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Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines

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

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Executive Summary

EPA is adopting new standards for emissions of oxides of nitrogen, hydrocarbons, and carbon monoxide from several categories of engines. This Final Regulatory Support Document provides technical, economic, and environmental analyses of the new emission standards for the affected engines. The anticipated emission reductions will translate into significant, long-term improvements in air quality in many areas of the U.S. Overall, the requirements will dramatically reduce individual exposure to dangerous pollutants and provide much needed assistance to states and regions facing ozone and particulate air quality problems that are causing a range of adverse health effects, especially in terms of respiratory impairment and related illnesses.

Chapter 1 reviews information related to the health and welfare effects of the pollutants of concern. Chapter 2 contains an overview of the affected manufacturers, including some description of the range of engines involved and their place in the market. Chapter 3 covers a broad description of engine technologies, including a wide variety of approaches to reducing emissions. Chapter 4 summarizes the available information supporting the specific standards we are adopting, providing a technical justification for the feasibility of the standards. Chapter 5 applies cost estimates to the projected technologies. Chapter 6 presents the calculated contribution of these engines to the nationwide emission inventory with and without the standards. Chapter 7 compares the costs and the emission reductions for an estimate of the cost-effectiveness of the rulemaking. Chapter 8 presents our Final Regulatory Flexibility Analysis, as called for in the Regulatory Flexibility Act. Chapters 9 and 10 describe the societal costs and benefits of the rulemaking. Chapter 11 presents a range of regulatory alternative we considered in developing the final rule.

There are three sets of engines and vehicles covered by the new standards. The following paragraphs describe the different types of engines and vehicles and the standards that apply.

Emission Standards

Large industrial spark-ignition engines

These are spark-ignition nonroad engines rated over 19 kW used in commercial applications. These include engines used in forklifts, electric generators, airport ground service equipment, and a variety of other construction, farm, and industrial equipment. Many Large SI engines, such as those used in farm and construction equipment, are operated outdoors, predominantly during warmer weather and often in or near heavily populated urban areas where they contribute to ozone formation and ambient CO and PM levels. These engines are also often operated in factories, warehouses, and large retail outlets throughout the year, where they contribute to high exposure levels to personnel who work with or near this equipment as well as to ozone formation and ambient CO and PM levels. In this rulemaking, we call these “Large SI” engines.

We are adopting two tiers of emission standards for Large SI engines. The first tier, scheduled to start in 2004, sets standards of 4 g/kW-hr (3 g/hp-hr) for HC+NOx and 50 g/kW-hr (37 g/hp-hr) for CO. These standards are the same as those adopted earlier by the California Air Resources Board.

Starting in 2007, the Tier 2 emission standards fall to 2.7 g/kW-hr (2.0 g/hp-hr) for HC+NOx emissions and 4.4 g/kW-hr (3.3 g/hp-hr) for CO emissions. However, we are including an option for manufacturers to certify their engines to different emission levels to reflect the inherent tradeoff of NOx and CO emissions and to add an incentive for HC+NOx emission reductions below the standard. Generally this involves meeting a less stringent CO standard if a manufacturer certifies an engine with lower HC+NOx emissions. Table 1 shows several examples of possible combinations of HC+NOx and CO emission standards. The highest allowable CO standard for duty-cycle testing is 20.6 g/kW-hr (15.4 g/hp-hr), which corresponds with HC+NOx emissions below 0.8 g/kW-hr (0.6 g/hp-hr).

Table 1
Samples of Possible Alternative
Emission Standards for Large SI Engines(g/kW-hr)*

	HC+NOx	CO
Duty-cycle testing	2.70	4.4
	2.20	5.6
	1.70	7.9
	1.30	11.1
	1.00	15.5
	0.80	20.6
Field testing	3.80	6.5
	3.10	8.5
	2.40	11.7
	1.80	16.8
	1.40	23.1
	1.10	31.0

*As described in the Final Regulatory Support Document and the regulations, the values in the table are related by the following formula: $(HC+NOx) \times CO^{0.784} = 8.57$. These values follow directly from the logarithmic relationship presented with the proposal in the Draft Regulatory Impact Analysis. The analogous formula for field-testing standards is $(HC+NOx) \times CO^{0.791} = 16.78$.

In addition, Tier 2 engines must have engine diagnostic capabilities that alert the operator to malfunctions in the engine's emission-control system. Gasoline-fueled Tier 2 engines will also be required to reduce evaporative emissions. The field-testing procedures and standards in this final rule make it possible for the manufacturer to easily test engines to meet the requirements of the in-use testing program for showing that engines undergoing several years of normal operation in the field continue to meet emission standards.

Nonroad recreational engines and vehicles

These are spark-ignition nonroad engines used primarily in recreational applications. These include off-highway motorcycles, all-terrain-vehicles (ATVs), and snowmobiles. Some of these engines, particularly those used on ATVs, are increasingly used for commercial purposes within urban areas, especially for hauling loads and other utility purposes. These vehicles are typically used in suburban and rural areas, where they can contribute to ozone formation and ambient CO and PM levels. They can also contribute to regional haze problems in our national and state parks. Tables 2 and 3 show the exhaust and permeation emission standards that apply to recreational vehicles.

Table 2
Recreational Vehicle Exhaust Emission Standards

Vehicle	Model Year	Emission standards		Phase-in
		HC g/kW-hr	CO g/kW-hr	
Snowmobile	2006	100	275	50%
	2007 through 2009	100	275	100%
	2010	75	275	
	2012*	75	200	
		HC+NOx g/km	CO g/km	
Off-highway Motorcycle	2006	2.0	25.0	50%
	2007 and later	2.0	25.0	100%
ATV	2006	1.5	35.0	50%
	2007 and later	1.5	35.0	100

* or equivalent per Section 1051.103; the long term program includes a provision which acts to cap NOx emission rates

Table 3
Permeation Standards for Recreational Vehicles

Emission Component	Implementation Date	Standard	Test Temperature
Fuel Tank Permeation	2008	1.5 $g/m^2/day$	28°C (82°F)
Hose Permeation	2008	15 $g/m^2/day$	23°C (73°F)

Recreational marine diesel engines

These are marine diesel engines used on recreational vessels such as yachts, cruisers, and other types of pleasure craft. Recreational marine engines are primarily used in warm weather and therefore contribute to ozone formation and PM levels, especially in marinas, which are often located in nonattainment areas.

Table 4
Recreational Marine Diesel Emission Limits and Implementation Dates

Displacement [liters per cylinder]	Implementation Date	HC+NOx g/kW-hr	PM g/kW-hr	CO g/kW-hr
power $\geq$ 37 kW 0.5 $\leq$ disp < 0.9	2007	7.5	0.40	5.0
0.9 $\leq$ disp < 1.2	2006	7.2	0.30	5.0
1.2 $\leq$ disp < 2.5	2006	7.2	0.20	5.0
2.5 $\leq$ disp	2009	7.2	0.20	5.0

Projected Impacts

The following paragraphs and tables summarize the projected emission reductions and costs associated with the emission standards. See the detailed analysis later in this document for further discussion of these estimates.

Tables 5 and 6 contain the projected emissions from the engines subject to this action. Projected figures compare the estimated emission levels with and without the emission standards for 2020.

Table 5
2020 HC and NOx Projected Emissions Inventories (thousand short tons)

Category	Exhaust HC*			Exhaust NOx		
	base case	with standards	percent reduction	base case	with standards	percent reduction
Industrial SI >19kW	318	34	89	472	43	91
Snowmobiles	358	149	58	5	10	(101)
ATVs	374	53	86	8	6	25
Off-highway motorcycles	232	117	50	1.3	1.5	(19)
Recreational Marine diesel	2.0	1.5	28	61	48	21
Total	1,284	355	72	547	109	80

* The estimate for Industrial SI >19kW includes both exhaust and evaporative emissions. The estimates for snowmobiles, ATVs and Off-highway motorcycles includes both exhaust and permeation emissions.

Table 6
2020 Projected CO and PM Emissions Inventories (thousand short tons)

Category	Exhaust CO			Exhaust PM		
	base case	with standards	percent reduction	base case	with standards	percent reduction
Industrial SI >19kW	2,336	277	88	2.3	2.3	0
Snowmobiles	950	508	46	8.4	4.9	42
ATVs	1,250	1,085	13	13.1	1.9	86
Off-highway motorcycles	321	236	26	8.7	4.4	50
Recreational Marine diesel	9	9	0	1.6	1.3	18
Total	4,866	2,115	56	34.2	14.8	57

Table 7 summarizes the projected costs to meet the emission standards. This is our best estimate of the cost associated with adopting new technologies to meet the emission standards. The analysis also considers total operating costs, including maintenance and fuel consumption. In many cases, the fuel savings from new technology are greater than the cost to upgrade the engines. All costs are presented in 2001 dollars.

Table 7
Estimated Average Cost Impacts of Emission Standards

Standards	Dates	Increased Production Cost per Vehicle*	Lifetime Operating Costs per Vehicle (NPV)
Large SI exhaust	2004	$611	$-3,981
Large SI exhaust	2007	$55	$0
Large SI evaporative	2007	$13	$-56
Snowmobile exhaust	2006	$73	$-57
Snowmobile exhaust	2010	$131	$-286
Snowmobile exhaust	2012	$89	$-191
Snowmobile permeation	2008	$7	$-11
ATV exhaust	2006	$84	$-24
ATV permeation	2008	$3	$-6
Off-highway motorcycle exhaust	2006	$155	$-48
Off-highway motorcycle permeation	2008	$3	$-5
Recreational marine diesel	2006	$346	—

*The estimated long-term costs decrease by about 35 percent. Costs presented for the Large SI and snowmobile second-phase standards are incremental to the first-phase standards.

We also calculated the cost per ton of emission reductions for the standards. For snowmobiles, this calculation is on the basis of HC plus NOx emissions and CO emissions. For all other engines, we attributed the entire cost of the program to the control of ozone precursor emissions (HC or NOx or both). A separate calculation could apply to reduced CO or PM emissions in some cases. Assigning the full compliance costs to a narrow emissions basis leads to cost-per-ton values that underestimate of the value of the program.

Table 8 presents the discounted cost-per-ton estimates for the various engine categories and standards being adopted. Reduced operating costs more than offset the increased cost of producing the cleaner engines for Large SI and snowmobile engines. The overall fuel savings associated with the standards being adopted are greater than the total projected costs to comply with the emission standards.

Table 8
Estimated Cost-per-Ton of Emission Standards

Standards	Dates	Discounted Reductions per Vehicle (short tons)*	Discounted Cost per Ton of HC+NOx		Discounted Cost per Ton of CO	
			Without Fuel Savings	With Fuel Savings	Without Fuel Savings	With Fuel Savings
Large SI exhaust (Composite of all fuels)	2004	3.07	$240	($1,150)	—	—
Large SI exhaust (Composite of all fuels)	2007	0.80	$80	$80	—	—
Large SI evaporative	2007	0.13	$80	($280)	—	—
Snowmobile exhaust	2006	HC: 0.40 CO: 1.02	$90	$20	$40	$10
Snowmobile exhaust	2010	HC: 0.10	$1,370	$0	—	—
Snowmobile exhaust	2012	CO: 0.25	—	—	$360	$0
Snowmobile permeation	2008	0.03	$210	($150)	—	—
ATV exhaust	2006	0.21	$400	$290	—	—
ATV permeation	2008	0.02	$180	($180)	—	—
Off-highway motorcycle exhaust	2006	0.38	$410	$280	—	—
Off-highway motorcycle permeation	2008	0.01	$230	($140)	—	—
Recreational marine diesel	2006	0.44	$670	$670	—	—
Aggregate	—	—	$240	($280)	$80	($20)

* HC reductions for evaporative and permeation, and HC+NOx reductions for exhaust (except snowmobiles where CO reductions are also presented).

Economic Impact Analysis

We performed an analysis to estimate the economic impacts of this final rule on producers and consumers of recreational marine diesel vessels (specifically, diesel inboard cruisers), forklifts, snowmobiles, ATVs, off-highway motorcycles, and society as a whole. This economic impact analysis focuses on market-level changes in price, quantity, and economic welfare (social gains or costs) associated with the regulation. A description of the methodology used can be found in Chapter 9 of this document.

We did not perform an economic impact analysis for categories of Large SI nonroad engines other than forklifts, even though those other Large SI engines are also subject to the standards contained in this final rule. This was due to the large number of different types of equipment that use Large SI engines and data availability constraints for those market segments. For the sake of completeness, the following analysis reports separate estimates for Large SI engines other than forklifts. Engineering costs are assumed to be equal to economic costs for those engines. This approach slightly overestimates the social costs associated with the relevant standards.

Based on the estimated regulatory costs associated with this rule and the predicted changes in prices and quantity produced in the affected industries, the total estimated annual social gains of the rule in the year 2030 is projected to be $553.3 million (in 2000 and 2001 dollars). The net present value of the social gains for the 2002 to 2030 time frame is equal to $4.9 billion. The social gains are equal to the fuel savings minus the combined loss in consumer and producer surplus (see Table 9), taking into account producers' and consumers' changes in behavior resulting from the costs associated with the rule.[1] Social gains do not account for the social benefits (the monetized health and environmental effects of the rule).

Table 9
Surplus Losses, Fuel Efficiency Gains, and Social Gains/Costs in 2030[a]

Vehicle Category	Surplus Losses in 2030 ($millions)	Fuel Efficiency Gains in 2030 ($millions)	Social Gains/Costs in 2030[b] ($millions)
Recreational marine diesel vessels	$6.6	$0	($6.6)
Forklifts	$47.8	$420.1	$372.3
Other Large SI[c]	$48.1	$138.4	$90.3
Snowmobiles	$41.9	$135.0	$93.1
ATVs	$47.2	$51.4	$4.2
Off-highway motorcycles	$25.0	$25.2	$0.2
All vehicles total	$216.6	$770.1	$553.3
NPV of all vehicles total[d]	$3,231.4	$8,130.3	$4,898.9

[a] Figures are in 2000 and 2001dollars.
[b] Figures in this column exclude estimated social benefits. Numbers in parentheses denote social costs.
[c] Figure is engineering costs; see Section 9.7.6 of Chapter 9 for explanation.
[d] Net Present Value is calculated over the 2002 to 2030 time frame using a 3 percent discount rate.

For most of the engine categories contained in this rule, we expect there will be a fuel savings as manufacturers redesign their engines to comply with emission standards. For ATVs and off-highway motorcycles, the fuel savings will be realized as manufacturers switch from

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[1] Consumer and producer surplus losses are measures of the economic welfare loss consumers and producers, respectively are likely to experience as a result of the regulations. Combined these losses represent an estimate of the economic or social costs of the rule. Note that for the Large SI and recreational vehicle rules, fuel efficiency gains must be netted from surplus losses to estimate the social costs or social gains (in cases where fuel efficiency gains exceed surplus losses) attributable to the rules.

two-stroke to four-stroke technologies. For snowmobiles, the fuel savings will be realized as manufacturers switch some of their engines to more fuel efficient two-stroke technologies and some of their engines to four-stroke technologies. For Large SI engines, the fuel savings will be realized as manufacturers adopt more sophisticated and more efficient fuel systems; this is true for all fuels used by Large SI engines. Overall, we project the fuel savings associated with the anticipated changes in technology to be about 800 million gallons per year once the program is fully phased in. These savings are factored into the calculated costs and costs per ton of reduced emissions, as described above.

Chapter 1: Health and Welfare Concerns

The engines and vehicles that would be subject to the standards in this final rule generate emissions of HC, NOx, CO, PM and air toxics. They contribute to ozone and CO nonattainment and to adverse health effects associated with ambient concentrations of PM and air toxics. They also contribute to visibility impairment in Class I areas and in other areas where people live, work, and recreate. This chapter presents our estimates of the contribution these engines make to our national air inventory. We include in this chapter estimates of pre- and post-control contributions. These estimates are described in greater detail in Chapter 6.

This chapter also describes the health and environmental effects related to these emissions. These pollutants cause a range of adverse health and welfare effects, especially in terms of respiratory impairment and related illnesses and visibility impairment both in Class I areas and in areas where people live, work and recreate. Air quality modeling and monitoring data presented in this chapter indicate that a large number of our citizens continue to be affected by these emissions.

1.1 Inventory Contributions

1.1.1 Inventory Contribution

The contribution of emissions from the nonroad engines and vehicles that would be subject to the standards to the national inventories of pollutants that are associated with the health and public welfare effects described in this chapter are considerable. To estimate nonroad engine and vehicle emission contributions, we used the latest version of our NONROAD emissions model. This model computes nationwide, state, and county emission levels for a wide variety of nonroad engines, and uses information on emission rates, operating data, and population to determine annual emission levels of various pollutants. A more detailed description of the model and our estimation methodology can be found in the Chapter 6 of this document.

Baseline emission inventory estimates for the year 2000 for the categories of engines and vehicles covered by this rulemaking are summarized in Table 1.1-1. This table show the relative contributions of the different mobile-source categories to the overall national mobile-source inventory. Of the total emissions from mobile sources, the categories of engines and vehicles covered by this rulemaking contribute about 9 percent, 3 percent, 4 percent, and 2 percent of HC, NOx, CO, and PM emissions, respectively, in the year 2000. The results for large SI engines indicate they contribute approximately 2 to 3 percent to HC, NOx, and CO emissions from mobile sources. The results for land-based recreational engines reflect the impact of the significantly different emissions characteristics of two-stroke engines. These engines are estimated to contribute about 6 percent of HC emissions and 2 percent of CO from mobile sources. Recreational CI marine contribute less than 1 percent to NOx mobile source inventories. When only nonroad emissions are considered, the engines and vehicles that would be subject to the standards would account for a larger share.

Our emission projections for 2020 and 2030 for the nonroad engines and vehicles subject to this rulemaking show that emissions from these categories are expected to increase over time if left uncontrolled. The projections for 2020 and 2030 are summarized in Tables 1.1-2 and 1.1-3, respectively. The projections for 2020 and 2030 indicate that the categories of engines and vehicles covered by this rulemaking are expected to contribute approximately 25 percent, 10 percent, 5 percent, and 5 percent of HC, NOx, CO, and PM emissions, respectively. Population growth and the effects of other regulatory control programs are factored into these projections. The relative importance of uncontrolled nonroad engines is higher than the projections for 2000 because there are already emission control programs in place for the other categories of mobile sources which are expected to reduce their emission levels. The effectiveness of all control programs is offset by the anticipated growth in engine populations.

Table 1.1-1
Modeled Annual Emission Levels for Mobile-Source Categories in 2000 (thousand short tons)

Category	NOx		HC		CO		PM	
	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source
Total for engines subject to today's standards*	**351**	**2.6%**	**645**	**8.8%**	**2,860**	**3.8%**	**14.6**	**2.1%**
Highway Motorcycles	8	0.1%	84	1.2%	331	0.4%	0.4	0.1%
Nonroad Industrial SI > 19 kW*	308	2.3%	226	3.1%	1,734	2.3%	1.6	0.2%
Recreational SI*	5	0.0%	418	5.7%	1,120	1.5%	12.0	1.7%
Recreational Marine CI*	38	0.3%	1	0.0%	6	0.0%	1	0.1%
Marine SI Evap	0	0.0%	100	1.4%	0	0.0%	0	0.0%
Marine SI Exhaust	32	0.2%	708	9.7%	2,144	2.8%	38	5.4%
Nonroad SI < 19 kW	106	0.8%	1,460	20.0%	18,359	24.3%	50	7.1%
Nonroad CI	2,625	19.5%	316	4.3%	1,217	1.6%	253	35.9%
Commercial Marine CI	963	7.2%	30	0.4%	127	0.2%	41	5.8%
Locomotive	1,192	8.9%	47	0.6%	119	0.2%	30	4.3%
Total Nonroad	5,269	39%	3,305	45%	24,826	33%	427	60%
Total Highway	7,981	59%	3,811	52%	49,813	66%	240	34%
Aircraft	178	1%	183	3%	1,017	1%	39	6%
Total Mobile Sources	13,428	100%	7,300	100%	75,656	100%	706	100%
Total Man-Made Sources	24,532	--	18,246	--	97,735	--	3,102	--
Mobile Source percent of Total Man-Made Sources	55%	--	40%	--	77%	--	23%	–

Table 1.1-2
Modeled Annual Emission Levels for Mobile-Source Categories in 2020 (thousand short tons)

Category	NOx		HC		CO		PM	
	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source
Total for engines subject to today's standards*	547	8.8%	1,305	24.1%	4,866	5.6%	34.1	5.2%
Highway Motorcycles	14	0.2%	142	2.6%	572	0.7%	0.8	0.1%
Nonroad Industrial SI > 19 kW*	472	7.6%	318	5.9%	2,336	2.7%	2.3	0.4%
Recreational SI*	14	0.2%	985	18.2%	2,521	2.9%	30.2	4.6%
Recreational Marine CI*	61	1.0%	2	0.0%	9	0.0%	1.6	0.2%
Marine SI Evap	0	0.0%	114	2.1%	0	0.0%	0	0.0%
Marine SI Exhaust	58	0.9%	284	5.2%	1,985	2.3%	28	4.3%
Nonroad SI < 19 kW	106	1.7%	986	18.2%	27,352	31.7%	77	11.8%
Nonroad CI	1,791	28.8%	142	2.6%	1,462	1.7%	261	40.0%
Commercial Marine CI	819	13.2%	35	0.6%	160	0.2%	46	7.0%
Locomotive	611	9.8%	35	0.6%	119	0.1%	21	3.2%
Total Nonroad	3,932	63%	2,901	54%	35,944	42%	467	71%
Total Highway	2,050	33%	2,276	42%	48,906	56%	145	22%
Aircraft	232	4%	238	4%	1,387	2%	43	7%
Total Mobile Sources	6,214	100%	5,415	100%	86,237	100%	655	100%
Total Man-Made Sources	16,190	--	15,475	--	109,905	--	3,039	--
Mobile Source percent of Total Man-Made Sources	38%	--	35%	--	79%	--	22%	–

Table 1.1-3
Modeled Annual Emission Levels for
Mobile-Source Categories in 2030 (thousand short tons)

Category	NOx		HC		CO		PM	
	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source	1000 tons	percent of mobile source
Total for engines subject to today's standards*	640	10.0%	1,411	23.5%	5,363	5.4%	36.5	4.8%
Highway Motorcycles	17	0.3%	172	2.9%	693	0.7%	1.0	0.1%
Nonroad Industrial SI > 19 kW*	553	8.6%	371	6.2%	2,703	2.7%	2.7	0.4%
Recreational SI*	15	0.2%	1,038	17.3%	2,649	2.7%	31.9	4.2%
Recreational Marine CI*	72	1.1%	2	0.0%	11	0.0%	1.9	0.3%
Marine SI Evap	0	0.0%	122	2.0%	0	0.0%	0	0.0%
Marine SI Exhaust	64	1.0%	269	4.5%	2,083	2.1%	29	3.8%
Nonroad SI < 19 kW	126	2.0%	1,200	20.0%	32,310	32.4%	93	12.3%
Nonroad CI	1,994	31.0%	158	2.6%	1,727	1.7%	306	40.4%
Commercial Marine CI	1,166	18.1%	52	0.9%	198	0.2%	74	9.8%
Locomotive	531	8.3%	30	0.5%	119	0.1%	18	2.4%
Total Nonroad	4,521	70%	3,242	54%	41,800	42%	557	74%
Total Highway	1,648	26%	2,496	42%	56,303	56%	158	21%
Aircraft	262	4%	262	4%	1,502	2%	43	6%
Total Mobile Sources	6,431	100%	6,000	100%	99,605	100%	758	100%
Total Man-Made Sources	16,639	—	17,020	—	123,983	—	3,319	—
Mobile Source percent of Total Man-Made Sources	39%	—	35%	—	80%	—	23%	–

1.1.2 Baseline Inventory Adjustment

Since we proposed this regulatory program, we revised our baseline inventories for the covered engines to reflect information we received during the comment period. These inventory adjustments are discussed in more detail in Chapter 6, and the changes are reflected in the tables above.

