+NOx emissions 1.3 g/kWh above Phase 2 stds with assumed 1.3 df)	493	SAE 910560
200cc, 4.5 hp (close in cc to a Class II engine)	447	EMA/EPA Round Robin Testing (avg of 10 mfr's and 2 engines) , 1997
570cc, 13 hp	465	EMA/EPA Round Robin Testing (avg of 6 mfr's and 2 engines), 1997

There is no BSFC data in the EPA Phase 1 certification database.

Table 4-16
Fuel Consumption of SV Class II Engines
(Engine Meets Phase 1 Standards)

ENGINE	BSFC (g/kWh)	Reference
465cc, 6.7 hp	520	Phase 1 RSD, Table 1-11

There is no BSFC data in the EPA Phase 1 certification database.

4.5.1.2. Handheld Equipment -- For 2-stroke handheld engines in Classes III-V, EPA estimates that internal engine improvements, such as decreased fuel scavenging, will result in a 6-16% decrease in fuel consumption (see Tables 4-18 and 4-19). 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. Limited publicly available test data, contained in Table 4-17, illustrates the basis for the expected fuel usage due to Phase 2 technology.

Table 4-17
Fuel Consumption of Class III to V 2-Stroke Engines
(NOTE: weightings have been changed from 90/10 to 85/15)

Manufacturer	BSFC (g/kWh)	Reference
Class IV		
Husqvarna E-tech	556	Testing at NVFEL
Class V		

4.5.1.3. BSFC Values and Estimated Fuel Savings -- The values listed in Tables 4-18 and 4-19 contain the fuel consumption values utilized to estimate fuel savings using the SEEM.

Table 4-18

Phase 1 Fuel Consumption Estimates Per Engine Per Class (g/kWh)

CLASS	SV	OHV	OTHER	2-STROKE
I	560	475	475	--
II	528	450	450	--
III	--	--	--	720
IV	--	515	--	720
V	--	--	--	529

Source: Small Engine Phase 1 RSD[7]

Table 4-19

Phase 2 Fuel Consumption Estimates Per Engine Per Class (g/kWh)

CLASS	SV	OHV	OTHER	2-STROKE
I	560	475	475	600
II	528	450	450	--
III	--	--	--	600
IV	--	515	--	600
V	--	--	--	500

Table 4-20 contains the estimated fuel savings (gallons/year) per class for this proposed rulemaking calculated from the SEEM. Class II engines account for the majority of fuel savings from this proposed rulemaking. This is due to the fact that these engines are utilized for longer hours than all other classes and therefore the fuel savings, from SV to OHV engine, is notable.

Table 4-20
FUEL SAVINGS PER CLASS
(Gallons/Yr)

	I	II	III	IV	V
2001	0	(14,665,841)	0	0	0
2002	0	(34,903,894)	(34,533)	(988,569)	(120,289)
2003	0	(57,689,956)	(102,681)	(2,795,979)	(321,088)
2004	0	(80,990,366)	(215,542)	(5,698,061)	(630,596)
2005	0	(104,876,108)	(363,440)	(9,412,945)	(1,014,235)
2006	0	(122,808,782)	(478,963)	(12,081,991)	(1,255,827)
2007	0	(135,310,216)	(556,558)	(13,807,683)	(1,402,812)
2008	0	(143,730,306)	(604,139)	(14,882,677)	(1,499,108)
2009	0	(149,697,258)	(635,285)	(15,591,104)	(1,564,566)
2010	0	(154,283,420)	(659,083)	(16,126,096)	(1,613,275)
2011	0	(157,993,281)	(678,430)	(16,553,036)	(1,650,773)
2012	0	(161,197,720)	(694,833)	(16,908,200)	(1,680,598)
2013	0	(164,049,781)	(709,373)	(17,218,353)	(1,705,484)
2014	0	(166,674,040)	(722,890)	(17,503,744)	(1,727,478)
2015	0	(169,149,753)	(735,912)	(17,776,969)	(1,747,901)
2016	0	(171,532,164)	(748,698)	(18,044,507)	(1,767,496)
2017	0	(173,858,004)	(761,381)	(18,309,470)	(1,786,657)
2018	0	(176,148,018)	(774,014)	(18,573,312)	(1,805,601)
2019	0	(178,413,765)	(786,623)	(18,836,701)	(1,824,426)
2020	0	(180,663,025)	(799,229)	(19,099,883)	(1,843,195)
2021	0	(182,450,454)	(809,254)	(19,309,239)	(1,858,157)
2022	0	(183,822,562)	(816,879)	(19,468,555)	(1,869,608)
2023	0	(184,893,615)	(822,765)	(19,591,512)	(1,878,488)
2024	0	(185,791,926)	(827,696)	(19,694,667)	(1,885,966)
2025	0	(186,602,241)	(832,197)	(19,788,583)	(1,892,766)
2026	0	(187,365,367)	(836,465)	(19,877,690)	(1,899,200)

4.5.2. Power

The power for handheld engines is expected to remain similar to Phase 1 engines. Changes in enleanment, optimization of combustion chamber design, etc. will essentially require new 2 stroke engine families to be manufactured. It is likely that new engine families will fulfill all power needs.

The power for nonhandheld engines in Class I is expected to remain the same. The added technologies including improved piston rings and valve seals are expected to result in no change. For Class II engines, power is expected to increase, however this is partially influenced by market demands which the industry stated has been asking for more powerful engines.

Chapter 4: References

1. "Investigation and Analysis of Low Emitting Small Spark-Ignited Engine Designs <19KW", Southwest Research Institute, SWRI Report 7633-807, October 1996, EPA Air Docket A-93-29, Docket Item #II-A-03.

2. "Exhaust Systems Subgroup of the Technology Task Group" Report to the Regulatory Negotiation Committee for Small spark Ignited Engines <19kW Phase II Rulemaking, September 25, 1995, EPA Air Docket A-93-29, Docket Item # II-M-33.

3. "Fuel Systems Subgroup of the Technology Task Group" Report to the Regulatory Negotiation Committee for Small spark Ignited Engines <19kW Phase II Rulemaking, September 20, 1995, EPA Air Docket A-93-29, Docket Item # II-M-33.

4. ICF and Engine, Fuel and Emissions Engineering, Incorporated; "Cost Study For Phase Two Small Engine Emission Regulations", Draft Final Report, October 25, 1996, EPA Air Docket A-93-29, Docket Item #II-A-04.

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

6. ICF Incorporated, "Small Business Impact Analysis of New Emission Standards for Small Spark-Ignition Nonroad engines and Equipment", Final report, September 1997, EPA Air Docket A-96-55, Docket Item # XXXX (yet to be assigned).

7. 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-01.