We also revised our national mobile source on-highway and nonroad inventories to reflect additional information and to incorporate routine updates since we finalized our On-Highway Heavy-Duty Engine/Diesel Fuel (HD07) rule. The inventory adjustments to our on-highway and nonroad inventories are of particular importance because the health and visibility results reported in the following sections of this chapter are based on the earlier national mobile source baselines that were used as inputs to the air quality model. We did not perform new health effects and visibility modeling for this rule; instead, we relied on the ozone and PM modeling performed for the HD07 rule. Because our estimates of baseline national mobile source inventories have increased since the HD07 rule, relying on the earlier inventories would underestimate future PM levels that we would expect if we conducted new modeling with the revised inventory inputs. Thus, the health effects and visibility information would underestimate the size of populations living in counties with air quality above certain levels compared to new modeling.

Table 1.1-4 contains a summary of the changes to the on-highway and nonroad inventories since the HD07 rule, and reports the percent change in the inventory for each pollutant. This table shows that the HD07 inventories used in the health and visibility modeling underestimate 2020 direct PM emissions by 0.3 percent for highway engines and 9.4 percent for nonroad engines. The HD07 inventories underestimate 2030 direct PM emissions by 0.1 percent for on-highway and 11.9 percent for nonroad engines. HC and NOx emissions could also affect predicted ambient PM concentrations via secondary formation in the atmosphere.

While the health effects and visibility analyses in the following section may thus underestimate the extent of health effects and visibility impairment we would predict if we were to model the information with our updated inventories, the HD07 analysis still supports our determination that these engines cause or contribute to such health and welfare concerns.

Table 1.1-4
Comparison of Inventory Projections to Projections Used for Air Quality Modeling in the 2007 Highway Heavy-Duty Engine/Diesel Fuel Rule (thousand short tons)

Category	Comparison	NOx	HC	CO	Direct PM
2020 Highway	HD07 Modeling Inventories	2,022	2,019	48,334	143
	Current Estimates	2,050	2,276	48,906	145
	Difference	28	257	572	2
	Difference as a percent of total mobile inventory	0.5%	4.7%	0.7%	0.3%
2020 Nonroad (including aircraft)	HD07 Modeling Inventories	4,040	1,995	33,938	449
	Current Estimates	4,164	3,139	37,331	510
	Difference	124	1,144	3,393	61
	Difference as a percent of total mobile inventory	2.0%	21.1%	3.9%	9.4%
2030 Highway	HD07 Modeling Inventories	2,181	1,624	55,610	157
	Current Estimates	2,496	1,648	56,303	158
	Difference	315	24	693	1
	Difference as a percent of total mobile inventory	4.9%	0.4%	0.7%	0.1%
2030 Nonroad (including aircraft)	HD07 Modeling Inventories	2,228	4,325	39,223	509
	Current Estimates	3,504	4,783	43,302	600
	Difference	1,276	458	4,079	91
	Difference as a percent of total mobile inventory	19.8%	7.6%	4.1%	11.9%

1.1.2 Inventory Impacts on a Per Vehicle Basis

In addition to the general inventory contributions described above, the engines that would be subject to the standards are more potent polluters than their highway counterparts in that they have much higher emissions on a per vehicle basis. This is illustrated in Table 1.1-5, which equates the emissions produced in one hour of operation from the different categories of equipment covered by the rulemaking to the equivalent miles of operation it would take for a car produced today to emit the same amount of emissions.

Table 1.1-5
Per-Vehicle Emissions Comparison

Equipment Category	Emission Comparison	Miles a Current Passenger Car Would Need to Drive to Emit the Same Amount of Pollution as the Equipment Category Emits in One Hour of Operation
Recreational Marine CI	HC+NOx	2,400
Large SI	HC+NOx	1,340
Snowmobiles	HC	24,300
Snowmobiles	CO	1,520
2-Stroke ATVs	HC	6,470
4-Stroke ATVs	HC	290
2-Stroke off-road motorcycles	HC	9,580
4-Stroke off-road motorcycles	HC	430

The per engine emissions are important because they mean that operators of these engines and vehicles, as well as those who work in their vicinity, are exposed to high levels of emissions, many of which are air toxics. These effects are of particular concern for people who operate forklifts in enclosed areas and for snowmobile riders following a lead rider. These effects are described in more detail in the next sections.

1.2 Ozone

1.2.1 General Background

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and NOx in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. Volatile organic compounds are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. Volatile organic compounds also are emitted by natural sources such as vegetation. Oxides of nitrogen are emitted largely from motor vehicles, off-highway equipment, power plants, and other sources of combustion. Hydrocarbons (HC) are a large subset of VOC, and to reduce mobile source VOC levels we set maximum emissions limits for hydrocarbon as well as particulate matter emissions.

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.[1] As a result, differences in weather patterns, as well as NOx and VOC levels, 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, resulting in higher ambient ozone levels 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 local VOC or NOx emissions.

On the chemical level, NOx and VOC are the principal precursors to ozone formation. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities on clear summer days. Relatively small amounts of NOx enable ozone to form rapidly when VOC levels are relatively 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 relatively low can be NOx limited.

When NOx levels are relatively high and VOC levels relatively low, NOx forms inorganic nitrates but relatively 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 under certain circumstances. Even in VOC limited urban areas, NOx reductions are not expected to increase ozone levels if the NOx reductions are sufficiently large.

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.

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.

1.2.2 Health and Welfare Effects of Ozone and Its Precursors

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.[2, 3] 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 (6 to 8 hours), repeated exposure to ozone can cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

Children and outdoor workers are most at risk from ozone exposure because they typically are active outside 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 are 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 prolonged 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 too uncertain to allow for direct quantification, the full body of evidence indicates the possibility of a 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 foliage damage in many crops, trees, and ornamental plants (i.e., grass, flowers, shrubs) 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.

Volatile organic compounds 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. The toxicologically significant VOCs emitted in substantial quantities from the engines that are the subject of this rule are discussed in more detail in Section 1.6, below.

1.2.3 Ozone Nonattainment and Contribution to Ozone Nonattainment

The current primary and secondary ozone National Ambient Air Quality Standard (NAAQS) is 0.12 ppm daily maximum 1-hour concentration, not to be exceeded more than once per year on average. The determination that an area is at risk of exceeding the ozone standard in the future was made for all areas with current design values grater than or equal to 0.125 ppm (or within a 10 percent margin) and with modeling evidence that exceedances will persist into the future.

Ground level ozone today remains a pervasive pollution problem in the United States. In 1999, 90.8 million people (1990 census) lived in 31 areas designated nonattainment under the 1-hour ozone NAAQS.[4] This sharp decline from the 101 nonattainment areas originally identified under the Clean Air Act Amendments of 1990 demonstrates the effectiveness of the last decade's worth of emission-control programs. However, elevated ozone concentrations remain a serious public health concern throughout the nation.

Over the last decade, declines in ozone levels were found mostly in urban areas, where emissions are heavily influenced by controls on mobile sources and their fuels. Twenty-three metropolitan areas have realized a decline in ozone levels since 1989, but at the same time ozone levels in 11 metropolitan areas with 7 million people have increased.[5] Regionally, California and the Northeast have recorded significant reductions in peak ozone levels, while four other regions (the Mid-Atlantic, the Southeast, the Central and Pacific Northwest) have seen ozone levels increase.

The highest ambient concentrations are currently found in suburban areas, consistent with downwind transport of emissions from urban centers. Concentrations in rural areas have risen to the levels previously found only in cities. Particularly relevant to this rulemaking, ozone levels at 17 of our National Parks have increased, and in 1998, ozone levels in two parks, Shenandoah National Park and the Great Smoky Mountains National Park, were 30 to 40 percent higher than the ozone NAAQS over the last decade.[6]

To estimate future ozone levels, we refer to the modeling performed in conjunction with the final HD07 rule.[7] We performed a series of ozone air quality modeling simulations for nearly the entire Eastern U.S. covering metropolitan areas from Texas to the Northeast.[8] This ozone air quality model was based upon the same modeling system as was used in the Tier 2 passenger vehicle air quality analysis,[9] with the addition of enhanced inventory estimates for 2007 and 2030 based on the state of knowledge at the time the modeling was performed. Emissions from nonroad engines, including the engines subject to this final rule, were included as input to the air quality modeling we describe in this section (as shown in Tables 1.1-2 to 1.1-4 above).

The model simulations were performed for several emission scenarios, and the model outputs were combined with current air quality data to identify areas expected to exceed the ozone NAAQS in 2007, 2020, and 2030.[10] The results of this modeling are contained in Table 1.2-1. Areas presented in Table 1.2-1 exhibit 1997-99 air quality data indicating violations of the

1-hour ozone NAAQS, or are within 10 percent of the standard, are predicted to have exceedance in 2007, 2020, or 2030. An area was considered likely to have future exceedances if exceedances were predicted by the model, and the area is currently violating the 1-hour standard, or is within 10 percent of violating the 1-hour standard. Table 1.2-1 shows that 37 areas with a 1999 population of 91 million people are at risk of exceeding the 1-hour ozone standard in 2007. These estimates include contributions from the engines subject to this rule.[2]

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[2] Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents.

Table 1.2-1
Eastern Metropolitan Areas with Modeled Exceedances of the 1-Hour Ozone Standard in 2007, 2020, or 2030 (Includes all national emission controls through HD07 standards)

MSA or CMSA / State	2007	2020	2030	pop (1999)
Atlanta, GA MSA	x	x	x	3.9
Barnstable-Yarmouth, MA MSA*	x			0.2
Baton Rouge, LA MSA	x	x	x	0.6
Beaumont-Port Arthur, TX MSA	x	x	x	0.4
Benton Harbor, MI MSA*	x	x	x	0.2
Biloxi-Gulfport-Pascagoula, MS MSA*	x	x	x	0.3
Birmingham, AL MSA	x	x	x	0.9
Boston-Worcester-Lawrence, MA CMSA	x	x	x	5.7
Charleston, WV MSA*	x	x		0.3
Charlotte-Gastonia-Rock Hill, NC MSA	x	x	x	1.4
Chicago-Gary-Kenosha, IL CMSA	x	x	x	8.9
Cincinnati-Hamilton, OH-KY-IN CMSA*	x	x	x	1.9
Cleveland-Akron, OH CMSA*	x	x	x	2.9
Detroit-Ann Arbor-Flint, MI CMSA	x	x	x	5.4
Grand Rapids-Muskegon-Holland, MI MSA*	x	x	x	1.1
Hartford, CT MSA	x	x	x	1.1
Houma, LA MSA*	x	x	x	0.2
Houston-Galveston-Brazoria, TX CMSA	x	x	x	4.5
Huntington-Ashland, WV-KY-OH MSA	x	x	x	0.3
Lake Charles, LA MSA*	x		x	0.2
Louisville, KY-IN MSA	x	x	x	1
Macon, GA MSA	x			0.3
Memphis, TN-AR-MS MSA	x	x	x	1.1
Milwaukee-Racine, WI CMSA	x	x	x	1.7
Nashville, TN MSA	x	x	x	1.2
New London-Norwich, CT-RI MSA	x	x	x	0.3
New Orleans, LA MSA*	x	x	x	1.3
New York-Northern NJ-Long Island, NY-NJ-CT-PA CMSA	x	x	x	20.2
Norfolk-Virginia Beach-Newport News, VA-NC MSA*	x		x	1.6
Orlando, FL MSA*	x	x	x	1.5
Pensacola, FL MSA	x			0.4
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	x	x	x	6
Providence-Fall River-Warwick,RI-MAMSA*	x	x	x	1.1
Richmond-Petersburg, VA MSA	x	x	x	1
St. Louis, MO-IL MSA	x	x	x	2.6
Tampa-St. Petersburg, FL MSA*	x	x		2.3
Washington-Baltimore	x	x	x	7.4
Total number of areas	37	32	32	
Population	91.2	88.5	87.8	91.4

* These areas have registered 1997-1999 ozone concentrations within 10 percent of standard.

With regard to future ozone levels, our air quality ozone modeling for 2020 predicts exceedances of the 1-hour ozone standard in 32 areas with a total of 89 million people (1999 census; see Table 1.2-1). We expect that the control strategies contained in this rulemaking will further assist state efforts already underway to attain and maintain the 1-hour ozone standard.

The inventories that underlie this predictive modeling for 2020 and 2030 include reductions from all current and committed to federal control programs, including the recently promulgated NOx and PM standards for heavy-duty vehicles and low sulfur diesel fuel (HD07 rule). The geographic scope of these areas at risk of future exceedances underscores the need for additional, nationwide controls of ozone precursors.

It should be noted that this modeling did not attempt to examine the prospect of areas attaining or maintaining the ozone standard with possible future controls (i.e., controls beyond current or committed controls). Therefore, this information should be interpreted as indicating what areas are at risk of ozone violations in 2007, 2020 or 2030 without federal, State, or local measures that may be adopted and implemented in the future. We expect many of these areas to adopt additional emission reduction programs, but we are unable to quantify or rely upon future reductions from additional State or local programs since they have not yet been adopted.

1.2.4 Public Health and Welfare Concerns from Prolonged and Repeated Exposures to Ozone

In addition to the health effects described above, there exists a large body of scientific literature that shows that harmful effects can occur from sustained levels of ozone exposure much lower than 0.125 ppm. Studies of prolonged exposures, those lasting about 7 hours, showed health effects from exposures to ozone concentrations as low as 0.08 ppm. Prolonged and repeated exposures to ozone at these levels are common in areas that do not attain the 1-hour NAAQS, and also occur in areas where ambient concentrations of ozone are in compliance with the 1-hour NAAQS.

Prolonged exposure to levels of ozone below the NAAQS have been reported to cause or be statistically associated with transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital and emergency room visits, and transient pulmonary respiratory inflamation. Such acute health effects have been observed following prolonged exposures at moderate levels of exertion at concentrations of ozone as low as 0.08 ppm, the lowest concentration tested. The effects are more pronounced as concentrations increase, affecting more subjects or having a greater effect on a given subject in terms of functional changes or symptoms. A detailed summary and discussion of the large body of ozone health effects research may be found in Chapters 6 through 9 (Volume 3) of the 1996 Criteria Document for ozone.[11] Monitoring data indicates that 333 counties in 33 states exceed these levels in 1997-99.[12]

To provide a quantitative estimate of the projected number of people anticipated to reside in areas in which ozone concentrations are predicted to exceed the 8-hour level of 0.08 to 0.12 ppm or higher for multiple days, we performed regional modeling using the variable-grid Urban Airshed Model (UAM-V) for the HD07 rule.[13] UAM-V is a photochemical grid model that numerically simulates the effects of emissions, advection, diffusion, chemistry, and surface removal processes on pollutant concentrations within a 3-dimensional grid. As with the previous modeling analysis, the inventories that underlie this predictive modeling include reductions from all current and committed to control programs, including the HD07 NOx and PM reductions.

This HD07 ozone modeling forecast that 111 million people are predicted to live in areas that areas at risk of exceeding these moderate ozone levels for prolonged periods of time in 2020 after accounting for expected inventory reductions due to controls on light- and heavy-duty on-highway vehicles; that number is expected to increase to 125 million in 2030.[14] Prolonged and repeated ozone concentrations at these levels are common in areas throughout the country. These concentrations are found both in areas that are exceeding, and areas that are not exceeding, the 1-hour ozone standard. Areas with these high concentrations are more widespread than those in nonattainment for that 1-hour ozone standard.

Ozone at these levels can have other welfare effects, with damage to plants and ecosystems being of most concern. Plant damage affects crop yields, forestry production, and ornamentals. The adverse effect of ozone on forests and other natural vegetation can in turn cause damage to associated ecosystems, with additional resulting economic losses. Prolonged ozone concentrations of 0.10 ppm can be phytotoxic to a large number of plant species, and can produce acute injury and reduced crop yield and biomass production. Ozone concentrations within the range of 0.05 to 0.10 ppm have the potential over a longer duration of creating chronic stress on vegetation that can result in reduced plant growth and yield, shifts in competitive advantages in mixed populations, decreased vigor, and injury. Ozone effects on vegetation are presented in more detail in Chapter 5, Volume II of the 1996 Criteria Document.

1.2.5 Additional Health and Welfare Effects of NOx Emissions

In addition to their role as an ozone precursor, NOx emissions are associated with a wide variety of other health and welfare effects.[15, 16] Nitrogen dioxide can irritate the lungs and reduce resistance to respiratory infection (such as influenza). 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. Elevated levels of nitrates in drinking water pose significant health risks, especially to infants. NOx emissions are an important precursor to acid rain that may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems (“eutrophication”). Deposition of nitrogen-containing compounds also affects terrestrial ecosystems.

1.2.3.1 Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when SO_2 and NOx react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles.[17] It contributes to damage of trees at high elevations and in extreme cases may cause lakes and streams to become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. To reduce damage to automotive paint caused by acid rain and acidic dry deposition, some manufacturers use acid-resistant paints, at an average cost of $5 per vehicle--a total of $61 million per year if applied to all new cars and trucks sold in the U.S.

Acid deposition primarily affects bodies of water that rest atop soil with a limited ability to neutralize acidic compounds. The National Surface Water Survey (NSWS) investigated the effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams. It found that acid deposition was the primary cause of acidity in 75 percent of the acidic lakes and about 50 percent of the acidic streams, and that the areas most sensitive to acid rain were the Adirondacks, the mid-Appalachian highlands, the upper Midwest and the high elevation West. The NSWS found that approximately 580 streams in the Mid-Atlantic Coastal Plain are acidic primarily due to acidic deposition. Hundreds of the lakes in the Adirondacks surveyed in the NSWS have acidity levels incompatible with the survival of sensitive fish species. Many of the over 1,350 acidic streams in the Mid-Atlantic Highlands (mid-Appalachia) region have already experienced trout losses due to increased stream acidity. Emissions from U.S. sources contribute to acidic deposition in eastern Canada, where the Canadian government has estimated that 14,000 lakes are acidic. Acid deposition also has been implicated in contributing to degradation of high-elevation spruce forests that populate the ridges of the Appalachian Mountains from Maine to Georgia. This area includes national parks such as the Shenandoah and Great Smoky Mountain National Parks.

1.2.3.2 Eutrophication and Nitrification

Nitrogen deposition into bodies of water can cause problems beyond those associated with acid rain. The Ecological Society of America has included discussion of the contribution of air emissions to increasing nitrogen levels in surface waters in a recent major review of causes and consequences of human alteration of the global nitrogen cycle in its Issues in Ecology series.[18] Long-term monitoring in the United States, Europe, and other developed regions of the world shows a substantial rise of nitrogen levels in surface waters, which are highly correlated with human-generated inputs of nitrogen to their watersheds. These nitrogen inputs are dominated by fertilizers and atmospheric deposition.

Human activity can increase the flow of nutrients into those waters and result in excess algae and plant growth. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration, and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can also adversely affect fish and shellfish populations. This problem is of particular concern in coastal areas with poor or stratified circulation patterns, such as the Chesapeake Bay, Long Island Sound, or the Gulf of Mexico. In such areas, the "overproduced" algae tends to sink to the bottom and decay, using all or most of the available oxygen and thereby reducing or eliminating populations of bottom-feeder fish and shellfish, distorting the normal population balance between different aquatic organisms, and in extreme cases causing dramatic fish kills.

Collectively, these effects are referred to as eutrophication, which the National Research Council recently identified as the most serious pollution problem facing the estuarine waters of the United States.[19] Nitrogen is the primary cause of eutrophication in most coastal waters and estuaries.[20] On the New England coast, for example, the number of red and brown tides and shellfish problems from nuisance and toxic plankton blooms have increased over the past two decades, a development thought to be linked to increased nitrogen loadings in coastal waters. We believe that airborne NOx contributes from 12 to 44 percent of the total nitrogen loadings to United States coastal water bodies. For example, some estimates assert that approximately one-quarter of the nitrogen in the Chesapeake Bay comes from atmospheric deposition.

Excessive fertilization with nitrogen-containing compounds can also affect terrestrial ecosystems.[21] Research suggests that nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem, providing beneficial nutrients to plant growth in areas that do not suffer from nitrogen over-saturation. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of the plants and microorganisms to utilize and retain the nitrogen. This phenomenon has already occurred in some areas of the U.S.

1.3 Carbon Monoxide

1.3.1 General Background

Unlike many gases, CO is odorless, colorless, tasteless, and nonirritating. Carbon monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. These conditions are common during vehicle starting when air supply is restricted ("choked"), when vehicles are not tuned properly, and at high altitude, where "thin" air effectively reduces the amount of oxygen available for combustion (except in engines that are designed or adjusted to compensate for altitude). Carbon monoxide emissions increase dramatically in cold weather. This is because engines need more fuel to start at cold temperatures and because some emission control devices (such as oxygen sensors and catalytic converters) operate less efficiently when they are cold. Also, nighttime inversion conditions are more frequent in the colder months of the year. This is due to the enhanced stability in the atmospheric boundary layer, which inhibits vertical mixing of emissions from the surface.

1.3.2 Health Effects of CO

Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood's capacity to carry oxygen to organs and tissues.[22] Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Although there are effective compensatory increases in blood flow to the brain, at some concentrations of COHb somewhere above 20 percent these compensations fail to maintain sufficient oxygen delivery, and metabolism declines[23]. The subsequent hypoxia in brain tissue then produces behavioral effects, including decrements in continuous performance and reaction time.[24]

Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects. Persons with heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising. In Ontario, 18 deaths of snowmobilers involved myocardial infarction and 14 involved sudden cardiac death[25]. It is unknown if these deaths are linked to CO exposures.

Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks. More importantly to many individuals is the frequent exposure of individuals to exhaust emissions from engines operating indoors. The Occupational Safety and Health Administration sets standards regulating the concentration of indoor pollutants, but high local CO levels are still commonplace.

Several recent epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases). Several studies in the United States and Canada have also reported an association of ambient CO exposures with frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association of ambient CO exposure with mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the Criteria Document review process.[26] There is emerging evidence suggesting that CO is linked with asthma exacerbations.

1.3.3 CO Nonattainment

The current primary NAAQS for CO are 35 parts per million for the one-hour average and 9 parts per million for the eight-hour average. These values are not to be exceeded more than once per year. Air quality carbon monoxide value is estimated using EPA guidance for calculating design values. Over 22.4 million people currently live in the 13 non-attainment areas for the CO NAAQS.[27] As described in Section 1.1, the engines subject to this rule currently account for about 3.8 percent of the mobile source CO inventory; this is expected to increase to 8.8 percent by 2020 without the emission controls in this action.

Emissions from the engines and vehicles covered by this rule contribute to the national CO inventory and to CO levels in several nonattainment areas. Large SI engines are used in forklifts and many types of construction, industrial, and lawn care equipment that are used in urban areas, including nonattainment areas.

ATVs and off-highway motorcycles are also used in counties and cities within CO-nonattainment areas, and are operated on private land and in and around non-attainment areas. This is illustrated by information about ATV use provided by Honda in public comments, which included recent warranty claims for ATVs in three serious CO non-attainment areas: Fairbanks, AK, in 1998 and 2001, in Phoenix, AZ in 2001, and in Las Vegas, NV in 2000.[28] In our December 7, 2000 notice finding that recreational vehicles cause or contribute to CO nonattainment, we provided information showing CO emissions in six nonattainment areas in 2000. Five of these areas remain in nonattainment.

In addition, Western state studies of off-highway vehicle use in Colorado and Utah both indicate that ATVs and off-highway motorcycles are operated on private land about 20 to 30 percent of the time (22.4 percent for off-highway motorcycles and 27.8 percent for ATVs in Utah, and combined vehicles 22.4 percent of off-highway vehicles are operated on the survey respondent's own private land or ranch).[29] In addition, operation of these vehicles is not limited to established trails. Half of the off-highway motorcyclists and 40 percent of the ATV owners in Utah reported riding off established trails or roads.[30] Furthermore, according to the U.S. Consumer Product Safety Commission, almost three quarters of ATV drivers use ATVs for at least one non-recreational activity; half use ATVs for farming or ranching; 63 percent use ATVs for household chores (e.g., yard work); and about 8 percent use ATVs for occupational or commercial tasks.[31] Another CO nonattainment area, Anchorage, AK, estimates ATVs and motorcycles (on- and off-road) contribute 0.19 tons per day in 2000.[32]

Several states that contain CO nonattainment areas also have large populations of registered off-highway motorcycles, as shown in Table 1.3-1 (similar information was not available for ATVs).

Table 1.3-1
Off-Highway Motorcycle Use in Selected CO Nonattainment Areas

City and State	CO Nonattainment Classification	2001 State off-highway motorcycle population[a]
Anchorage, AK	Serious	5,100[b]
Fairbanks, AK	Serious	
Las Vegas, NV	Serious	15,800
Los Angeles, CA	Serious	175,100
Phoenix, AZ	Serious	20,400
Spokane, WA	Serious	44,800
New York/New Jersey/Long Island, NY, NJ, CT	Moderate > 12.7 ppm	81,300
Provo, UT	Moderate > 12.7 ppm	16,600
El Paso, TX	Moderate	61,600
Fort Collins, CO	Moderate	30,200
Medford, OR	Moderate	28,800
Missoula, MT	Moderate	96,00
Reno, NV	Moderate	15,800[b]

[a] Source: Motorcycle Industry Council, 2001 Motorcycle Statistical Annual, Docket A-2000-01, Document No. II-G.
[b] State has more than one CO nonattainment area.

Snowmobiles, which have relatively high per engine CO emissions, can also be an important source of ambient CO levels in CO nonattainment areas. While some of these areas have experienced improved CO air quality in recent years, an area cannot be redesignated to attainment until it can show EPA that it has had air quality levels within the level required for attainment and that it has a plan in place to maintain such levels. Until areas have been redesignated, they remain non-attainment areas.[33] Snowmobiles contribute to CO nonattainment in more than one of these areas.

The state of Alaska estimated (and a National Research Council study confirmed) that snowmobiles contributed 0.3 tons/day in 2001 to Fairbanks' CO nonattainment area or 1.2 percent of a total inventory of 23.3 tons per day in 2001.[3, 4] There is some indication that

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[3] Draft Anchorage Carbon Monoxide Emission Inventory and Year 2000 Attainment Projections, Air Quality Program, May 2001, Docket Number A-2000-01, Document II-A-40; Draft Fairbanks 1995-2001 Carbon Monoxide Emissions Inventory, June 1, 2001, Docket

Fairbanks' snowmobile population is significantly higher than EPA's estimates.[34] While Fairbanks has made significant progress in reducing ambient CO concentrations, existing climate conditions make achieving and maintaining attainment challenging. Anchorage, AK, reports a similar contribution of snowmobiles to their emissions inventories (0.34 tons per day in 2000). Furthermore, a recent National Academy of Sciences report concludes that "Fairbanks will be susceptible to violating the CO health standards for many years because of its severe meteorological conditions. That point is underscored by a December 2001 exceedance of the standard in Anchorage which had no violations over the last 3 years."[5] There is also a snowmobile trail within the Spokane, WA, CO nonattainment area.

Several states that contain CO nonattainment areas also have large populations of registered snowmobiles. This is shown in Table 1.3-2. A review of snowmobile trail maps and public comments indicate that snowmobiles are used in counties containing these CO nonattainment areas or in adjoining counties.[35] These include the Mt. Spokane and Riverside trails near the Spokane, Washington, CO nonattainment area; the Larimer trails near the Fort Collins, Colorado CO nonattainment area; and the Hyatt Lake, Lake of the Woods, and Cold Springs trails near the Klamath Falls and Medford, Oregon CO nonattainment area. There are also trails in Missoula County, Montana that demonstrate snowmobile use in the Missoula, Montana CO nonattainment area. While Colorado has a large snowmobile population, the snowmobile trails are fairly distant from the Colorado Springs CO nonattainment area.[36]

Number A-2000-01, Document II-A-39.

[4] National Research Council. The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, AK. May 2002. Docket A-2000-01, Document No. IV-A-115.

[5] National Research Council. The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, AK. May 2002. Docket A-2000-01, Document IV-A-115.

Table 1.3-2
Snowmobile Use in Selected CO Nonattainment Areas

City and State	CO Nonattainment Classification	2001 State snowmobile population*
Anchorage, AK	Serious	35,576
Fairbanks, AK	Serious	
Spokane, WA	Serious	31,532
Fort Collins, CO	Moderate	32,500
Medford, OR	Moderate	16,809
Missoula, MT	Moderate	23,440

* Source: Letter from International Snowmobile Manufacturers Association to US-EPA, March 14, 2002, Docket A-2000-01, Document No. II-G

While snowmobile trails are often located in rural areas and many are located outside CO nonattainment areas, it is nevertheless the case that snowmobiles are used in urban areas within nonattainment areas. In some northeast cities, "snowmobiles are a common sight in downtown areas [and] are driven in large numbers along streets and recreational paths ... in close proximity to pedestrians, motorists, and those using public parks such as cross-country skiers."[37] A search of the available literature indicates that snowmobiles are ridden in areas other than trails. For example, a report by the Michigan Department of Natural Resources indicates that from 1993 to 1997, of the 146 snowmobile fatalities studied, 46 percent occurred on a state or county roadway (another 2 percent on roadway shoulders) and 27 percent occurred on private lands.[38] Furthermore, accident reports in the CO nonattainment area Fairbanks, AK, document that snowmobiles driven on streets have collided with motor vehicles.[39] On certain days there may be concentrations of snowmobiles operated in non-attainment areas due to public events such as snowmachine races (such as the Iron Dog Gold Rush Classic, which finishes in Fairbanks, AK), during which snowmobiles will be present and operated. There is some indication that Fairbanks snowmobile population is significantly higher than EPA's estimates.[40]

While the operation of snowmobiles alone in an area would not necessarily result in CO nonattainment, emissions from regulated categories need only contribute to, not themselves cause, nonattainment. Concentrations of NAAQS-related pollutants are by definition a result of multiple sources of pollution. The above discussion shows that snowmobiles are operated on snowmobile trails and some are within CO nonattainment areas (e.g., Spokane). Snowmobiles are also used for maintenance operations and other uses in CO nonattainment areas (e.g., Fairbanks and Anchorage), and there is evidence that snowmobiles are operated in town along streets in these and other CO nonattainment areas.

While CO air quality is improving in several northern areas, further reductions may still be required. Exceedances of the 8-hour CO standard were recorded in three of the six CO nonattainment areas located in the northern portion of the country over the five year period from 1994 to 1999: Fairbanks, AK; Medford, OR; and Spokane, WA.[41] Given the variability in CO ambient concentrations due to weather patterns such as inversions, the absence of recent exceedances for some of these nonattainment areas should not be viewed as eliminating the need for further reductions to consistently attain and maintain the standard. A review of CO monitor data in Fairbanks from 1986 to 1995 shows that while median concentrations have declined steadily, unusual combinations of weather and emissions have resulted in elevated ambient CO concentrations well above the 8-hour standard of 9 ppm. Specifically, a Fairbanks monitor recorded average 8-hour ambient concentrations at 16 ppm in 1988, around 9 ppm from 1990 to 1992, and then a steady increase in CO ambient concentrations at 12, 14 and 16 ppm during some extreme cases in 1993, 1994 and 1995, respectively.[42] Furthermore, a recent National Academy of Sciences report concludes that "Fairbanks will be susceptible to violating the CO health standards for many years because of its severe meteorological conditions. That point is underscored by a December 2001 exceedance of the standard in Anchorage which had no violations over the last 3 years."[43] Fairbanks is located in a mountain valley with a much higher potential for air stagnation than cities within the contiguous United States. Nocturnal inversions that give rise to elevated CO concentrations can persist 24-hours a day due to the low solar elevation, particularly in December and January. These inversions typically last from 2 to 4 days, and thus inversions may continue during hours of maximum CO emissions from mobile sources. While Fairbanks has made significant progress in reducing ambient CO concentrations, existing climate conditions make achieving and maintaining attainment challenging.

In addition to the CO nonattainment areas, there are 6 areas that have not been classified as non-attainment where air quality monitoring indicated a need for CO control. For example, CO monitors in northern locations such as Des Moines, IA, and Weirton, WV/Steubenville, OH, registered levels above the level of the CO standards in 1998.[44]

1.4 Particulate Matter

1.4.1 General Background

Particulate pollution is a problem affecting urban and non-urban localities in all regions of the United States. Nonroad engines and vehicles that would be subject to the standards contribute to ambient particulate matter (PM) levels in two ways. First, they contribute through direct emissions of particulate matter. Second, they contribute to indirect formation of PM through their emissions of organic carbon, especially HC. As shown in Table 1.4-1, organic carbon accounts for between 27 and 36 percent of ambient fine particle mass depending on the area of the country.

Table 1.4-1
Percent Contribution to $PM_{2.5}$ by Component, 1998

	East	West
Sulfate	56	33
Elemental Carbon	5	6
Organic Carbon	27	36
Nitrate	5	8
Crustal Material	7	17

Source: National Air Quality and Emissions Trends Report, 1998, March, 2000, at 28. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

PM represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. All particles equal to and less than 10 microns are called PM_{10}. Fine particles can be generally defined as those particles with an aerodynamic diameter of 2.5 microns or less (also known as $PM_{2.5}$), and coarse fraction particles are those particles with an aerodynamic diameter greater than 2.5 microns, but equal to or less than a nominal 10 microns.

Manmade emissions that contribute to airborne particulate matter result principally from combustion sources (stationary and mobile sources) and fugitive emissions from industrial processes and non-industrial processes (such as roadway dust from paved and unpaved roads, wind erosion from crop land, construction, etc.). Human-generated sources of particles include a variety of stationary sources (including power generating plants, industrial operations, manufacturing plants, waste disposal) and mobile sources (light- and heavy-duty on-road vehicles, and off-highway vehicles such as construction, farming, industrial, locomotives, marine vessels and other sources). Natural sources also contribute to particulate matter in the atmosphere and include sources such as wind erosion of geological material, sea spray, volcanic emissions, biogenic emanation (e.g., pollen from plants, fungal spores), and wild fires.

The chemical and physical properties of PM vary greatly with time, region, meteorology, and source category. Particles may be emitted directly to the atmosphere (primary particles) or may be formed by transformations of gaseous emissions of sulfur dioxide, nitrogen oxides or volatile organic compounds (secondary particles). Secondary PM is dominated by sulfate in the eastern U.S. and nitrate in the western U.S.[45] The vast majority (>90 percent) of the direct mobile source PM emissions and their secondary formation products are in the fine PM size range. Mobile sources can reasonably be estimated to contribute to ambient secondary nitrate and sulfate PM in proportion to their contribution to total NOx and SOx emissions.

1.4.2 Health and Welfare Effects of PM

Particulate matter can adversely affect human health and welfare. Discussions of the health and welfare effects associated with ambient PM can be found in the Air Quality Criteria for Particulate Matter.[46]

Key EPA findings regarding the health risks posed by ambient PM are summarized as follows:

a. Health risks posed by inhaled particles are affected both by the penetration and deposition of particles in the various regions of the respiratory tract, and by the biological responses to these deposited materials.

b. The risks of adverse effects associated with deposition of ambient particles in the thorax (tracheobronchial and alveolar regions of the respiratory tract) are markedly greater than for deposition in the extrathoracic (head) region. Maximum particle penetration to the thoracic regions occurs during oronasal or mouth breathing.

c. Published, peer-reviewed studies have reported statistical associations between PM and several key health effects, including premature death; aggravation of respiratory and cardiovascular disease, as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days; changes in lung function and increased respiratory symptoms; changes to lung tissues and structure; and altered respiratory defense mechanisms. Most of these effects have been consistently associated with ambient PM concentrations, which have been used as a measure of population exposure, in a large number of community epidemiological studies. Additional information and insights on these effects are provided by studies of animal toxicology and controlled human exposures to various constituents of PM conducted at higher than ambient concentrations. Although mechanisms by which particles cause effects are not well known, there is general agreement that the cardio-respiratory system is the major target of PM effects.

d. Based on a qualitative assessment of the epidemiological evidence of effects associated with PM for populations that appear to be at greatest risk with respect to particular health endpoints, we have concluded the following with respect to sensitive populations:

    1. Individuals with respiratory disease (e.g., chronic obstructive pulmonary disease, acute bronchitis) and cardiovascular disease (e.g., ischemic heart disease) are at greater risk of premature mortality and hospitalization due to exposure to ambient PM.

    2. Individuals with infectious respiratory disease (e.g., pneumonia) are at greater risk of premature mortality and morbidity (e.g., hospitalization, aggravation of respiratory symptoms) due to exposure to ambient PM. Also, exposure to PM may increase individuals' susceptibility to respiratory infections.

3. Elderly individuals are also at greater risk of premature mortality and hospitalization for cardiopulmonary problems due to exposure to ambient PM.

4. Children are at greater risk of increased respiratory symptoms and decreased lung function due to exposure to ambient PM.

5. Asthmatic individuals are at risk of exacerbation of symptoms associated with asthma, and increased need for medical attention, due to exposure to PM.

e. There are fundamental physical and chemical differences between fine and coarse fraction particles. The fine fraction contains acid aerosols, sulfates, nitrates, transition metals, diesel exhaust particles, and ultra fine particles; the coarse fraction typically contains high mineral concentrations, silica and resuspended dust. It is reasonable to expect that differences may exist in both the nature of potential effects elicited by coarse and fine PM and the relative concentrations required to produce such effects. Both fine and coarse particles can accumulate in the respiratory system. Exposure to coarse fraction particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles are closely associated with health effects such as premature death or hospital admissions, and for cardiopulmonary diseases.

With respect to welfare or secondary effects, fine particles have been clearly associated with the impairment of visibility over urban areas and large multi-State regions. Particles also contribute to soiling and materials damage. Components of particulate matter (e.g., sulfuric or nitric acid) also contribute to acid deposition, nitrification of surface soils and water eutrophication of surface water.

1.4.3 PM Nonattainment

1.4.3.1 PM_{10} Concentrations and Nonattainment

The NAAQS for PM_{10} was established in 1987. According to these standards, the short term (24-hour) standard of 150 $\mu g/m^3$ is not to be exceeded more than once per year on average over three years. The long-term standard specifies an expected annual arithmetic mean not to exceed 50 $\mu g/m^3$ over three years.

PM_{10} monitoring data indicate that 14 designated PM_{10} nonattainment areas with a projected population of 23 million violated the PM_{10} NAAQS in the period 1997-1999. Table 1.4-2 lists the 14 areas, and also indicates the PM_{10} nonattainment classification, and 1999 projected population for each PM_{10} nonattainment area. The projected population in 1999 was based on 1990 population figures which were then increased by the amount of population growth in the county from 1990 to 1999.

Table 1.4-2
PM_{10} Nonattainment Areas Violating the PM_{10} NAAQS in 1997-1999

Nonattainment Area or County	1999 Population (projected, in thousands)
Anthony, NM (Moderate)[b]	3
Clark Co [Las Vegas], NV (Serious)	1,200
Coachella Valley, CA (Serious)	239
El Paso Co, TX (Moderate)[a]	611
Hayden/Miami, AZ (Moderate)	4
Imperial Valley, CA (Moderate)	122
Los Angeles South Coast Air Basin, CA (Serious)	14,352
Nogales, AZ (Moderate)	25
Owens Valley, CA (Serious)	18
Phoenix, AZ (Serious)	2,977
San Joaquin Valley, CA (Serious)	3,214
Searles Valley, CA (Moderate)	29
Wallula, WA (Moderate)[b]	52
Washoe Co [Reno], NV (Moderate)	320
Total Areas: 14	23,167

[a] EPA has determined that continuing PM_{10} nonattainment in El Paso, TX is attributable to transport under section 179(B).

[b] The violation in this area has been determined to be attributable to natural events under section 188(f) of the Act.

In addition to the 14 PM_{10} nonattainment areas that are currently violating the PM_{10} NAAQS listed in Table 1.4-2, there are 25 unclassifiable areas that have recently recorded ambient concentrations of PM_{10} above the PM_{10} NAAQS. EPA adopted a policy in 1996 that allows areas with PM_{10} exceedances that are attributable to natural events to retain their designation as unclassifiable if the State is taking all reasonable measures to safeguard public health regardless of the sources of PM_{10} emissions. Areas that remain unclassifiable areas are not required under the Clean Air Act to submit attainment plans, but we work with each of these areas to understand the nature of the PM_{10} problem and to determine what best can be done to reduce it. With respect to the monitored violations reported in 1997-99 in the 25 areas designated as unclassifiable, we have not yet excluded the possibility that factors such as a one-time monitoring upset or natural events, which ordinarily would not result in an area being designated as nonattainment for PM_{10}, may be responsible for the problem. Emission reductions from today’s action will assist these currently unclassifiable areas to achieve ambient PM_{10} concentrations below the current PM_{10} NAAQS.

1.4.3.2 $PM_{2.5}$ Concentrations

Fine particle concentrations contribute to both health effects and visibility impairment. This section presents our assessment of current and future PM2.5 levels. Because monitoring data are not available for all areas, we have modeled PM2.5 levels for those areas using the EPA’s Regulatory Model System for Aerosols and Deposition (REMSAD) model. These concentrations are related to both health effects and visibility impairment. After a brief description of the PM air quality model, we present current PM2.5 data, both modeled and estimated. Then we present projections of PM2.5 levels that were estimated using REMSAD.

1.4.3.2.1 Description of PM Air Quality Modeling

To estimate both current PM2.5 levels in areas for which no monitoring data are available and future $PM_{2.5}$ levels for all areas, we refer to the PM air quality modeling performed in conjunction with EPA's on-highway Heavy Duty Engine/Diesel Fuel (HD07) final rule. This modeling was performed using EPA's Regulatory Model System for Aerosols and Deposition (REMSAD) model.[47] We describe the REMSAD modeling because we use the modeling examine visibility impairment and population exposures related to the PM health effects we would anticipate would occur without the emissions reductions from this rulemaking. The REMSAD modeling was also a key input for the economic benefits transfer technique described in Chapter 10 related to selected PM health effects.

REMSAD simulates every hour of every day of the year and, thus, requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, 3-hour average emissions estimates and meteorological fields, initial and boundary conditions, and land-use information. As applied to the contiguous U.S., the model segments the area within the region into square blocks called grids (roughly equal in size to counties), each of which has several layers of air conditions. Using this data, REMSAD generates predictions of 3-hour average PM concentrations for every grid. We then calculated daily and seasonal PM air quality metrics.

REMSAD was peer-reviewed in 1999 for EPA as reported in "*Scientific Peer-Review of the Regulatory Modeling System for Aerosols and Deposition.*" Earlier versions of REMSAD have been employed for the EPA's Prospective CAA Section 812 Report to Congress and for EPA's Analysis of the Acid Deposition and Ozone Control Act (Senate Bill 172). Version 4.1 of REMSAD was employed for the HD07 final rule analysis and is fully described in the air quality technical support documents for that HD07 rulemaking. We focus on the HD07 modeling because it is the most current modeling for mobile sources.

For the HD07 rulemaking, EPA modeled PM air quality in 1996 and in 2030 after those requirements were to take effect using REMSAD. Although we did not undertake new air quality modeling for this rulemaking, the modeling from the HD07 rulemaking can be considered a baseline for this rulemaking. As explained in Section 1.1.2, the emissions inventories that were used in the HD07 REMSAD modeling have been updated and that the HD07 modeling may underestimate the PM2.5 levels that we would expect with revised emissions inventories.

1.4.3.2.2 Current PM Air Quality

The 1999-2000 $PM_{2.5}$ monitored values, which cover about a third of the nation's counties, indicate that at least 82 million people live in areas where long-term ambient fine particulate matter levels are at or above 15 µg/m^3.[48]

To estimate the current number of people who live in areas where long-term ambient fine particulate matter levels are at or above 16 µg/m^3 but for which there are no monitors, we can use the HD07 REMSAD modeling described above. At the time the HD07 modeling was performed, 1999 PM monitoring data were not yet available, so we conducted 1996 base year modeling to reproduce the atmospheric processes resulting in formation and dispersion of $PM_{2.5}$ across the U.S. and to evaluate operational model performance for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon) which are important to visibility impairment. This 1996 modeling included emissions from the engines subject to this final rule (although earlier emissions estimates were used). According to our national modeled predictions, there were a total of 76 million people (1996 population) living in areas with modeled annual average $PM_{2.5}$ concentrations at or above 16 µg/m^3 (29 percent of the population).[49]

1.4.3.2.3 Future PM Air Quality

To estimate future year concentrations, we can use the air quality model to predict changes between current and future states. The most reliable information would be to compare future levels in counties for which we have monitoring data. Thus, we estimated future conditions for the areas with current $PM_{2.5}$ monitored data (which covered about a third of the nation's counties at that time).[50] For these counties, REMSAD predicts the current level of 37 percent of the population living in areas where fine PM levels above 15 µg/m3 to increase to 49 percent in 2030.[51] Again, this 2030 modeling included emissions from the engines subject to this final rule (although earlier emissions estimates were used). These emissions are contributing to air quality levels that may result in future PM nonattainment. Nonattainment status is related to both health impacts described above and welfare impacts, such as visibility impairment, soiling, and material damage. Thus, for areas with levels above the NAAQS, unacceptable health and welfare effects are anticipated to be occurring, and emissions from the engines subject to this rulemaking are contributing to these anticipated adverse effects. In Table 1.4-3, we summarize the national PM air quality based on the HD07 REMSAD modeling.

Table 1.4-3
Summary of Anticipated 2030 National PM Baseline Air Quality (μg/m^3)

Statistic	2030 Air Quality Value (μg/m^3)[a]
PM_{10}	
Minimum Annual Mean[b]	1.49
Maximum Annual Mean[b]	64.29
Average Annual Mean	10.03
Median Annual Mean	7.97
Population-Weighted Average Annual Mean[c]	21.04
$PM_{2.5}$	
Minimum Annual Mean[b]	1.16
Maximum Annual Mean[b]	38.2
Average Annual Mean	7.6
Median Annual Mean	5.79
Population-Weighted Average Annual Mean[c]	14.2

[a] Based on public comment received on the proposed Large SI/Recreational Vehicle rule and other updated information, we revised our emissions estimates in some categories downwards and other categories upwards; however, on net, we believe this modeling would underestimate the baseline PM emissions without regulation.
[b] The minimum (maximum) is the value for the populated grid-cell with the lowest (highest) annual average.
[c] Calculated by summing the product of the projected 2030 grid-cell population and the estimated 2030 PM concentration, for that grid-cell and then dividing by the total population in the 48 contiguous States.

Nonroad engines and vehicles that are subject these standards contribute to ambient fine PM levels in two ways. First, they contribute through direct emissions of fine PM. As shown in Table 1.1-1, these engines emitted 14,600 tons of PM (about 2.1 percent of all mobile source PM) in 2000. As shown in Table 1.1-3, they are modeled to emit 36,500 tons of PM (about 4.8 percent of all mobile source PM) in 2030. Second, these engines contribute to indirect formation of PM through their emissions of gaseous precursors which are then transformed in the atmosphere into particles. For example, these engines emitted about 1,411,000 tons of HC or 23.5 percent of the HC emitted from mobile sources in 2030. Furthermore, recreational vehicles, such as snowmobiles and ATVs emit high levels of organic carbon (as HC) on a per engine basis. Some organic emissions are transformed into particles in the atmosphere and other volatile organics can condense if emitted in cold temperatures, as is the case for emissions from snowmobiles, for example. Organic carbon accounts for between 27 and 36 percent of ambient fine particle mass depending on the area of the country. The relationship between HC and PM have implications for the most efficient controls of ambient PM as discussed in Chapter 4.

Further, as discussed below, the nonroad engines we are regulating contribute to PM levels in areas with PM levels above 15 µg/m3.

1.5 Visibility Degradation

1.5.1 General Background

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[52] Visibility impairment has been considered the "best understood and most easily measured effect of air pollution."[53] Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. It is an easily noticeable effect of fine PM present in the atmosphere, and fine PM is the major cause of reduced visibility in parts of the United States, including many of our national parks and in places where people live, work, and recreate. Fine particles with significant light-extinction efficiencies include organic matter, sulfates, nitrates, elemental carbon (soot), and soil.

Visibility is an important effect because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, both in where they live and work, and in places where they enjoy recreational opportunities. Visibility is highly valued in significant natural areas such as national parks and wilderness areas, because of the special emphasis given to protecting these lands now and for future generations.

To quantify changes in visibility, the analysis presented in this chapter computes a light-extinction coefficient, based on the work of Sisler, which shows the total fraction of light that is decreased per unit distance.[54] This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Visibility can be described in terms of visual range, light extinction or deciview.[6]

In addition to limiting the distance that one can see, the scattering and absorption of light caused by air pollution can also degrade the color, clarity, and contrast of scenes. Visibility impairment also has a temporal dimension in that impairment might relate to a short-term

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[6] Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. It is typically described in miles or kilometers. Light extinction is the sum of light scattering and absorption by particles and gases in the atmosphere. It is typically expressed in terms of inverse megameters (Mm^{-1}), with larger values representing worse visibility. The deciview metric describes perceived visual changes in a linear fashion over its entire range, analogous to the decibel scale for sound. A deciview of 0 represents pristine conditions. Under many scenic conditions, a change of 1 deciview is considered perceptible by the average person.

excursion or to longer periods (e.g., worst 20 percent of days or annual average levels). More detailed discussions of visibility effects are contained in the EPA Criteria Document for PM.

Visibility effects are manifest in two principal ways: (1) as local impairment (e.g., localized hazes and plumes) and (2) as regional haze. The emissions from engines covered by this rule contribute to both types of visibility impairment.

Local-scale visibility degradation is commonly in the form of either a plume resulting from the emissions of a specific source or small group of sources, or it is in the form of a localized haze such as an urban "brown cloud." Plumes are comprised of smoke, dust, or colored gas that obscure the sky or horizon relatively near sources. Impairment caused by a specific source or small group of sources has been generally termed as "reasonably attributable."

The second type of impairment, regional haze, results from pollutant emissions from a multitude of sources located across a broad geographic region. It impairs visibility in every direction over a large area, in some cases over multi-state regions. Regional haze masks objects on the horizon and reduces the contrast of nearby objects. The formation, extent, and intensity of regional haze is a function of meteorological and chemical processes, which sometimes cause fine particulate loadings to remain suspended in the atmosphere for several days and to be transported hundreds of kilometers from their sources.[55]

On an annual average basis, the concentrations of non-anthropogenic fine PM are generally small when compared with concentrations of fine particles from anthropogenic sources.[56] Anthropogenic contributions account for about one-third of the average extinction coefficient in the rural West and more than 80 percent in the rural East.[57] Because of significant differences related to visibility conditions in the eastern and western U.S., we present information about visibility by region. Furthermore, it is important to note that even in those areas with relatively low concentrations of anthropogenic fine particles, such as the Colorado plateau, small increases in anthropogenic fine particle concentrations can lead to significant decreases in visual range. This is one of the reasons Class I areas have been given special consideration under the Clean Air Act.

1.5.2 Visibility Impairment Where People Live, Work and Recreate

Visibility impairment occurs in many areas throughout the country, where people live, work, and recreate. In this section, in order to estimate the magnitude of the problem, we use monitored PM2.5 data and modeled air quality using emissions inventories from the engines subject to this rule. The engines covered by this rule contribute to PM2.5 levels in areas across the country with unacceptable visibility conditions.

1.5.2.1 Areas Affected by Visibility Impairment

The secondary PM NAAQS is designed to protect against adverse welfare effects such as visibility impairment. In 1997, the secondary PM NAAQS was set as equal to the primary (health-based) PM NAAQS (62 Federal Register No. 138, July 18, 1997). EPA concluded that PM can and does produce adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. In 1997, EPA demonstrated that visibility impairment is an important effect on public welfare and that visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote Federal Class I areas.

In many cities having annual mean PM2.5 concentrations exceeding 17 ug/m3, improvements in annual average visibility resulting from the attainment of the annual PM2.5 standard are expected to be perceptible to the general population (e.g., to exceed 1 deciveiew). Based on annual mean monitored PM2.5 data, many cities in the Northeast, Midwest, and Southeast as well as Los Angeles would be expected to experience perceptible improvements in visibility if the PM2.5 annual standard were attained. For example, in Washington, DC, where the IMPROVE monitoring network shows annual mean PM2.5 concentrations at about 19 ug/m3 during the period of 1992 to1995, approximate annual average visibility would be expected to improve from 21 km (29 deciview) to 27 km (27 deciview). The PM2.5 annual average in Washington, DC, was 18.9 ug/m3 in 2000.

The updated monitored data and air quality modeling presented below confirm that the visibility situation identified during the NAAQS review in 1997 is still likely to exist. Specifically, there will still likely be a broad number of areas that are above the annual PM2.5 NAAQS in the Northeast, Midwest, Southeast and California , such that the determination in the NAAQS rulemaking about broad visibility impairment and related benefits from NAAQS compliance are still relevant. Thus, levels above the fine PM NAAQS cause adverse welfare impacts, such as visibility impairment (both regional and localized impairment).

In addition, in setting the PM NAAQS, EPA acknowledged that levels of fine particles below the NAAQS may also contribute to unacceptable visibility impairment and regional haze problems in some areas, and Clean Air Act Section 169 provides additional authorities to remedy existing impairment and prevent future impairment in the 156 national parks, forests and wilderness areas labeled as Class I areas.

In making determinations about the level of protection afforded by the secondary PM NAAQS, EPA considered how the Section 169 regional haze program and the secondary NAAQS would function together. Regional strategies are expected to improve visibility in many urban and non-Class I areas as well. The following recommendation for the National Research Council, Protecting Visibility in National Parks and Wilderness Areas (1993), addresses this point: “Efforts to improve visibility in Class I areas also would benefit visibility outside these areas. Because most visibility impairment is regional in scale, the same haze that degrades visibility within or looking out from a national park also degrade visibility outside it. Class I areas cannot be regarded as potential islands of clean air in a polluted sea.”

Visibility impairment (localized and regional haze) in Class I areas is discussed in the next section.

1.5.2.1.1 Areas Affected by Visibility Impairment: Monitored Data

The 1999-2000 $PM_{2.5}$ monitored values, which cover only a portion of the nation's counties, indicate that at least 82 million people live in areas where long-term ambient fine particulate matter levels are at or above 15 μg/m^3.[58] Thus, these populations (plus others who travel to these areas) would be experiencing visibility impairment that is unacceptable, and based on our modeling, emissions of PM and its precursors from engines in these categories contribute to this unacceptable impairment.

Another way to consider this information is to compare the values directly to the PM NAAQS in the format required by regulation. EPA regulations require 3 consecutive years of PM2.5 data in order to make comparisons with the National Ambient Air Quality Standards; see Part 50, Appendix N. In Table 1.5-1, we list areas with 1999 and 2000 monitored annual average PM2.5 levels above 15 ug/m3 in 2000, as represented by design values that can be compared to the PM2.5 NAAQS. There were a total of 129 counties representing 65 million people with levels above the design value for the annual PM2.5 NAAQS based on 1999 and 2000 monitored data. The table also notes areas which have made a note of "exceptional events" in their reporting of the monitored data.

Table 1.5-1.
Areas with Monitored Annual Average PM2.5 Concentrations Above 15 ug/m3.

EPA regulations require 3 consecutive years of PM2.5 data in order to make comparisons with the National Ambient Air Quality Standards; see Part 50, Appendix N. The data represented in this table reflect air quality monitoring from 1999 to 2001, although not all data have been verified by the monitoring agency.

State	County	Population 2000	Annual PM2.5 Standard Design Value	Design Value Data Flagged for Exceptional Events? 1
ALABAMA	CLAY	14,254	15.5	
ALABAMA	COLBERT	54,984	15.3	
ALABAMA	DE KALB	64,452	16.8	
ALABAMA	HOUSTON	88,787	16.3	
ALABAMA	JEFFERSON*	662,047	20.8*	
* Two sites in Jefferson County are encompassed in a Community Monitoring Zone (i.e. utilize spatial averaging); the spatially averaged design value for the CMZ is 20.8, which is the maximum for the county.				
ALABAMA	MADISON	276,700	15.5	
ALABAMA	MOBILE	399,843	15.3	
ALABAMA	MONTGOMERY	223,510	16.8	
ALABAMA	MORGAN	111,064	19.1	
ALABAMA	RUSSELL	49,756	18.4	
ALABAMA	SHELBY	143,293	17.2	
ALABAMA	TALLADEGA	80,321	17.8	
CALIFORNIA	BUTTE	203,171	15.4	yes
CALIFORNIA	FRESNO	799,407	24.0	yes
CALIFORNIA	IMPERIAL	142,361	15.7	
CALIFORNIA	KERN	661,645	23.7	yes
CALIFORNIA	KINGS	129,461	16.6	
CALIFORNIA	LOS ANGELES	9,519,338	25.9	
CALIFORNIA	MERCED	210,554	18.9	yes
CALIFORNIA	ORANGE	2,846,289	22.4	
CALIFORNIA 2	RIVERSIDE	1,545,387	29.8	
CALIFORNIA 2	SAN BERNARDINO	1,709,434	25.8	
CALIFORNIA	SAN DIEGO	2,813,833	17.1	
CALIFORNIA	SAN JOAQUIN	563,598	16.4	yes
CALIFORNIA	STANISLAUS	446,997	19.7	yes

State	**County**	**Population 2000**	**Annual Std Design Value**	**DataFlagged for Exc. Events?1**
CALIFORNIA	TULARE	368,021	24.7	
CONNECTICUT	NEW HAVEN	824,008	16.8	
DELAWARE	NEW CASTLE	500,265	16.6	
DISTRICT OF COLUMBIA	WASHINGTON	572,059	16.6	yes
GEORGIA	BIBB	153,887	17.6	
GEORGIA	CHATHAM	232,048	16.5	
GEORGIA	CLARKE	101,489	18.6	
GEORGIA	CLAYTON	236,517	19.2	
GEORGIA	COBB	607,751	18.6	
GEORGIA	DE KALB	665,865	19.6	
GEORGIA	DOUGHERTY	96,065	16.6	
GEORGIA	FLOYD	90,565	18.5	yes
GEORGIA	FULTON	816,006	21.2	
GEORGIA	HALL	139,277	17.2	
GEORGIA	MUSCOGEE	186,291	18.0	
GEORGIA	PAULDING	81,678	16.8	
GEORGIA	RICHMOND	199,775	17.4	
GEORGIA	WASHINGTON	21,176	16.5	
GEORGIA	WILKINSON	10,220	18.1	
ILLINOIS	COOK	5,376,741	18.8	
ILLINOIS	DU PAGE	904,161	15.4	
ILLINOIS	MADISON	258,941	17.3	
ILLINOIS	ST CLAIR	256,082	17.4	
ILLINOIS	WILL	502,266	15.9	
INDIANA	CLARK	96,472	17.3	
INDIANA	FLOYD	70,823	15.6	
INDIANA	LAKE	484,564	16.3	
INDIANA	MARION	860,454	17.0	
KENTUCKY	BOYD	49,752	15.5	yes
KENTUCKY	BULLITT	61,236	16.0	yes
KENTUCKY	CAMPBELL	88,616	15.5	yes
KENTUCKY	FAYETTE	260,512	16.8	yes
KENTUCKY	JEFFERSON	693,604	17.1	
KENTUCKY	KENTON	151,464	15.9	yes

State	County	Population 2000	Annual Std Design Value	DataFlagged for Exc. Events?1
KENTUCKY	MC CRACKEN	65,514	15.1	yes
KENTUCKY	PIKE	68,736	16.1	yes
KENTUCKY	WARREN	92,522	15.4	yes
MARYLAND	BALTIMORE (CITY)	651,154	17.8	
MICHIGAN	WAYNE	2,061,162	18.9	
MISSISSIPPI	HINDS	250,800	15.1	
MISSISSIPPI	JONES	64,958	16.6	
MISSOURI	ST LOUIS (CITY)	348,189	16.3	
MONTANA	LINCOLN	18,837	16.4	
NEW JERSEY	HUDSON	608,975	17.5	
NEW JERSEY	UNION	522,541	16.3	
NEW YORK	NEW YORK	1,537,195	17.8	yes
NORTH CAROLINA	ALAMANCE	130,800	15.3	
NORTH CAROLINA	CABARRUS	131,063	15.7	yes
NORTH CAROLINA	CATAWBA	141,685	17.1	yes
NORTH CAROLINA	CUMBERLAND	302,963	15.4	yes
NORTH CAROLINA	DAVIDSON	147,246	17.3	yes
NORTH CAROLINA	DURHAM	223,314	15.3	
NORTH CAROLINA	FORSYTH	306,067	16.2	yes
NORTH CAROLINA	GASTON	190,365	15.3	yes
NORTH CAROLINA	GUILFORD	421,048	16.3	yes
NORTH CAROLINA	HAYWOOD	54,033	15.4	yes
NORTH CAROLINA	MC DOWELL	42,151	16.2	yes
NORTH CAROLINA	MECKLENBURG	695,454	16.8	yes
NORTH CAROLINA	MITCHELL	15,687	15.5	yes
NORTH CAROLINA	WAKE	627,846	15.3	yes
OHIO	BUTLER	332,807	17.4	
OHIO	CUYAHOGA	1,393,978	20.3	

State	County	Population 2000	Annual Std Design Value	DataFlagged for Exc. Events?1
OHIO	FRANKLIN	1,068,978	18.1	
OHIO	HAMILTON	845,303	19.3	
OHIO	JEFFERSON	73,894	18.9	
OHIO	LORAIN	284,664	15.1	
OHIO	MAHONING	257,555	16.4	
OHIO	MONTGOMERY	559,062	17.6	
OHIO	PORTAGE	152,061	15.3	
OHIO	SCIOTO	79,195	20.0	
OHIO	STARK	378,098	18.3	
OHIO	SUMMIT	542,899	17.3	
OHIO	TRUMBULL	225,116	16.2	
PENNSYLVANIA	ALLEGHENY	1,281,666	21.0	
PENNSYLVANIA	BERKS	373,638	15.6	
PENNSYLVANIA	CAMBRIA	152,598	15.3	
PENNSYLVANIA	DAUPHIN	251,798	15.5	
PENNSYLVANIA	LANCASTER	470,658	16.9	
PENNSYLVANIA	PHILADELPHIA	1,517,550	16.6	
PENNSYLVANIA	WASHINGTON	202,897	15.5	
PENNSYLVANIA	WESTMORELAND	369,993	15.6	
PENNSYLVANIA	YORK	381,751	16.3	
SOUTH CAROLINA	GREENVILLE	379,616	17.0	yes
SOUTH CAROLINA	LEXINGTON	216,014	15.6	yes
SOUTH CAROLINA	RICHLAND	320,677	15.4	yes
SOUTH CAROLINA	SPARTANBURG	253,791	15.4	yes
TENNESSEE	DAVIDSON	569,891	17.0	
TENNESSEE	HAMILTON	307,896	18.9	
TENNESSEE	KNOX	382,032	20.4	yes
TENNESSEE	ROANE	51,910	17.0	yes
TENNESSEE	SHELBY	897,472	15.6	
TENNESSEE	SULLIVAN	153,048	17.0	yes
				DataFlagged

State	County	Population 2000	Annual Std Design Value	for Exc. Events?1
TENNESSEE	SUMNER	130,449	15.7	
VIRGINIA	BRISTOL	17,367	16.0	yes
VIRGINIA	ROANOKE (CITY)	94,911	15.2	yes
WEST VIRGINIA	BERKELEY	75,905	16.0	
WEST VIRGINIA	BROOKE	25,447	17.4	
WEST VIRGINIA	CABELL	96,784	17.8	yes
WEST VIRGINIA	HANCOCK	32,667	17.4	
WEST VIRGINIA	KANAWHA	200,073	18.4	yes
WEST VIRGINIA	MARSHALL	35,519	16.5	
WEST VIRGINIA	OHIO	47,427	15.7	
WEST VIRGINIA	WOOD	87,986	17.6	yes
TOTAL	**129 Counties**	**65,185,812**		

1. Design Values include all valid data. Some valid data were impacted by exceptional events. These special situations are being reviewed by EPA.

2. Sacramento County CA does not exceed the PM2.5 annual standard but does exceed the daily standard.

Source: EPA Trends Reports

1.5.2.1.2 Areas Affected by Visibility Impairment: Modeled Future PM Levels and Visibility Index Estimates

Because the chemical composition of the PM affects visibility impairment, we used REMSAD air quality model to project visibility conditions in 2030 accounting for the chemical composition of the particles and to estimate visibility impairment directly as changes in deciview. Our projections included anticipated emissions from the engines subject to this rule, and although our emission predictions reflected our best estimates of emissions projections at the time the modeling was conducted, we now have new estimates, as discussed above in Table 1.1-4. Based on public comment for this rule and new information, we have revised our emissions estimates in some categories downwards and other categories upwards; however, on net, we believe the HD07 modeling underestimates the PM air quality levels that would be predicted if new inventories were used.

The most reliable information about the future visibility levels would be in areas for which monitoring data are available to evaluate model performance for a base year (e.g., 1996). Accordingly, we predicted that in 2030, 49 percent of the population will be living in areas where fine PM levels are above 15 µg/m3 and monitors are available.[59] This can be compared with the 1996 level of 37 percent of the population living in areas where fine PM levels are above 15 µg/m3 and monitors are available.

Based upon the light-extinction coefficient, we also calculated a unitless visibility index, called a “deciview,” which is used in the valuation of visibility. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

As shown in Table 1.5-2, in 2030 we estimate visibility in the East to be about 19 deciviews (or visual range of 60 kilometers) on average, with poorer visibility in urban areas, compared to the visibility conditions without man-made pollution of 9.5 deciviews (or visual range of 150 kilometers). Likewise, in we estimate visibility in the West to be about 9.5 deciviews (or visual range of 150 kilometers) in 2030, compared to the visibility conditions without man-made pollution of 5.3 deciviews (or visual range of 230 kilometers). Thus, in the future, a substantial percent of the population may experience unacceptable visibility impairment in areas where they live, work and recreate.

Table 1.5-2
Summary of 2030 National Visibility Conditions Based on REMSAD Modeling (Deciviews)

Regions[b]	Predicted 2030 Visibility[a] (annual average)	Natural Background Visibility
Eastern U.S.	18.98	9.5
Urban	20.48	
Rural	18.38	
Western U.S.	9.54	5.3
Urban	10.21	
Rural	9.39	

[a] The results incorporate earlier emissions estimates from the engines subject to this rule. We have revised our estimates both upwards for some categories and downwards for others based on public comment and updated information; however, on net, we believe that the results would underestimate future PM emissions.

[b] Eastern and Western Regions are separated by 100 degrees north longitude. Background visibility conditions differ by region.

The emissions from nonroad engines generally, and in particular the engines subject to this rule, contribute to this visibility impairment shown in Table 1.5-2. Nonroad engines emissions contribute a large portion of the total PM emissions from mobile sources and anthropogenic sources, in general. These emissions occur in and around areas with PM levels above the annual PM2.5 NAAQS. The engines subject to the final rule will contribute to these effects. They are estimated to emit 36,500 tons of direct PM in 2030, which is 1.1 percent of the total anthropogenic PM emissions in 2030. Similarly, for PM precursors, the engines subject to this rule will emit 640,000 tons of NOx and 1,411,000 tons HC in 2030, which are 3.8 and 8.3 percent of the total anthropogenic NOx and HC emissions, respectively, in 2030. Recreational vehicles in particular contribute to these levels. In Table I.E-1 through I.E-3, we show that recreational vehicles emitted about 1.7 percent of mobile source PM emissions in 2000. Similarly, recreational vehicles are modeled to emit over 4 percent of mobile source PM in 2020 and 2030. Thus, the emissions from these sources contribute to the visibility impairment modeled for 2030 summarized in the table.

Snowmobiles are operated in and around areas with PM2.5 levels above the level of the secondary NAAQS. For 20 counties across nine states, snowmobile trails are found within or near counties that registered ambient $PM_{2.5}$ concentrations at or above 15 µg/m^3, the level of the $PM_{2.5}$ NAAQS.[7] These counties are listed in Table 1.5-3. To obtain the information about

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[7] Memo to file from Terence Fitz-Simons, OAQPS, Scott Mathias, OAQPS, Mike Rizzo, Region 5, “Analyses of 1999 PM Data for the PM NAAQS Review,” November 17, 2000, with attachment B, 1999 PM2.5 Annual Mean and 98th Percentile 24-Hour Average Concentrations.

snowmobile trails contained in the table, we consulted snowmobile trail maps that were supplied by various states.[60] Fine particles may remain suspended for days or weeks and travel hundreds to thousands of kilometers, and thus fine particles emitted or created in one county may contribute to ambient concentrations in a neighboring county.[8]

Docket No. A-2000-01, Document No. II-B-17.

[8] Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment for Scientific and Technical Information, OAQPS Staff Paper, EPA-452\R-96-013, July, 1996, at IV-7. This document is available from Docket A-99-06, Document II-A-23.

Table 1.5-3
Counties with Annual $PM_{2.5}$ Levels Above 16 μg/m3 and Snowmobile Trails

State	$PM_{2.5}$ Exceedances County	County with Snowmobile Trails	Proximity to $PM_{2.5}$ Exceedances County
Ohio	Machining	Machining	Same County
	Trumbull	Trumbull	Same County
	Summit	Summit	Same County
	Montgomery	Montgomery	Same County
	Portage	Portage	Same County
	Franklin	Delaware	Borders North
	Marshall/Ohio (WV)	Belmont	Borders West
Montana	Lincoln	Lincoln	Same County
California	Tulane	Tulane	Same County
	Butte	Butte	Same County
	Fresno	Fresno	Same County
	Kern	Kern	Same County
Minnesota	Washington	Washington	Same County
	Wright	Wright	Same County
Wisconsin	Waukesha	Waukesha	Same County
	Milwaukee	Milwaukee	Same County
Oregon	Jackson	Douglas	Borders NNE
	Klammath	Douglas	Borders North
Pennsylvania	Washington	Layette	Borders East
		Somerset	—
Illinois	Rock Island	Rock Island	Same County
		Henry	Borders East
Iowa	Rock Island (IL)	Dubuque	Borders West

Achieving the annual $PM_{2.5}$ NAAQS will help improve visibility across the country, but it will not be sufficient (64 FR 35722 July 1, 1999 and 62 FR July 18, 1997 PM NAAQS). In setting the NAAQS, EPA discussed how the NAAQS in combination with the regional haze program, is deemed to improve visibility consistent with the goals of the CAA. In the East, there are wide areas above 15 ug/m^3 and light extinction is significantly above natural background. Thus, large areas of the Eastern United States have air pollution that is causing unacceptable visibility problems. In the West, scenic vistas are especially important to public welfare. Although the annual $PM_{2.5}$ NAAQS is met in most areas outside of California, virtually the entire West is in close proximity to a scenic Class I area protected by 169A and 169B of the CAA.

1.5.3 Visibility Impairment in Class I Areas

The Clean Air Act establishes special goals for improving visibility in many national parks, wilderness areas, and international parks. In the 1977 amendments to the Clean Air Act, Congress set as a national goal for visibility the "prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution" (CAA section 169A(a)(1)). The Amendments called for EPA to issue regulations requiring States to develop implementation plans that assure "reasonable progress" toward meeting the national goal (CAA Section 169A(a)(4)). EPA issued regulations in 1980 to address visibility problems that are "reasonably attributable" to a single source or small group of sources, but deferred action on regulations related to regional haze, a type of visibility impairment that is caused by the emission of air pollutants by numerous emission sources located across a broad geographic region. At that time, EPA acknowledged that the regulations were only the first phase for addressing visibility impairment. Regulations dealing with regional haze were deferred until improved techniques were developed for monitoring, for air quality modeling, and for understanding the specific pollutants contributing to regional haze.

In the 1990 Clean Air Act amendments, Congress provided additional emphasis on regional haze issues (see CAA section 169B). In 1999 EPA finalized a rule that calls for States to establish goals and emission reduction strategies for improving visibility in all 156 mandatory Class I national parks and wilderness areas. In this rule, EPA established a "natural visibility" goal.[61] In that rule, EPA also encouraged the States to work together in developing and implementing their air quality plans. The regional haze program is focused on long-term emissions decreases from the entire regional emissions inventory comprised of major and minor stationary sources, area sources and mobile sources. The regional haze program is designed to improve visibility and air quality in our most treasured natural areas from these broad sources. At the same time, control strategies designed to improve visibility in the national parks and wilderness areas will improve visibility over broad geographic areas. In the PM NAAQS rulemaking, EPA also anticipated the need in addition to the NAAQS and Section 169 regional haze program to continue to address localized impairment that may relate to unique circumstances in some Western areas. For mobile sources, there may also be a need for a Federal role in reduction of those emissions, in particular, because mobile sources are regulated primarily at the federal level.

As described above, regional haze is caused by the emission from numerous sources located over a wide geographic area.[62] Visibility impairment is caused by pollutants (mostly fine particles and precursor gases) directly emitted to the atmosphere by several activities (such as electric power generation, various industry and manufacturing processes, truck and auto emissions, construction activities, etc.). These gases and particles scatter and absorb light, removing it from the sight path and creating a hazy condition. Visibility impairment is caused by both regional haze and localized impairment.

Because of evidence that fine particles are frequently transported hundreds of miles, all 50 states, including those that do not have Class I areas, participate in planning, analysis and, in many cases, emission control programs under the regional haze regulations. Even though a given State may not have any Class I areas, pollution that occurs in that State may contribute to impairment in Class I areas elsewhere. The rule encourages states to work together to determine whether or how much emissions from sources in a given state affect visibility in a downwind Class I area.

The regional haze program calls for states to establish goals for improving visibility in national parks and wilderness areas to improve visibility on the haziest 20 percent of days and to ensure that no degradation occurs on the clearest 20 percent of days. The rule requires states to develop long-term strategies including enforceable measures designed to meet reasonable progress goals toward natural visibility conditions. Under the regional haze program, States can take credit for improvements in air quality achieved as a result of other Clean Air Act programs, including national mobile-source programs.[9]

As noted above, EPA issued regulations in 1980 to address Class I area localized visibility impairment that is “reasonably attributable” to a single source or small group of sources. In 40 CFR Part 51.301 of the visibility regulations, visibility impairment is defined as “any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.” States are required to develop implementation plans that include long-term strategies for improving visibility in each Class I area. The long-term strategies under the 1980 regulations should consist of measures to reduce impacts from local sources and groups of sources that contribute to poor air quality days in the

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[9] Though a recent case, American Corn Growers Association v. EPA, 291F.3d 1(D.C .Cir 2002) vacated the BART provisions of the Regional Haze rule, the court denied industry’s challenge to EPA’s requirement that state’s SIPS provide for reasonable progress towards achieving natural visibility conditions in national parks and wilderness areas and the “no degradation” requirement. Industry did not challenge requirements to improve visibility on the haziest 20 percent of days. The court recognized that mobile source emission reductions would need to be a part of a long-term emission strategy for reducing regional haze. A copy of this decision can be found in Docket A-2000-01, Document IV- A-113.

class I area. Types of impairment covered by these regulations includes layered hazes and visible plumes. While these kinds of visibility impairment can be caused by the same pollutants and processes as those that cause regional haze, they generally are attributed to a smaller number of sources located across a smaller area. The Clean Air Act and associated regulations call for protection of visibility impairment in Class I areas from localized impacts as well as broader impacts associated with regional haze.

As part of the HD07 PM air quality modeling described above, we modeled visibility conditions in the Class I areas nationally. The results by region are summarized in Table 1.5-4. In Figure 1.5-1, we define the regions used in this analysis based on a visibility study.[63] These results show that visibility is impaired in most Class I areas and additional reductions from behicles subject to this rule are needed to achieve the goals of the Clean Air Act of preserving natural conditions in Class I areas.

Table 1.5-4
Summary of 2030 Visibility Conditions in Class I Areas Based on REMSAD Modeling (Annual Average Deciview)

Region	Predicted 2030 Visibility	Natural Background Visibility
Eastern		9.5
Southeast	25.02	
Northeast/Midwest	21.00	
Western		5.3
Southwest	8.69	
California	11.61	
Rocky Mountain	12.30	
Northwest	15.44	
National Class I Area Average	14.04	

[a] Regions are depicted in Figure 1-5.1. Background visibility conditions differ by region based on differences in relative humidity and other factors: Eastern natural background is 9.5 deciviews (or visual range of 150 kilometers) and in the West natural background is 5.3 deciviews (or visual range of 230 kilometers).

[b] The results incorporate earlier emissions estimates from the engines subject to this rule. We have revised our estimates both upwards for some categories and downwards for others based on public comment and updated information; however, on net, we believe that the HD07 analyses underestimate future PM emissions.

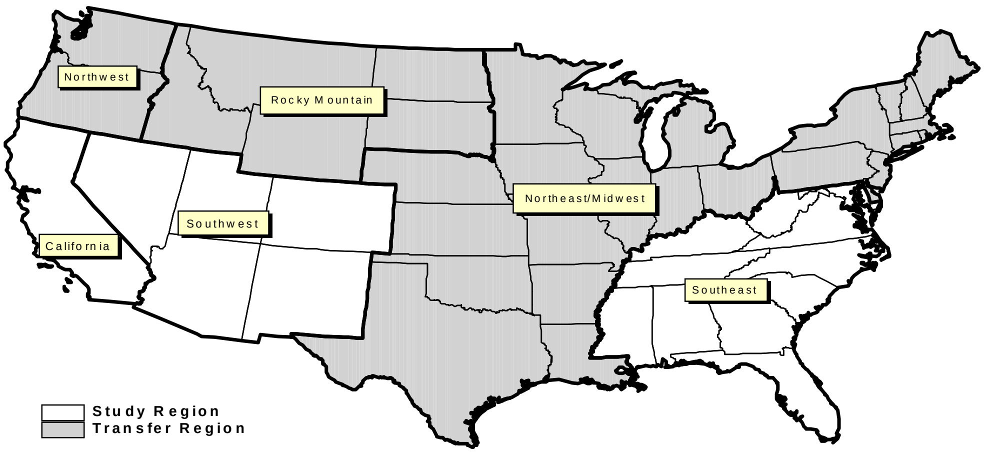


Figure 1.5-1. Visibility Regions for Continental U.S.

Note: Study regions were represented in the Chestnut and Rowe (1990a, 1990b) studies used in evaluating the benefits of visibility improvements.

The overall goal of the regional haze program is to prevent future and remedy existing visibility impairment in Class I areas. As shown by the future deciview estimates in Table 1.5-4, additional emissions reductions will be needed from the broad set of sources that contribute, including the emissions from engines subject to this rule.

1.5.4 Recreational Vehicles and Visibility Impairment in Class I Areas

This section presents information about the contribution of recreational vehicles to visibility impairment in Class I areas. Although this discussion focuses primarily on snowmobiles, we present information on other recreational vehicles as well. We use monitoring data to show that many of the worst 20 percent of days in terms of visibility levels occur in the wintertime, when snowmobiles are used. We also summarize air quality modeling information of future visibility for Class I areas where snowmobiles are operated and a case study of localized impairment in a national park.

1.5.4.1 Snowmobiles Emissions in Class I Areas

Emissions of HC from snowmobiles contribute to direct and secondary formation of fine particulate matter which can cause a variety of adverse health and welfare effects, including visibility impairment discussed above. This section presents snowmobile-related emissions information for Class I areas where snowmobiles are operated as further evidence of their contribution in Class I areas.

Ambient concentrations of fine particles are the primary pollutant responsible for visibility impairment. The classes of fine particles principally responsible for visibility impairment are sulfates, nitrates, organic carbon particles, elemental carbon, and crustal material. Hydrocarbon emissions from automobiles, trucks, snowmobiles, and other industrial processes are common sources of organic carbon. The organic carbon fraction of fine particles ranges from 47 percent in western Class I areas such as Denali National Park, to 28 percent in Rocky Mountain National Park, to 13 percent in Acadia National Park.[64]

The contribution of snowmobiles to elemental carbon and nitrates is relatively small. Their contribution to sulfates is a function of fuel sulfur and is small and will decrease even more as the sulfur content of their fuel decreases due to our recently finalized fuel sulfur requirements. In the winter months, however, hydrocarbon emissions from snowmobiles can be significant, as indicated in Table 1.5-5 and these HC emissions can contribute significantly to the organic carbon fraction of fine particles which are largely responsible for visibility impairment. This is because snowmobiles are typically powered by two-stroke engines that emit large amounts of hydrocarbons. In Yellowstone, a park with high snowmobile usage during the winter months, snowmobile hydrocarbon emissions can exceed 500 tons per year, as much as several large stationary sources. Other parks with less snowmobile traffic are also impacted, though to a lesser extent, by these hydrocarbon emissions.[65]

Table 1.5-5
1999 Winter Season Snowmobile Emissions in Selected Class I Areas (tons)

Class I area	HC	CO	NOx	PM
Denali NP and Preserve	>9.8	>26.1	>0.08	>0.24
Grand Teton NP	13.7	36.6	0.1	0.3
Rocky Mountain NP	106.7	284.7	0.8	2.6
Voyager NP	138.5	369.4	1.1	3.4
Yellowstone NP	492	1311.9	3.8	12

Source: Letter from Aaron J. Worstell, Environmental Engineer, National Park Service, Air Resources Division, to Drew Kodjak, August 21, 2001, particularly Table 1. Docket No. A-2000-01, Document No. II-G-178.

The national park areas outside of Denali in Alaska are open to snowmobile operation in accordance with special regulations (36 CFR Part 7). Denali National Park permits snowmobile operation by local rural residents engaged in subsistence uses (36 CFR Part 13). Emission calculations are based on an assumed 2 hours of use per snowmobile visit at 16 hp with the exception of Yellowstone where 4 hours of use at 16 hp was assumed. The emission factors used to estimate these emissions are identical to those used by the NONROAD model. Two-stroke snowmobile emission factors are: 111 g/hp-hr HC, 296 g/hp-hr CO, 0.86 g/hp-hr NOx, and 2.7

g/hp-hr PM. These emission factors are based on a number of engine tests performed by the International Snowmobile Manufacturers Association (ISMA) and the Southwest Research Institute (SwRI).

1.5.4.2 Air Quality Monitoring Information

To explore whether recreational vehicles, such as snowmobiles, contribute to visibility impairment in Class I areas, we examine current monitored PM levels. Visibility and particulate monitoring data are available for 8 Class I areas where snowmobiles are commonly used. These are Acadia, Boundary Waters, Denali, Mount Ranier, Rocky Mountain, Sequoia and Kings Ganyon, Voyager, and Yellowstone. Monitored fine particle data for these parks are set out in Table 1.5-6. This table shows the number of monitored days in the winter that fell within the 20-percent haziest days for each of these eight parks. Monitors collect data two days a week for a total of about 104 days of monitored values. Thus, for a particular site, a maximum of 21 worst possible days of these 104 days with monitored values constitute the set of 20-percent haziest days during a year which are tracked as the primary focus of regulatory efforts.[66] With the exception of Denali in Alaska, we defined the snowmobile season as January 1 through March 15 and December 15 through December 31 of the same calendar year, consistent with the methodology used in the Regional Haze Rule, which is calendar-year based. For Denali, Alaska, the snowmobile season is October 1 to April 30.

Table 1.5-6
Winter Days That Fall Within the 20 Percent Worst Visibility Days At National Parks Where Snowmobiles Are Operated

Class I Area	State(s)	Number of Sampled Wintertime Days Within 20 Percent Worst Visibility Days (maximum of 21 out of 104 monitored days)			
		1996	1997	1998	1999
Acadia NP	ME	4	4	2	1
Denali NP and Preserve	AK	10	10	12	9
Mount Rainier NP	WA	1	3	1	1
Rocky Mountain NP	CO	2	1	2	1
Sequoia and Kings Canyon NP	CA	4	9	1	8
Voyager NP (1989-1992)	MN	1989 3	1990 4	1991 6	1992 8
-- Boundary Waters USFS Wilderness Area (close to Voyaguers with recent data)	MN	2	5	1	5
Yellowstone NP	ID, MT, WY	0	2	0	0

Source: Letter from Debra C. Miller, Data Analyst, National Park Service, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01.

1.5.4.3 Future Visibility Impairment in Class I Areas: Regional Haze

We also examined future air quality information to whether the emissions from recreational vehicles, such as snowmobiles, contribute to regional visibility impairment in Class I areas. We present results from the HD07 future air quality modeling described above for these Class I areas in addition to inventory and air quality measurements. Specifically, in Table 1-5.7, we summarize the expected future visibility conditions in these areas without these regulations.

Table 1.5-7
Estimated 2030 Visibility in Selected Class I Areas

Class I Area	County	State	Predicted 2030 Visibility (annual average deciview)	Natural Background Visibility (annual average deciview)
				9.5
Eastern areas				
Acadia	Hancock Co	ME	23.42	
Boundary Waters	St. Louis Co	MN	22.07	
Voyager	St. Louis Co	MN	22.07	
Western areas				5.3
Grand Teton NP	Teton Co	WY	11.97	
Kings Canyon	Fresno Co	CA	10.39	
Mount Rainier	Lewis Co	WA	16.19	
Rocky Mountain	Larimer Co	CO	8.11	
Sequoia-Kings	Tulare Co	CA	9.36	
Yellowstone	Teton Co	WY	11.97	

[a] Natural background visibility conditions differ by region because of differences in factors such as relative humidity: Eastern natural background is 9.5 deciviews (or visual range of 150 kilometers) and in the West natural background is 5.3 deciviews (or visual range of 230 kilometers).

[b] The results incorporate earlier emissions estimates from the engines subject to this rule. We have revised our estimates both upwards for some categories and downwards for others based on public comment and updated information; however, on net, we believe that HD07 analysis would underestimate future PM emissions from these categories.

In these areas, snowmobiles represent a signficant part of wintertime visibility-impairing emissions. In fact, as the following discussion shows, snowmobile emissions can even be a sizable percentage of annual emissions in some Class I areas. The snowmobiles thus are a significant contributor to visibility impairment in these areas during the winter. As indicated, winter days can often be among the worst visibility impairment. In addition, as the CAA specifically states a goal of prevention and of remedying of any impairment of visibility in Class I areas, the contribution of snowmobiles to visibility impairment even on winter days that are not among the days of greatest impairment is a contribution to pollution that may reasonably be anticipated to endanger public welfare and is properly regulated in this rule.

The information presented in Table 1.5-6 shows that visibility data supports a conclusion that there are at least 8 Class I areas frequented by snowmobiles with one or more wintertime days within the 20-percent worst visibility days of the year. For example, Rocky Mountain National Park in Colorado was frequented by about 27,000 snowmobiles during the 1998-1999 winter. Of the monitored days characterized as within the 20-percent worst visibility monitored days, 2 of those days occurred during the wintertime when snowmobile emissions such as HC contributed to visibility impairment. The information in Table 1.5-7 shows that these areas also have high predicted annual average deciview levels in the future. According to the National Park Service, "[s]ignificant differences in haziness occur at all eight sites between the averages of the clearest and haziest days. Differences in mean standard visual range on the clearest and haziest days fall in the approximate range of 115-170 km."[67]

1.5.4.4 Localized Visibility Impairment in Class I Areas: Yellowstone National Park

The Class I are with the most detailed analysis of snowmobile contribution is Yellowstone National Park. This provides an example of the extent to which snowmobiles can contribute to emissions that can cause visibility impairment in Class I areas. Annual and particularly wintertime hydrocarbon emissions from snowmobiles are high in the five parks considered in Table 1.5-7, with two parks having HC emissions nearly as high as Yellowstone (Rocky Mountain and Voyageurs). The proportion of snowmobile emissions to emissions from other sources affecting air quality in these parks is likely to be similar to that in Yellowstone.

Inventory analysis performed by the National Park Service for Yellowstone National Park suggests that snowmobile emissions can be a significant source of total annual mobile source emissions for the park year round. Table 1.5-8 shows that in the 1998 winter season snowmobiles contributed 64 percent, 39 percent, and 30 percent of HC, CO, and PM emissions.[68] When the emission factors used by EPA in its NONROAD model are used, the contribution of snowmobiles to total emissions in Yellowstone is still high: 59 percent, 33 percent, and 45 percent of HC, CO and PM emissions. The University of Denver used remote-sensing equipment to estimate snowmobile HC emissions at Yellowstone during the winter of 1998-1999, and estimated that snowmobiles contribute 77 percent of annual HC emissions at the park.[69] The portion of wintertime emissions attributable to snowmobiles is even higher, since all snowmobile emissions occur during the winter months.

Table 1.5-8
1998 Annual HC Emissions (tons per year), Yellowstone National Park

Source	HC		CO		NOx		PM	
Coaches	2.69	0%	24.29	1%	0.42	0%	0.01	0%
Autos	307.17	33%	2,242.12	54%	285.51	88%	12.20	60%
RVs	15.37	2%	269.61	6%	24.33	7%	0.90	4%
Snowmobiles	596.22	64%	1,636.44	39%	1.79	1%	6.07	30%
Buses	4.96	1%	18.00	0%	13.03	4%	1.07	5%
TOTAL	926.4		4190.46		325.08		20.25	

Source: National Park Service, February 2000. Air Quality Concerns Related to Snowmobile Usage in National Parks. Air Docket A-2000-01, Document No. II-A-44.

As part of public comments, Sierra Research conducted modeling of local impairment using EPA's SCREEN3 Model Version 96043. This methodology consists of a single source Gaussian plume model, which provides maximum ground-level concentrations for point, area, flare, and volume sources, as well as concentrations in the cavity zone and concentrations due to inversion break-up and shoreline fumigation.

The Sierra Research modeling demonstrated that there is up to an 8 percent contribution to visibility degradation from snowmobile exhaust based on worst case conditions in Yellowstone national park. It should be noted that SCREEN3 is not an EPA-approved model for conducting visibility modeling. In interpreting the results of this modeling, the International Snowmobile Manufacturers Association (ISMA) notes that the conversion factors used by SCREEN3 are "conservatively high" and meant for worst case conditions, where there is a "pronounced [wind] polarity…such as where a sea breeze exists."[70] Consequently, ISMA appears to believe that data gathered away from a coastline would actually have a lower demonstrated visual impact than the impact determined by the model. Even using this modeling, ISMA presents modeling results that support an 8 percent contribution to visibility impairment. ISMA reasons that by using the same model for automobiles, the impairment contribution is double of what was expected, and therefore, the 8 percent is most likely double of what it should be. As a result, ISMA concludes an up to 4% contribution to visibility impairment from snowmobile emissions in national parks "on best visibility days."[71] Though the contribution levels in this industry-sponsored study are lower than those discussed above, and though we have some concerns with this study, as discussed in the Summary and Analysis of Comments, they still confirm that snowmobiles are indeed a significant contributor to visibility degradation in Yellowstone.

In addition to the national modeling presented in Tables 1.4-3, 1.5-1, and 1.5-6, we also conducted local-scale modeling using an EPA-approved visibility model, VISCREEN Version 1.01, to evaluate whether current emissions from recreational vehicles, such as snowmobiles, contribute to localized visibility impairment in Class I areas. This analysis focused on localized visibility impairments in Yellowstone National Park.[72] The VISCREEN model is a visibility screening level-I and -II model that characterizes point source plumes and visibility effects at 34 lines of sight. Thus, in this modeling, EPA treated snowmobiles as a synthetic point source in order to determine plume perceptibility effects in a national park.

Using VISCREEN Version 1.01, we determined plume perceptibility from snowmobile usage at four entrances (North, South, East, and West) in Yellowstone National Park as a case study of visibility impairment from recreational vehicles. We conclude that plume perceptibility would be noticeable at all entrances, even at the North entrance where the smallest numbers of snowmobiles enter. Variations in the parameters concluded that perceptibility increased as the observer neared the plume and at smaller plume-offset angles. As well, a sensitivity analysis was conducted in order to demonstrate visibility impairment when the source is located within the Class I boundaries and concluded that visibility impairment increases if the source is located within the boundary. This provides further proof that snowmobile usage can lead to visibility impairment at Yellowstone.

These results all indicate that snowmobiles contribute to visibility impairment concerns in Yellowstone National Park, a Class I area.

1.6 Gaseous Air Toxics

In addition to the human health and welfare impacts described above, emissions from the engines covered by this rulemaking also contain several other substances that are known or suspected human or animal carcinogens, or have serious non-cancer health effects. These include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and toluene. The health effects of these air toxics are highlighted below. Additional information can also be found in the Technical Support Document four our final Mobile Source Air Toxics rule.[73]

1.6.1 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 other aromatics in the fuel, but is generally about three to five percent. The benzene fraction of evaporative emissions depends on control technology and fuel composition and characteristics (e.g., benzene level and the evaporation rate), and is generally about one percent.[74]

EPA has recently reconfirmed that benzene is a known human carcinogen by all routes of exposure.[75] Respiration is the major source of human exposure. Long-term respiratory exposure to high levels of ambient benzene concentrations has been shown to cause cancer of the tissues that form white blood cells. Among these are acute nonlymphocytic leukemia,[76] chronic lymphocytic leukemia and possibly multiple myeloma (primary malignant tumors in the bone marrow), although the evidence for the latter has decreased with more recent studies.[77,78] Leukemias, lymphomas, and other tumor types have been observed in experimental animals exposed to benzene by inhalation or oral administration. Exposure to benzene and/or its metabolites has also been linked with genetic changes in humans and animals[79] and increased proliferation of mouse bone marrow cells.[80] 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.[81]

A number of adverse non-cancer health effects, blood disorders such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene.[82] 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,[83] a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[84,85] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,[86] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[87] [88] The most sensitive non-cancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood.[89]

1.6.2 1,3-Butadiene

1,3-Butadiene is formed in vehicle exhaust by the incomplete combustion of fuel. It is not present in vehicle evaporative emissions, because it is not present in any appreciable amount in fuel. 1,3-Butadiene accounts for 0.4 to 1.0 percent of total organic gas exhaust, depending on control technology and fuel composition.[90]

1,3-Butadiene was classified by EPA as a Group B2 (probable human) carcinogen in 1985.[91] This classification was based on evidence from two species of rodents and epidemiologic data. In the EPA1998 draft Health Risk Assessment of 1,3-Butadiene, that was reviewed by the Science Advisory Board (SAB), the EPA proposed that 1,3-butadiene is a known human carcinogen based on human epidemiologic, laboratory animal data, and supporting data such as the genotoxicity of 1,3-butadiene metabolites.[92] The Environmental Health Committee of EPA's Scientific Advisory Board (SAB) reviewed the draft document in August 1998 and recommended that 1,3-butadiene be classified as a probable human carcinogen, stating that designation of 1,3-butadiene as a known human carcinogen should be based on observational studies in humans, without regard to mechanistic or other information.[93] In applying the 1996 Guidelines for Carcinogen Risk Assessment, the Agency relies on both observational studies in humans as well as experimental evidence demonstrating causality, and therefore the designation of 1,3-butadiene as a known human carcinogen remains applicable.[94] The Agency has revised the draft Health Risk Assessment of 1,3-Butadiene based on the SAB and public comments. The draft Health Risk Assessment of 1,3-Butadiene will undergo the Agency consensus review, during which time additional changes may be made prior to its public release and placement on the Integrated Risk Information System (IRIS).

1,3-Butadiene also causes a variety of non-cancer reproductive and developmental effects in mice and rats (no human data) when exposed to long-term, low doses of butadiene.[95] 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 4.0 microgram/m^3 to avoid appreciable risks of these reproductive and developmental effects.[96] EPA has developed a draft chronic, subchronic, and acute RfC values for 1,3-butadiene exposure as part of the draft risk characterization mentioned above. The RfC values will be reported on IRIS.

1.6.3 Formaldehyde

Formaldehyde is the most prevalent aldehyde in vehicle exhaust. It is formed from incomplete combustion of both gasoline and diesel fuel and accounts for one to four percent of total organic gaseous emissions, depending on control technology and fuel composition. It is not found in evaporative emissions.

Formaldehyde exhibits extremely complex atmospheric behavior.[97] It is formed by the atmospheric oxidation of virtually all organic species, including biogenic (produced by a living organism) hydrocarbons. Mobile sources contribute both primary formaldehyde (emitted directly from motor vehicles) and secondary formaldehyde (formed from photooxidation of other VOCs emitted from vehicles).

EPA has classified formaldehyde as a probable human carcinogen based on limited evidence for carcinogenicity in humans and sufficient evidence of carcinogenicity in animal studies, rats, mice, hamsters, and monkeys.[98] Epidemiological studies in occupationally exposed workers suggest that long-term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity (generally the area at the back of the mouth near the nose), nasal cavity, and sinus. Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to formaldehyde causes an increase in the incidence of squamous (epithelial) cell carcinomas (tumors) of the nasal cavity. The distribution of nasal tumors in rats suggests that not only regional exposure but also local tissue susceptibility may be important for the distribution of formaldehyde-induced tumors.[99] Research has demonstrated that formaldehyde produces mutagenic activity in cell cultures.[100]

Formaldehyde exposure also causes a range of non-cancer health effects. At low concentrations (0.05-2.0 ppm), irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes is the principal effect observed in humans. At exposure to 1-11 ppm, other human upper respiratory effects associated with acute formaldehyde exposure include a dry or sore throat, and a tingling sensation of the nose. Sensitive individuals may experience these effects at lower concentrations. Forty percent of formaldehyde-producing factory workers reported nasal symptoms such as rhinitis (inflammation of the nasal membrane), nasal obstruction, and nasal discharge following chronic exposure.[101] In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm.[102] Formaldehyde exposure may also cause bronchial asthma-like symptoms in non-asthmatics.[103] [104]

Immune stimulation may occur following formaldehyde exposure, although conclusive evidence is not available. Also, little is known about formaldehyde's effect on the central nervous system. Several animal inhalation studies have been conducted to assess the developmental toxicity of formaldehyde. The only exposure-related effect noted in these studies was decreased maternal body weight gain at the high-exposure level. No adverse effects on reproductive outcome of the fetuses that could be attributed to treatment were noted. An inhalation reference concentration (RfC), below which long-term exposures would not pose appreciable non-cancer health risks, is not available for formaldehyde at this time.

1.6.4 Acetaldehyde

Acetaldehyde is a saturated aldehyde that is found in vehicle exhaust and is formed as a result of incomplete combustion of both gasoline and diesel fuel. It is not a component of evaporative emissions. Acetaldehyde comprises 0.4 to 1.0 percent of total organic gas exhaust, depending on control technology and fuel composition.[105]

The atmospheric chemistry of acetaldehyde is similar in many respects to that of formaldehyde.[106] Like formaldehyde, it is produced and destroyed by atmospheric chemical transformation. Mobile sources contribute to ambient acetaldehyde levels both by their primary emissions and by secondary formation resulting from their VOC emissions. Acetaldehyde emissions are classified as a probable human carcinogen. Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to acetaldehyde causes an increase in the incidence of nasal squamous cell carcinomas (epithelial tissue) and adenocarcinomas (glandular tissue).[107] [108]

Non-cancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes.[109] [110] [111] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract. At high concentrations, irritation and pulmonary effects can occur, which could facilitate the uptake of other contaminants. Little research exists that addresses the effects of inhalation of acetaldehyde on reproductive and developmental effects. The *in vitro* and *in vivo* studies provide evidence to suggest that acetaldehyde may be the causative factor in birth defects observed in fetal alcohol syndrome, though evidence is very limited linking these effects to inhalation exposure. Long-term exposures should be kept below the reference concentration of 9 $\mu g/m^3$ to avoid appreciable risk of these non-cancer health effects.[112]

1.6.5 Acrolein

Acrolein is extremely toxic to humans from the inhalation route of exposure, with acute exposure resulting in upper respiratory tract irritation and congestion. Although no information is available on its carcinogenic effects in humans, based on laboratory animal data, EPA considers acrolein a possible human carcinogen.[113]

1.6.6 Toluene

Toluene is a known respiratory irritant with central nervous system effects. Reproductive toxicity has been observed in exposed humans and rats.[114] Toluene toxicity is most prominent in the central nervous system after acute and chronic exposure, and that the brain is the principal target organ for toluene toxicity in humans. Specifically, recent studies indicate that toluene and other similar solvents alter the function of ion channels in neuronal membranes, including receptors stimulated by γ-amino butyric acid (GABA), *n*-methyl-D-aspartate (NMDA), nicotinic acetylcholine (nACh), and those sensitive to membrane voltage.[115, 116, 117, 118, 119] Anesthetic agents, ethanol, toluene, and other solvents inhibit the function of receptors that are excitatory in the nervous system (NMDA, nACh), and enhance the function of inhibitory receptors (GABA).[120, 121] Thus, these compounds tend to suppress the activity of the nervous system, yielding slowed reaction times, reduced arousal and, at high concentrations, anesthesia, unconsciousness and respiratory failure.[122]

1.7 Exposure to CO and Air Toxics Associated with Nonroad Engines and Vehicles

The previous section describes national-scale adverse public health effects associated with the nonroad engines and vehicles covered by this rulemaking. This section describes significant adverse health and welfare effects arising from the usage patterns of snowmobiles, large SI engines, and gasoline marine engines on the regional and local scale. Studies suggest that emissions from these engines can be concentrated in specific areas, leading to elevated ambient concentrations of particular pollutants and associated elevated exposures to operators and by-standers. This section describes these exposures.

1.7.1 Large SI Engines

Exhaust emissions from applications with significant indoor use can expose individual operators or bystanders to dangerous levels of pollution. Forklifts, ice-surfacing machines, sweepers, and carpet cleaning equipment are examples of large industrial spark-ignition engines that often operate indoors or in other confined spaces. Forklifts alone account for over half of the engines in this category. Indoor use may include extensive operation in a temperature-controlled environment where ventilation is kept to a minimum (e.g., for storing, processing, and shipping produce). Although our standards are not designed to eliminate occupational exposures, the standards will reduce CO and HC emissions that contribute to those exposures.

The principal concern for human exposure relates to CO emissions. One study showed several forklifts with measured CO emissions ranging from 10,000 to 90,000 ppm (1 to 9 percent).[123] The threshold limit value for a time-weighted average 8-hour workplace exposure set by the American Conference of Governmental Industrial Hygienists is 25 ppm.

One example of a facility that addressed exposure problems with new technology is in the apple-processing field.[124] Trout Apples in Washington added three-way catalysts to about 60 LPG-fueled forklifts to address multiple reports of employee health complaints related to CO exposure. The emission standards are based on the same technologies installed on these in-use engines.

Additional exposure concerns occur at ice rinks. Numerous papers have identified ice-surfacing machines with spark-ignition engines as the source of dangerous levels of CO and NO_2, both for skaters and for spectators.[125] This is especially problematic for skaters, who breathe air in the area where pollutant concentration is highest, with higher respiration rates resulting from their high level of physical activity. This problem has received significant attention from the medical community.

In addition to CO emissions, HC emissions from these engines can also lead to increased exposure to harmful pollutants, particularly air toxics. Since many gasoline or dual-fuel engines are in forklifts that operate indoors, reducing evaporative emissions could have direct health benefits to operators and other personnel. Fuel vapors can also cause odor problems.

1.7.2 Snowmobiles

In addition to their contribution to CO concentrations generally and visibility impairment, snowmobile emissions are of concern because of their potential impacts on riders and on park attendants, as well as other groups of people who are in contact with these vehicles for extended periods of time.

Snowmobile users can be exposed to high air toxic and CO emissions, both because they sit very close to the vehicle's exhaust port and because it is common for them to ride their vehicles in lines or groups on trails where they travel fairly close behind other snowmobiles. Because of these riding patterns, snowmobilers breathe exhaust emissions from their own vehicle, the vehicle directly in front as well as those farther up the trail. This can lead to relatively high personal exposure levels of harmful pollutants. A study of snowmobile rider CO exposure conducted at Grand Teton National Park showed that a snowmobiler riding at distances of 25 to 125 feet behind another snowmobiler and traveling at speeds from 10 to 40 mph can be exposed to average CO levels ranging from 0.5 to 23 ppm, depending on speed and distance. The highest CO level measured in this study was 45 ppm, as compared to the current 1-hour NAAQS for CO of 35 ppm.[126] While exposure levels can be less if a snowmobile drives 15 feet off the centerline of the lead snowmobile, the exposure levels are still of concern. This study led to the development of an empirical model for predicting CO exposures from riding behind snowmobiles.

Hydrocarbon speciation for snowmobile emissions was performed for the State of Montana in a 1997 report.[127] Using the dispersion model for CO from the Grand Teton exposure study with air toxic emission rates from the State of Montana's emission study, average benzene exposures for riders driving at an average speed of 23 mph, 25 feet behind another snowmobile were predicted to be 0.402 ppm, (95% bootstrap confidence intervals = 0.285-0.555). Average toluene concentrations in this scenario were modeled at 10.3 ppm (95% bootstrap CI = 8.1-12.8). With an average speed of 23 mph with a 50 foot space between snowmobiles, average benzene concentrations were estimated to be 0.210 ppm (95% bootstrap CI = 0.154 – 0.271).

The cancer risk posed to those exposed to benzene emissions from snowmobiles must be viewed within the broader context of expected lifetime benzene exposure. Observed monitoring data and predicted modeled values demonstrate that a significant cancer risk already exists from ambient concentrations of benzene for a large portion of the US population. The Agency's 1996 National-Scale Air Toxics Assessment of personal exposure to ambient concentrations of air toxic compounds emitted by outside sources (e.g., cars and trucks, power plants) found that benzene was among the five air toxics appear to pose the greatest risk to people nationwide. This national assessment found that for approximately 50% of the US population in 1996, the inhalation cancer risks associated with benzene exceeded 10 in one million. Modeled predictions for ambient benzene from this assessment correlated well with observed monitored concentrations of benzene ambient concentrations.

Specifically, the draft National-Scale Assessment predicted nationwide annual average benzene exposures from outdoor sources to be 1.4 µg/m3.[128] In comparison, snowmobile riders and those directly exposed to snowmobile exhaust emissions had predicted benzene levels two to three orders of magnitude greater than the 1996 national average benzene concentrations.[129] These elevated levels are also known as air toxic "hot spots," which are of particular concern to the Agency. Thus, total annual average exposures to typical ambient benzene concentrations combined with elevated short-term exposures to benzene from snowmobiles may pose a significant risk of adverse public health effects to snowmobile riders and those exposed to exhaust benzene emissions from snowmobiles.

Toluene concentrations, also elevated in snowmobile plumes, were predicted to be within the concentrations typically observed in occupational settings. While not considered a human carcinogenic hazard, toluene at high concentrations can affect the central nervous system, causing effects similar to intoxication. Weakness, confusion, euphoria, dizziness, and headache are associated with high exposures to toluene. National Institute of Occupational Safety and Health. NIOSH Pocket Guide to Chemical Hazards. NIOSH web site. http://www.cdc.gov/niosh/npg/npgd0619.html. Exposure to constituents of snowmobile exhaust at the levels predicted is anticipated to cause such effects in the human central nervous system.

Since snowmobile riders often travel in large groups, the riders towards the back of the group are exposed to the accumulated exhaust of those riding ahead. This scenario was not modeled, given the lack of data on snowmobile plume concentrations in trains of several vehicles. However, snowmobile trains, consisting of multiple riders in a line, are common riding scenarios. In these conditions, exhaust concentrations are anticipated to be significantly higher than those predicted here. These exposure levels can continue for hours at a time, depending on the length of a ride. An additional consideration is that the risk to health from CO exposure increases with altitude, especially for unacclimated individuals. Therefore, a park visitor who lives at sea level and then rides his or her snowmobile on trails at high-altitude is more susceptible to the effects of CO than local residents.

In addition to snowmobilers themselves, people who are active in proximity to the areas where snowmobilers congregate may also be exposed to high CO levels. An OSHA industrial hygiene survey reported a peak CO exposure of 268 ppm for a Yellowstone employee working at an entrance kiosk where snowmobiles enter the park. This level is greater than the NIOSH peak recommended exposure limit of 200 ppm. OSHA’s survey also measured employees’ exposures to several air toxics. Benzene exposures in Yellowstone employees ranged from 67-600 µg/m3, with the same individual experiencing highest CO and benzene exposures. The highest benzene exposure concentrations exceeded the NIOSH Recommended Exposure Limit of 0.1 ppm for 8-hour exposures.

Notes to Chapter 1

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

2.U.S. EPA, 1996, Review of National Ambient Air Quality Standards for Ozone, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-96-007. A copy of this document can be obtained from Air Docket A-99-06, Document No. II-A-22.

3.U.S. EPA, 1996, Air Quality Criteria for Ozone and Related Photochemical Oxidants, EPA/600/P-93/004aF. The document is available on the internet at http://www.epa.gov/ncea/ozone.htm. A copy can also be obtained from Air Docket No. A-99-06, Documents Nos. II-A-15, II-A-16, II-A-17.

4.National Air Quality and Emissions Trends Report, 1999, EPA, 2001, at Table A-19. This document is available at http://www.epa.gov/oar/aqtrnd99/. The data from the Trends report are the most recent EPA air quality data that has been quality assured. A copy of this table can also be found in Docket No. A-2000-01, Document No. II-A-64.

5.National Air Quality and Emissions Trends Report, 1998, March, 2000, at 28. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

6.National Air Quality and Emissions Trends Report, 1998, March, 2000, at 32. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

7.Additional information about this modeling can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. II-A-13. This document is also available at http://www.epa.gov/otaq/diesel.htm#documents.

8.We also performed ozone air quality modeling for the western United States but, as described further in the air quality technical support document, model predictions were well below corresponding ambient concentrations for out heavy-duty engine standards and fuel sulfur control rulemaking. Because of poor model performance for this region of the country, the results of the Western ozone modeling were not relied on for that rule.

9.U.S. EPA Regulatory Impact Analysis – Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements. EPA420-R-99-023. December 1999. A copy of this document is also available in Docket A-97-10, Document No. V-B-01.

10.Additional information about these studies can be found in Chapter 2 of "Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements," December 2000, EPA420-R-00-026. Docket No. A-2000-01, Document Number II-A-13. This document is also available at http://www.epa.gov/otaq/diesel.htm#documents.

11.Air Quality Criteria Document for Ozone and Related Photochemical Oxidants, EPA National Center for Environmental Assessment, July 1996, Report No. EPA/600/P-93/004cF. The document is available on the internet at http://www.epa.gov/ncea/ozone.htm. A copy can also be obtained from Air Docket No. A-99-06, Documents Nos. II-A-15, II-A-16, II-A-17.

12.A copy of this data can be found in Air Docket A-2000-01, Document No.II-A-80.

13.Memorandum to Docket A-99-06 from Eric Ginsburg, EPA, "Summary of Model-Adjusted Ambient Concentrations for Certain Levels of Ground-Level Ozone over Prolonged Periods," November 22, 2000. Docket A-2000-01, Document Number II-B-13.

14.Memorandum to Docket A-99-06 from Eric Ginsburg, EPA, "Summary of Model-Adjusted Ambient Concentrations for Certain Levels of Ground-Level Ozone over Prolonged Periods," November 22, 2000, at Table C, Control Scenario – 2020 Populations in Eastern Metropolitan Counties with Predicted Daily 8-Hour Ozone greater than or equal to 0.080 ppm. Docket A-2000-01, Document Number II-B-13.

15.U.S. EPA, 1995, Review of National Ambient Air Quality Standards for Nitrogen Dioxide, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-95-005.

16.U.S.EPA, 1993, Air Quality Criteria for Oxides of Nitrogen, EPA/600/8-91/049aF.

17.Much of the information in this subsection was excerpted from the EPA document, *Human Health Benefits from Sulfate Reduction*, written under Title IV of the 1990 Clean Air Act Amendments, U.S. EPA, Office of Air and Radiation, Acid Rain Division, Washington, DC 20460, November 1995. Air Docket A-2000-01, Document No. II-A-32.

18.Vitousek, Peter M., John Aber, Robert W. Howarth, Gene E. Likens, et al. 1997. Human Alteration of the Global Nitrogen Cycle: Causes and Consequences. *Issues in Ecology*. Published by Ecological Society of America, Number 1, Spring 1997.

19. National Research Council, 1993. Protecting Visibility in National Parks and Wilderness Areas. National Academy of Sciences Committee on Haze in National Parks and Wilderness Areas. National Academy Press, Washington, DC. This document is available on the internet at http://www.nap.edu/books/0309048443/html/

20.Much of this information was taken from the following EPA document: *Deposition of Air Pollutants to the Great Waters-Second Report to Congress*, Office of Air Quality Planning and

Standards, June 1997, EPA-453/R-97-011.

21.Terrestrial nitrogen deposition can act as a fertilizer. In some agricultural areas, this effect can be beneficial.

22. Coburn, R.F. (1979) Mechanisms of carbon monoxide toxicity. *Prev. Med.* 8:310-322.

23. Helfaer, M.A., and Traystman, R.J. (1996) Cerebrovascular effects of carbon monoxide. In: *Carbon Monoxide* (Penney, D.G., ed). Boca Raton, CRC Press, 69-86.

24. Benignus, V.A. (1994) Behavioral effects of carbon monoxide: meta analyses and extrapolations. *J. Appl. Physiol.* 76:1310-1316. Docket A-2000-01, Document IV-A-127.

25. Rowe, B., Milner, R., Johnson, C. Bota, G. Snowmobile-Related Deaths in Ontario: A 5-Year Review. *Canadian Medical Association Journal*, Vol. 146, Issue 2, pp 147-152. Docket A-2000-01, Document IV-A-194.

26.The CO Criteria Document (EPA 600/P-99/001F) contains additional information about the health effects of CO, human exposure, and air quality. It was published as a final document and made available to the public in August 2000 (www.epa.gov/ncea/co/). A copy of this document is also available in Docket A-2000-01, Document A-II-29.

27.National Air Quality and Emissions Trends Report, 1999, EPA, 2001, at Table A-19. This document is available at http://www.epa.gov/oar/aqtrnd99/. The data from the Trends report are the most recent EPA air quality data that has been quality assured. A copy of this table can also be found in Docket No. A-2000-01, Document No. II-A-64.

28. Information attached to written comments, P. Amette, Vice President, Motorcycle Industry Council, Incorporated. Docket A-2000-01, Document IV-D-214.

29. Economic Contribution of Off-Highway Vehicle Use in Colorado” Prepared for the Colorado Of-Highway Vehicle Coalition, by Hazen and Sawer Environmental Engineers & Scientists. July, 2001. Colorado OHV User Survey” Summary of Results: prepared for State of Colorado OHV Coalition under a contract with the Colorado State Parks OHV Program, prepared by T. Crimins, Trails Consultant. January 1999. Off Highway Vehicle Uses and Owners Preferences in Uta”, prepared for Utah DNR, Div. Of Parks and recreation, prepared by Institute for Outdoor recreation and Tourism Department of Forest Resources, Utah State University. July 22, 2001. These documents are available in Docket A-2000-01, Documents IV-A-02, 03, 05.

30. Off Highway Vehicle Uses and Owners Preferences in Uta”, prepared for Utah DNR, Div. Of Parks and recreation, prepared by Institute for Outdoor recreation and Tourism Department of Forest Resources, Utah State University. July 22, 2001. This document is available in Docket A-2000-01, Document IV-A-03.

31. All-Terrain Vehicle Exposure, Injury, Death and Risk Studies. U.S. Consumer Product Safety Commission, April, 1998. Docket A-2000-01, Document IV-A-197.

32. Anchorage Carbon Monoxide Emission Inventory and Year 2000 Attainment Projections" Air Quality Program, Environmental Services Division, Department of Health and Human Services [DRAFT]. May, 2001. Docket A-2000-01, Document II-A-40.

33.Areas with a few years of attainment data can and often do have exceedances following such years of attainment because of several factors including different climatic events during the later years, increases in inventories, etc. Thus, a plan to maintain the NAAQS is critical to showing attainment.

34.Dulla, Robert G. Sierra Research, Inc. "A Review of Vehicle Test Programs Conducted in Alaska in Recent Years and a Summary of the Fairbanks Co. Inventory 1995-2001. June 4, 2001. Docket A-2000-01, Document IV-A-198.

35.St. Paul, Minnesota was recently reclassified as being in attainment but is still considered a maintenance area. There is also a significant population of snowmobiles in Minnesota, with snowmobile trails in Washington County.

36.The trail maps consulted for this rulemaking can be found in Docket No. A-2000-01, Document No. II-A-65.

37. Written comments from J.S. Grumet, Executive Director, Northeast States for Coordinated Use Management (NESCAUM), Docket A-2000-01, Document IV-D-196.

38. Doss, Howard. Snowmobile Safety. Michigan Agricultural Safety Health Center. A copy of this document can be found in Docket A-2000-01, Document IV-A-148 (an attachment).

39. Mauer, Richard. "Snowmobile Perils" Anchorage Daily News. Internet search 7/3/02. Docket A-2000-01, IV-A-184.

40.Dulla, Robert G. Sierra Research, Inc. "A Review of Vehicle Test Programs Conducted in Alaska in Recent Years and a Summary of the Fairbanks Co. Inventory 1995-2001. June 4, 2001. Docket A-2000-01, Document IV-A-198.

41. Technical Memorandum to Docket A-2000-01 from Drew Kodjak, Attorney-Advisor, Office of Transportation and Air Quality, "Air Quality Information for Selected CO Nonattainment Areas," July 27, 2001, Docket Number A-2000-01, Document Number II-B-18.

42. Air Quality Criteria for Carbon Monoxide, US EPA, EPA 600/P-99/001F, June 2000, at 3-38, Figure 3-32 (Federal Bldg, AIRS Site 020900002). Air Docket A-2000-01, Document

Number II-A-29. This document is also available at http://www.epa.gov/ncea/coabstract.htm.

43.National Research Council. The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, AK. May 2002. Docket A-2000-01, Document IV-A-115.

44. National Air Quality and Emissions Trends Report, 1999, EPA, 2001, at Table A-19. This document is available at http://www.epa.gov/oar/aqtrnd99/. The data from the Trends report are the most recent EPA air quality data that have been quality assured. A copy of this table can also be found in Docket No. A-2000-01, Document No. II-A-64. See also the air quality update, 1998-2000 Ozone and 1999-2000 Carbon Monoxide, available at www.epa.gov/oar/aqtrnd00. A copy of this document is also available at Docket A-2000-01, Document No. IV-A-141.

45. Air Quality and Emissions Trends Report, 1998, March, 2000. This document is available at http://www.epa.gov/oar/aqtrnd98/. Relevant pages of this report can be found in Memorandum to Air Docket A-2000-01 from Jean Marie Revelt, September 5, 2001, Document No. II-A-63.

46.EPA (1996) Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information OAQPS Staff Paper. EPA-452/R-96-013. Docket Number A-99-06, Documents Nos. II-A-18, 19, 20, and 23. The particulate matter air quality criteria documents are also available at http://www.epa.gov/ncea/partmatt.htm.

47.Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents.

48.Memorandum to Docket A-99-06 from Eric O. Ginsburg, Senior Program Advisor, “Summary of 1999 Ambient Concentrations of Fine Particulate Matter,” November 15, 2000. Air Docket A-2000-01, Document No. II-B-12.

49.Memorandum to Docket A-99-06 from Eric O. Ginsburg, Senior Program Advisor, “Summary of Absolute Modeled and Model-Adjusted Estimates of Fine Particulate Matter for Selected Years,” December 6, 2000. This memo is also available in the docket for this rule. Docket A-2000-01, Document Number II-B-14.

50.The fine particle monitoring network was expanding with more monitors being added between 1996 and 2002.

51. Technical Memorandum, EPA Air Docket A-99-06, Eric O. Ginsburg, Senior Program Advisor, Emissions Monitoring and Analysis Division, OAQPS, Summary of Absolute Modeled and Model-Adjusted Estimates of Fine Particulate Matter for Selected Years, December 6, 2000, Table P-2. Docket Number 2000-01, Document Number II-B-14.

52.National Research Council, 1993 (Ibid); U.S. EPA Criteria for Particulate Matter, 8-3; US EPA Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information OAQPS Staff Paper. EPA-452/R-96-013. 1996. Docket Number A-99-06, Documents Nos. II-A-18, 19, 20, and 23. The particulate matter air quality criteria documents are also available at http://www.epa.gov/ncea/partmatt.htm.

53. Council on Environmental Quality, 1978. Visibility Protection for Class I Areas, the Technical Basis. Washington DC. Cited in US EPA, Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. EPA-452 \ R-96-013. This document is available in Docket A-99-06, Document II-A-23.

54. Sisler, James F. Spatial and Seasonal Patterns and Long Term Variability of the Composition of Haze in the United States: An Analysis of Data from the IMPROVE Network. 1996. A copy of the relevant pages of this document can be found in Docket A-99-06, Document No. II-B-21.

55. National Research Council, 1993 (Ibid).

56.National Research Council, 1993 (Ibid).

57. National Acid Precipitation Assessment Program (NAPAP), 1991. Office of the Director. Acid Deposition: State of Science and Technology. Report 24, Visibility: Existing and Historical Conditions - Causes and Effects. Washington, DC. Cited in US EPA, Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. EPA-452 \ R-96-013. This document is available in Docket A-99-06, Document II-A-23. Also, US EPA. Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. Preliminary Draft. June 2001. Docket A-2000-01, Document IV-A-199.

58.Memorandum to Docket A-99-06 from Eric O. Ginsburg, Senior Program Advisor, “Summary of 1999 Ambient Concentrations of Fine Particulate Matter,” November 15, 2000. Air Docket A-2000-01, Document No. II-B-12.

59. Technical Memorandum, EPA Air Docket A-99-06, Eric O. Ginsburg, Senior Program Advisor, Emissions Monitoring and Analysis Division, OAQPS, Summary of Absolute Modeled and Model-Adjusted Estimates of Fine Particulate Matter for Selected Years, December 6, 2000, Table P-2. Docket Number 2000-01, Document Number II-B-14.

60. The trail maps consulted for this rulemaking can be found in Docket No. A-2000-01, Document No. II-A-65.

61.This goal was recently upheld by the US Court of Appeals. American Corn Growers Association v. EPA, 291F.3d 1(D.C .Cir 2002). A copy of this decision can be found in Docket A-2000-01, Document IV- A-113..

62.U.S. EPA Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information OAQPS Staff Paper. EPA-452/R-96-013. 1996. Docket Number A-99-06, Documents Nos. II-A-18, 19, 20, and 23. The particulate matter air quality criteria documents are also available at http://www.epa.gov/ncea/partmatt.htm.

63. Chestnut, L.G., and R.D. Rowe. 1990a. *Preservation for Visibility Protection at the National Parks: Draft Final Report*. Prepared for Office of Air Quality Planning and Standards, US Environmental Protection Agency, and Air Quality Management Division, National Park Service; Chestnut, L.G., and R.D. This document is available from Docket A-97-10, Document II-A-33 Rowe. 1990b. A New National Park Visibility Value Estimates. In *Visibility and Fine Particles*, Transactions of an AWMA/EPA International Speciality Conference. C.V. Mathai, ed., Air and Waste Management Association, Pittsburg. Docket A-2000-01, IV-A-2000.

64.Letter from Debra C. Miller, Data Analyst, National Park Service, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01, Document Number. II-B-28.

65.Technical Memorandum, Aaron Worstell, Environmental Engineer, National Park Service, Air Resources Division, Denver, Colorado, particularly Table 1. Docket No. A-2000-01, Document Number II-G-178.

66.Letter from Debra C. Miller, Data Analyst, National Park, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01, Document Number. II-B-28.

67.Letter from Debra C. Miller, Data Analyst, National Park Service, to Drew Kodjak, August 22, 2001. Docket No. A-2000-01, Document. Number. II-B-28.

68.National Park Service, February 2000. Air Quality Concerns Related to Snowmobile Usage in National Parks. Air Docket A-2000-01, Document No. II-A-44.

69.G. Bishop, et al., Snowmobile Contributions to Mobile Source Emissions in Yellowstone National Park, Environmental Science and Technology, Vol. 35, No. 14, at 2873. Docket No. A-2000-01, Document No. II-A-47.

70.Memorandum to IV-D-204 at 13

71.Ibid, at 14.

72.Julia Rege, Environmental Scientist, EPA. Memorandum to Docket A-2000-0. Predicted visibility effects from snowmobile exhaust (particulate matter) on or near snowmobile trails in Yellowstone National Park. July, 12, 2002. Docket A-2000-01, Document IV-A-147.

73.See our Mobile Source Air Toxics final rulemaking, 66 FR 17230, March 29, 2001, and the Technical Support Document for that rulemaking. Docket No. A-2000-01, Documents Nos. II-A-42 and II-A-30.

74.U.S. EPA. (1999) Analysis of the Impacts of Control Programs on Motor Vehicle Toxic Emissions and Exposure in Urban Areas and Nationwide: Volume I. Prepared for EPA by Sierra Research, Inc. and Radian International Corporation/Eastern Research Group, November 30, 1999. Report No. EPA420-R-99-029. http://www.epa.gov/otaq/toxics.htm.

75.U.S. EPA (1998) Environmental Protection Agency, Carcinogenic Effects of Benzene: An Update, National Center for Environmental Assessment, Washington, DC. 1998. EPA/600/P-97/001F. http://www.epa.gov/ncepihom/Catalog/EPA600P97001F.html.

76.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 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.

77.U.S. EPA (1985) Environmental Protection Agency, Interim quantitative cancer unit risk estimates due to inhalation of benzene, prepared by the Office of Health and Environmental Assessment, Carcinogen Assessment Group, Washington, DC. for the Office of Air Quality Planning and Standards, Washington, DC., 1985. Air Docket A-2000-01, Document No. II-A-74.

78.Clement Associates, Inc. (1991) Motor vehicle air toxics health information, for U.S. EPA Office of Mobile Sources, Ann Arbor, MI, September 1991. Air Docket A-2000-01, Document No. II-A-49.

79.International Agency for Research on Cancer (IARC) (1982) IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France, p. 345-389.

80.Irons, R.D., W.S. Stillman, D.B. Colagiovanni, and V.A. Henry (1992) Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor *in vitro*, Proc. Natl. Acad. Sci. 89:3691-3695.

81.Lumley, M., H. Barker, and J.A. Murray (1990) Benzene in petrol, *Lancet* 336:1318-1319.

82.U.S. EPA (1993) Motor Vehicle-Related Air Toxics Study, U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, EPA Report No. EPA 420-R-93-005, April 1993.

83.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.

84.Aksoy, M (1991) Hematotoxicity, leukemogenicity and carcinogenicity of chronic exposure to benzene. In: Arinc, E.; Schenkman, J.B.; Hodgson, E., Eds. Molecular Aspects of Monooxygenases and Bioactivation of Toxic Compounds. New York: Plenum Press, pp. 415-434.

85.Goldstein, B.D. (1988) Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541-554.

86.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).

87.Aksoy, M., S. Erdem, and G. Dincol. (1974) Leukemia in shoe-workers exposed chronically to benzene. Blood 44:837.

88.Aksoy, M. and K. Erdem. (1978) A follow-up study on the mortality and the development of leukemia in 44 pancytopenic patients associated with long-term exposure to benzene. Blood 52: 285-292.

89.Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes (1996) Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236-246.

90.U.S. EPA. (1999) Analysis of the Impacts of Control Programs on Motor Vehicle Toxic Emissions and Exposure in Urban Areas and Nationwide: Volume I. Prepared for EPA by Sierra Research, Inc. and Radian International Corporation/Eastern Research Group, November 30, 1999. Report No. EPA420-R-99-029. http://www.epa.gov/otaq/toxics.htm.

91.U.S. EPA (1985) Mutagenicity and Carcinogenicity Assessment of 1,3-Butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC.

92.U.S. EPA (1998) Draft Health Risk Assessment of 1,3-Butadiene, National Center for Environmental Assessment, Office of Research and Development, U.S. EPA, EPA/600/P-98/001A, February 1998.

93.Scientific Advisory Board. 1998. An SAB Report: Review of the Health Risk Assessment of 1,3-Butadiene. EPA-SAB-EHC-98, August, 1998.

94.EPA 1996. guidelines for carcinogen risk assessment. Federal Register 61(79):17960-18011.

95.U.S. EPA (1985) Mutagenicity and carcinogenicity assessment of 1,3-butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC. http://www.epa.gov/ngispgm3/iris/subst/0139.htm.

96.U.S. EPA (1985) Mutagenicity and carcinogenicity assessment of 1,3-butadiene. EPA/600/8-85/004F. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. Washington, DC. http://www.epa.gov/ngispgm3/iris/subst/0139.htm.

97.Ligocki, M.P., G.Z. Whitten, R.R. Schulhof, M.C. Causley, and G.M. Smylie (1991) Atmospheric transformation of air toxics: benzene, 1,3-butadiene, and formaldehyde, Systems Applications International, San Rafael, CA (SYSAPP-91/106).

98.U.S. EPA (1987) Environmental Protection Agency, Assessment of health risks to garment workers and certain home residents from exposure to formaldehyde, Office of Pesticides and Toxic Substances, April 1987. Air Docket A-2000-01, Document No. II-A-48.

99.Clement Associates, Inc. (1991) Motor vehicle air toxics health information, for U.S. EPA Office of Mobile Sources, Ann Arbor, MI, September 1991. Air Docket A-2000-01, Document No. II-A-49.

100.U.S. EPA (1993) Motor Vehicle-Related Air Toxics Study, U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, EPA Report No. EPA 420-R-93-005, April 1993. http://www.epa.gov/otaq/toxics.htm.

101.Wilhelmsson, B. and M. Holmstrom. (1987) Positive formaldehyde PAST after prolonged formaldehyde exposure by inhalation. *The Lancet*:164.

102.Burge, P.S., M.G. Harries, W.K. Lam, I.M. O'Brien, and P.A. Patchett. (1985) Occupational asthma due to formaldehyde. *Thorax* 40:225-260.

103.Hendrick, D.J., R.J. Rando, D.J. Lane, and M.J. Morris (1982) Formaldehyde asthma: Challenge exposure levels and fate after five years. *J. Occup. Med*. 893-897.

104.Nordman, H., H. Keskinen, and M. Tuppurainen. (1985) Formaldehyde asthma - rare or overlooked? *J. Allergy Clin. Immunol*. 75:91-99.

105.U.S. EPA. (1999) Analysis of the Impacts of Control Programs on Motor Vehicle Toxic Emissions and Exposure in Urban Areas and Nationwide: Volume I. Prepared for EPA by Sierra Research, Inc. and Radian International Corporation/Eastern Research Group, November 30, 1999. Report No. EPA420-R-99-029. http://www.epa.gov/otaq/toxics.htm

106.Ligocki, M.P., G.Z. Whitten (1991) Atmospheric transformation of air toxics: acetaldehyde and polycyclic organic matter, Systems Applications International, San Rafael, CA, (SYSAPP-91/113).

107. Environmental Protection Agency, Health assessment document for acetaldehyde, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Research Triangle Park, NC, EPA-600/8-86/015A (External Review Draft), 1987. Air Docket A-2000-01, Document No. II-A-33.

108.Environmental Protection Agency, Integrated Risk Information System (IRIS), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH, 1992. Acetaldehyde. http://www.epa.gov/iris/subst/0290.htm

109.U.S. EPA (1987) Health Assessment Document for Acetaldehyde — External Review Draft. Office of Health and Environmental Assessment, Research Triangle Park, NC. Report No. EPA 600/8-86/015A.

110.California Air Resources Board (CARB) (1992) Preliminary Draft: Proposed identification of acetaldehyde as a toxic air contaminant, Part B Health assessment, California Air Resources Board, Stationary Source Division, August, 1992. Air Docket A-2000-01, Document No. II-A-34.

111.U.S. EPA (1997) Environmental Protection Agency, Integrated Risk Information System (IRIS), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH, 1997. Acetaldehyde. http://www.epa.gov/iris/subst/0290.htm

112.U.S. EPA (1999) Environmental Protection Agency, Integrated Risk Information System (IRIS), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. 1,3-Butadiene. http://www.epa.gov/iris/subst/0139.htm .

113.U.S. EPA (1993) Environmental Protection Agency, Integrated Risk Information System (IRIS), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. Acrolein http://www.epa.gov/iris/subst/0364.htm .

114. U.S. EPA Integrated Risk Information System (IRIS) summary for Toluene. Www.epa.gov/iris/subst/0118.htm

115. Peoples, R.W., Li, C., and Weight, F.F. (1996) Lipid vs. protein theories of alcohol action in the nervous system. *Annu. Rev. Pharmacol. Toxicol.* 36:185-201.

116. Beckstead, M.J., Weiner, J.L., Eger, E.I. II, Gong, D.H. and Mihic, S.J. (2000) Glycine and ã-aminobutyric acid$_A$ receptor function is enhanced by inhaled drugs of abuse. *Mol. Pharm.* 57:1199-1205.

117. Cruz, S.L., R.L. Balster, and J.J. Woodward. 2000. Effects of volatile solvents on recombinant N-methyl-D-aspartate receptors expressed in Xenopus oocytes. Brit. J. Pharmacol. 131:1303-1308. Cruz, S.L., T. Mirshahi, B. Thomas, R.L. Balster and J.J. Woodward. 1998. Effects of the abused solvent toluene on recombinant N-methyl-D-aspartate and non-N-methyl-D-aspartate receptors expressed in Xenopus oocytes. J. Pharmacol. Exp. Ther. 286:334-40. Both of these documents are cited in Benignus, V., Bushnell, P. and Boyes, W. “Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust” Docket A-2000-01, Document IV-A-143.

118. Bale, A.S., Cruz, S.L., Balster, R.L., and Woodward, J.J. Effects of Toluene on Nicotinic Acetylcholine Receptors Expressed in Xenopus Oocytes. Presented at the Sixty-First Annual College on Problems of Drug Dependence, Acapulco, Mexico, 1999. This document is cited in Benignus, V., Bushnell, P. and Boyes, W. “Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust” Docket A-2000-01, Document IV-A-143.

119. Tillar, R., Shafer, T.J. and Woodward, J.J. (2002) Toluene inhibits voltage-sensitive calcium channels expressed in pheochromocytoma cells. *Neurochemistry International,* in press.

120. Danysz, W., W. Dyr, E. Jankowska, S. Glazewski, W. Kostowski. The involvement of NMDA receptors in acute and chronic effects of ethanol. Alcohol. Clin. Exp. Res. 16:499-504, 1992. This document is cited in Benignus, V., Bushnell, P. and Boyes, W. “Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust” Docket A-2000-01, Document IV-A-143.; Tassonyi, E., Charpantier, E., Muller, D., Dumont, L. and Bertrand, D. (2002 The role of nicotinic acetylcholine receptors in the mechanisms of anesthesia. *Brain Res. Bull.* 57:133-150.

121.Mihic, S.J., McQuilkin, S.J., Eger, E.I. II, Ionescu, P. and Harris, R.A. (1994) Potentiation of ã-aminobutyric acid type A receptor-mediated chloride currents by novel halogenated compounds correlates with their abilities to induce general anesthesia. *Mol. Pharm.* 46:851-857. Olsen, R.W. (1998) The molecular mechanism of action of general anesthetics: Structural aspects of interactions with GABA$_A$ receptors. *Toxicol. Lett.* 100-101:193-201.

122. Balster, R.L. (1998) Neural basis of inhalant abuse. *Drug Alc. Dependence* 51:207-214.

123.“Warehouse Workers’ Headache, Carbon Monoxide Poisoning from Propane-Fueled Forklifts,” Thomas A. Fawcett, et al, *Journal of Occupational Medicine,* January 1992, p. 12. Docket A-2000-01, Document No. II-A-36.

124.“Terminox System Reduces Emissions from LPG Lift Trucks,” Material Handling Product News. Docket A-2000-01, Document No. II-A-14.

125.Summary of Medical Papers Related to Exhaust Emission Exposure at Ice Rinks,” EPA Memorandum from Alan Stout to Docket A-2000-01. Docket A-2000-01, Document No. II-A-38.

126. Snook and Davis, 1997, “An Investigation of Driver Exposure to Carbon Monoxide While Traveling Behind Another Snowmobile.” Docket No. A-2000-01, Document Number II-A-35.

127. Emissions from Snowmobile Engines Using Bio-based Fuels and Lubricants, Southwest Research Institute, August, 1997, at 22. Docket No. A-2000-01, Document Number II-A-50.

128. National-Scale Air Toxics Assessment for 1996, EPA-453/R-01-003, Draft, January 2001.

129. Technical Memorandum, Chad Bailey, Predicted benzene exposures and ambient concentrations on and near snowmobile trails, August 17, 2001. Air Docket A-2000-01, Document No. II-B-27.

Chapter 2: Industry Characterization

To accurately assess the potential impact of this emission control program, it is important to understand the nature of the affected industries. This chapter describes relevant background information related to each of the categories of engines and vehicles subject to this proposal. For each engine category, descriptions of the supply and demand sides of the markets are provided. Additionally, industry organization and historical market trends data are discussed.

2.1 CI Marine Engines and Recreational Boats

This section gives a general characterization of the segments of the marine industry that may be affected by the regulation. The emission control program may affect diesel marine engines and recreational boats that contain these engines. We therefore focus on the compression-ignition (CI) diesel marine engine manufacturing and recreational boat building industries. Information is also provided for several spark-ignition vessel categories, even though they are not directly affected by this rule (spark-ignition engines and vessels are the subject of a separate proposed rulemaking regarding evaporative emissions; See 67 FR 53050, August 14, 2002). This industry characterization was developed in part under contract with ICF Consulting[1] as well as independent analyses conducted by EPA through interaction with the industry and other sources.[2,3,4]

2.1.1 The Supply Side

This section describes the types of recreational boats that may contain CI marine engines, the inputs used to manufacture both boats and engines, and the costs associated with boat and engine production.

2.1.1.1 Product Types

Diesel engines are primarily available in inboard marine configurations and are most commonly found in inboard cruisers and inboard runabouts. The National Marine Manufacturers Association estimates that 18 percent of all inboard boats are equipped with diesel engines, with the dominant application being cruisers.[5] Diesel engines are also available in sterndrive configurations on a limited basis, and in the past, a small number of outboard boats contained diesel engines as well (currently there are no outboard diesel engines being manufactured). Descriptions of these boat types, taken from the Economic Impact Analysis of the Proposed Boat Manufacturing NESHAP, are provided here[6]:

- **Inboard runabouts** are mid-sized boats powered by an attached engine located inside the hull at the middle or rear of the boat, with a prop shaft running through the bottom of the boat. Most inboard runabouts are tournament ski boats.

- **Inboard cruisers** are large boats with cabins. Almost all cruisers are equipped with two inboard engines.
- **Sterndrives** are mid-sized boats powered by an attached inboard engine combined with a drive unit that is located on the transom at the stern (rear) of the boat. Sterndrives are also known as inboard/outboards or I/Os.
- **Outboards** are small to medium-sized boats powered by a self-contained detachable engine and propulsion system, which is attached to the transom. This category of boats includes most runabouts, bass boats, utility boats, offshore fishing boats, and pontoons.

Larger boats are powered exclusively by diesel inboard engines. These boats are generally 40 feet or greater in length. Recreational boats in ports with access to the ocean (e.g. Seattle) can be 80 to 100 feet or longer. The larger boats typically require twin inboard diesel engines with 2,000 total horsepower or more. Recreational diesel marine engines are generally produced by domestic companies that have been long-standing players in the marine diesel engine market. The three companies that tend to dominate the market are Caterpillar, Cummins, and Detroit Diesel (see Section 2.1.3.2 for details about these companies). Nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to these three companies.

Sterndrive boats equipped with diesel engines account for less than 1 to 2 percent of the market. A minority of mid-sized boat owners insist on diesel powered sterndrive engines for their boats. Diesel marine sterndrive systems generally power the same types of boats as their gasoline counterparts, which tend to be 15 to 30 feet in length. Customers that choose a diesel sterndrive marine engine are generally seeking three main advantages over gasoline sterndrive marine engines. First, diesel fumes are much less ignitable and explosive that gasoline fumes. Second, diesel powered craft have a greater range than gasoline powered craft with similar fuel capacity. Lastly, diesel engines tend to be more reliable and tend to run more hours between major overhauls than gasoline engines. This last point is particularly important to boat owners who operate their boats higher than the average.

One major disadvantage of diesel sterndrive engines is their cost relative to comparably powered gasoline sterndrive engines. For example, a 40 foot twin cabin cruiser with twin gasoline sterndrive engines costs $238,000. For twin diesel sterndrive engines, the price increases by approximately $50,000. The fact that the diesel engine is more expensive, coupled with the fact that diesel fuel is often less available than gasoline in the U.S., has resulted in limited domestic demand for recreational diesel sterndrive marine engines.

2.1.1.2 Primary Inputs

The primary inputs used to produce marine engines and recreational boats, can be divided into four major categories: capital, labor, energy, and materials. Capital refers to the type of equipment used in production where the type of capital depends upon the good being produced. The same is true for labor, as different skills are required for the production of boats relative to engines. Energy refers to the electricity, natural gas, or other power sources used to operate production equipment and plants at which boats and engines are manufactured. Material inputs are what differ the most across the production of these end products. The remainder of this section focuses on the different materials used to produce CI marine engines and recreational boats.

Some of the main materials used to produce CI marine engines include fluid power pumps, motors, and transmissions; fluid power cylinders, filters, valves, hoses, and their assemblies; metal bolts, nuts, screws, washers, and tanks; iron, steel, and nonmetal forgings and castings; steel bars, plates, piston rings, and other steel shapes and forms; gears, gaskets, and fabricated plastic products; engine electrical equipment such as spark plugs, generators, and starters; and rubber and plastic hosing and belting. All of these inputs are used in conjunction with energy, capital, and skilled labor to manufacture engines.

Main inputs used in the production of recreational boats include marine engines, plastic and aluminum fuel tanks, and rubber fuel hoses. However, these are but a few of the materials used in boat manufacturing. Others include marine metal hardware, such as propellers, castings, screws, washers, and rivets; metal forgings, castings, and other steel forms; aluminum and aluminum-base alloy sheet, plate, foil, rod, bars, and pipes; fiberglass, lumber, plywood, canvas products, and carpeting; plastic rods, tubes, and shapes; and paints, varnishes and lacquers.

2.1.1.3 Costs of Production

The historical production costs of marine engines and recreational boats are divided into the primary input categories of labor, materials, and capital expenditures. Table 2.1-1 presents the value of shipments (VOS), production costs, and production costs as a share of the VOS for the other engine equipment manufacturing industry (which includes marine engine manufacturing). Table 2.1-2 shows the same figures for the boat manufacturing industry. The other engine equipment manufacturing industry is identified by Standard Industrial Classification (SIC) code 3519 and the North American Industrial Classification System (NAICS) code 333618. The SIC code and the NAICS code for the boat building industry are 3732 and 336612.

For both engine manufacturing and boat building, the average share of the cost of materials and total capital expenditures is similar. The cost of materials represents an average of 57 to 58 percent of the VOS for both industries and average share of capital expenditures for both industries is approximately 2 to 3 percent. Another trend evident for both industries is that the cost shares of materials and payroll tended to be higher in the earlier part of the 1990s than in the late 1990s. Payroll, which includes the costs associated with employee wages and benefits, differs slightly across the industries. For the boat manufacturing industry, payroll represents an average of 20 percent of VOS while for engine manufacturing, it is equal to an average share of 14 percent of its shipment value.

Also notable in these tables is that the average VOS for the engine manufacturing industry, over $16 billion, is about three times the average VOS for the boat manufacturing industry. It is important to keep in mind that the data in Table 2.1-1 include other engine equipment manufacturing and does not represent marine engine manufacturing exclusively. Likewise, the figures in Table 2.1-2 for boat manufacturing include vessels that are not powered by CI engines, such as outboards, jet skis, personal water craft, and boats that are not motorized, such as canoes and kayaks.

Table 2.1-1
Value of Shipments and Production Costs for the SIC and NAICS Codes that Include Recreational Boat Engine Manufacturers*, 1992 - 1999 [7,8,9,10,11,12,13]

Year	Industry Code	Value of Shipments ($$10^6$)	Payroll ($$10^6$)	Payroll % of VOS	Cost of Materials ($$10^6$)	Cost of Materials % of VOS	Total Capital Expenditures ($$10^6$)	Total Capital Expenditures % of VOS
1992	SIC 3519	$11,827	$2,072	18%	$6,996	59%	$461	4%
1993	SIC 3519	$12,600	$1,900	15%	$7,545	60%	$371	3%
1994	SIC 3519	$15,308	$2,162	14%	$8,977	59%	$406	3%
1995	SIC 3519	$16,642	$2,238	13%	$9,940	60%	$499	3%
1996	SIC 3519	$17,286	$2,237	13%	$9,905	57%	$528	3%
1997	NAICS 333618	$19,011	$2,374	12%	$10,539	55%	$631	3%
1998	NAICS 333618	$20,312	$2,471	12%	$11,963	59%	$682	3%
1999	NAICS 333618	$22,389	$2,652	12%	$12,474	56%	$786	4%
	Average	$16,922	$2,263	14%	$9,792	58%	$545	3%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars

Table 2.1-2
Value of Shipments, and Production Costs for the SIC and NAICS Codes that Include Recreational Boat Manufacturers*, 1992 - 1999 [14,15,16,17,18,19,20]

Year	Industry Code	Value of Shipments ($$10^6$)	Payroll ($$10^6$)	Payroll % of VOS	Cost of Materials ($$10^6$)	Cost of Materials % of VOS	Total Capital Expenditures ($$10^6$)	Total Capital Expenditures % of VOS
1992	SIC 3732	$4,599	$1,006	22%	$2,609	57%	$63	1%
1993	SIC 3732	$4,975	$1,033	21%	$2,919	59%	$83	2%
1994	SIC 3732	$5,334	$1,081	20%	$3,075	58%	$90	2%
1995	SIC 3732	$5,597	$1,105	20%	$3,218	57%	$89	2%
1996	SIC 3732	$5,823	$1,177	20%	$3,396	58%	$109	2%
1997	NAICS 336612	$5,607	$1,030	18%	$3,237	58%	$122	2%
1998	NAICS 336612	$5,939	$1,114	19%	$3,202	54%	$263	4%
1999	NAICS 336612	$7,463	$1,361	18%	$4,099	55%	$231	3%
	Average	$5,667	$1,113	20%	$3,219	57%	$131	2%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars

Looking specifically at the engine manufacturing industry, we see that the share of payroll steadily declined over the 1992 - 1999 time period. In 1992, payroll represented 18 percent of the VOS but by 1995, it was down to 13 percent. Labor costs fell to 12 percent of the VOS in 1997 and remained at this lower share value through 1999. A declining trend is also evident for the share of payroll for the boat manufacturing industry, however it was more recently that the share of labor costs fell. In 1992, labor costs were equal to 22 percent of the boat manufacturing industry's VOS. It dropped to 20 percent from 1994 to 1996 and most recently was equal to 18 to 19 percent in the late 1990s.

2.1.1.4 Recreational Boat Production Practices

Based on information supplied by a variety of recreational boat builders, the following discussion provides a description of the general production practices used in this sector of the marine industry.

Engines are usually purchased from factory authorized distribution centers. The boat builder provides the specifications to the distributor who helps match an engine for a particular application. It is the boat builders responsibility to fit the engine into their vessel design. The reason for this is that sales directly to boat builders are a very small part of engine manufacturers' total engine sales. These engines are not generally interchangeable from one design to the next. Each recreational boat builder has their own designs. In general, a boat builder will design one or two molds that are intended to last 5-8 years. Very few changes are tolerated in the molds because of the costs of building and retooling these molds.

Recreational vessels are designed for speed and therefore typically operate in a planing mode. To enable the vessel to be pushed onto the surface of the water where it will subsequently operate, recreational vessels are constructed of lighter materials and use engines with high power density (power/weight). The tradeoff on the engine side is less durability, and these engines are typically warranted for fewer hours of operation. Fortunately, this limitation typically corresponds with actual recreational vessel use. With regard to design, these vessels are more likely to be serially produced. They are generally made out of light-weight fiberglass. This material, however, minimizes the ability to incorporate purchaser preferences, not only because many features are designed into the fiberglass molds, but also because these vessels are very sensitive to any changes in their vertical or horizontal centers of gravity. Consequently, optional features are generally confined to details in the living quarters, and engine choice is very limited or is not offered at all.

Based on information supplied by a variety of recreational boat builders, fuel tanks for recreational boats are usually purchased from fuel tank manufacturers. However, some boat builders construct their own fuel tanks. The boat builder provides the specifications to the fuel tank manufacturer who helps match the fuel tank for a particular application. It is the boat builder's responsibility to install the fuel tank and connections into their vessel design. For vessels designed to be used with small outboard engines, the boat builder may not install a fuel tank; therefore, the end user would use a portable fuel tank with a connection to the engine.

2.1.2 The Demand Side

The information provided in this section addresses the various options consumers have available regarding recreational marine vessels and the engines used to power them. Some of the engine-powered recreational boats available to consumers include inboards, sterndrives, outboards, personal water craft, and jet boats.

2.1.2.1 Uses and Consumers

Recreational boats are used for a number of water-related pastimes including fishing, waterskiing, cruising, vacationing, relaxing on the water, sunning, and a host of other activities. Runabouts are commonly used for waterskiing, tubing, and wakeboarding. Larger cruisers and yachts can be used for extended trips because they may be equipped with cabins for cooking and sleeping. Fishing boats can vary in size depending on whether they are used for offshore sport fishing or local lake fishing. Other boats, such as personal water craft, sailboats, canoes, and rowboats can be used for cruising along the water.

According to the National Marine Manufacturers Association (NMMA), there are currently close to 70 million people participating in recreational boating. In the late 1990s, this figure was closer to 80 million, but the recent economic downturn has led consumers to engage in fewer leisure activities. From Table 2.1-3, we can see that outboard boats are the most common boat type, followed further behind by inboard and sterndrive boats. The number of inboards and sterndrives owned in the U.S. are roughly equivalent over the 1997 to 2001 time period.

Table 2.1-3
Recreational Boating Population Estimates (10^3)*, 1997 - 2001 [21,22]

	1997	1998	1999	2000	2001
People participating in recreational boating	78,406	74,847	73,208	72,269	69,486
All boats in use	16,230	16,824	16,790	16,991	16,999
Outboard boats owned	8,125	8,300	8,211	8,288	8,342
Inboard boats owned	1,587	1,609	1,635	1,660	1,678
Sterndrive boats owned	1,582	1,673	1,665	1,709	1,743
Personal water craft	1,000	1,100	1,096	1,078	1,631

* These in-use figures are based on the actual state and Coast Guard registrations. Population estimates are rounded to the nearest thousandths.

The type of boat purchased by a consumer and the type of engine it is equipped with are affected by the recreational activity the consumer plans to engage in, the size of the boat being purchased, and other consumer preferences. For example, if a larger inboard cruiser is selected for purchase, the consumer will likely opt for a diesel engine. Diesel engines are, in general, more expensive, but have a longer life span than gasoline engines. In addition, diesel engines are available at much higher power ratings. However, if the consumer prefers a smaller fishing boat with an outboard engine configuration, it will be equipped with a gasoline engine.

Generally speaking, recreational boats are considered final goods while the engines that power them are intermediate goods. As discussed in Section 2.1.1.4, boat builders purchase engines from distribution centers and then use these engines as inputs to the production of boats. Boat builders may provide their own engine designs to engine manufacturers so that the engines will properly fit into the boat builders' specific models.

2.1.2.2 Substitution Possibilities

Consumers can substitute across different boat types but may be limited by the water-related activities they want to engage in. Runabouts and cruisers are available in different engine configurations and different engine types. Consumers will first evaluate the purpose for which they'd like to buy a boat and will then consider the various types of boats that will suit their preferences. If consumers choose to purchase either sterndrive or inboard boats, they have both diesel and gasoline engines available to them. Outboards, on the other hand, are only available with gasoline engines.

Consumers may be interested in engaging in water-related activities, but may instead consider purchasing non-motorized boats. For example, consumers who are like to float out on the water or engage in lake fishing may choose to purchase a sailboat, row boat, or canoe. These non-motorized boating options do not allow the consumer to participate in the same set of water-related activities as would the purchase of a motorized boat, but they may be considered substitutes for less intensive water-related past times.

2.1.3 Industry Organization

It is important to gain an understanding of how the recreational marine vessel and CI marine engine industries may be affected by the emissions control program. One way to determine how increased costs might affect the market is to examine the organization of each industry. This section provides data to measure the competitive nature of the boat building and marine engine industries and lists the manufacturers of recreational boats, marine engines, and marine fuel tanks.

2.1.3.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in production. This condition is most likely to hold if the industry has a large number of buyers and sellers, the products sold and inputs used are homogeneous, and entry and exit of firms is unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firm is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and Herfindahl-Hirschman indices (HHI) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the six digit NAICS code level for the year 1997, the most recent year available. Tables 2.1-4 and 2.1-5 provide the four- and eight-firm concentration ratios (CR4 and CR8, respectively) and the Herfindahl-Hirschman indices for the other engine equipment manufacturing and boat building industries (the other engine equipment manufacturing industry includes manufacturers of marine engines). These industries are represented by NAICS codes 333618 and 336612, respectively. Concentration ratios are provided in percentage terms while HHI are based on a scale formulated by the Department of Justice.

Table 2.1-4
Measures of Market Concentration for the NAICS Code that Includes Recreational Boat Engine Manufacturers, 1997 [23]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 333618	55.8	76.0	1019.1	$19,011.09	245

Table 2.1-5
Measures of Market Concentration for the NAICS Code that Includes Recreational Boat Manufacturers, 1997 [24]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 336612	41.4	48.9	644.5	$5,607.30	984

The criteria for evaluating the HHI are based on the 1992 Department of Justice Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries have more ability to influence market prices. Based on these criteria, the marine vessel industry can be modeled as perfectly competitive for the purposes of the economic impact analysis. The other engine equipment manufacturing industry is slightly more concentrated, with higher CRs and an HHI value just over 1,000. However, it is reasonable to assume that the marine engine manufacturing industry is perfectly competitive for the economic analysis.

2.1.3.2 CI Marine Engine and Recreational Boat Manufacturers

We have determined that there are at least 16 companies that manufacture CI marine engines for recreational vessels. Nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to three large companies. Six of the identified companies are considered small businesses as defined by the Small Business Administration SBA) size standard for NAICS code 333618 (less than 1000 employees). Based on sales estimates for 2000, these six companies represent less than 5 percent of recreational marine diesel engine sales. Table 2.1-6 provides a list of the diesel engine manufacturers identified to date by EPA.

Table 2.1-6
Annual Sales for Recreational Diesel Marine Engine Manufacturers Identified by EPA, 2000/2001 [25,26,27]

Companies with greater than 1,000 employees	Annual Sales[a] ($$10^6$)	Companies with less than 1,000 employees	Annual Sales[a] ($$10^6$)
Caterpillar, Inc. (Engines Div.)[b]	**$2,176.0**	Alaska Diesel Electric/Lugger	$9.2
Cummins Engine Company, Inc.	**$6,600.0**	American Diesel Corporation	$5.0
Detroit Diesel Engines	**$2,358.7**	Daytona Marine	$2.9
Isotta Fraschini	NA[c]	Marine Power, Inc.	$7.0
Deere & Company	$13,137.0	Peninsular Diesel Engines, Inc.	NA[c]
Marine Corporation of America	NA[c]	Westerbeke Corporation	$29.1
Mercruiser	$68.6		
MTU Aero Engine Components	$7.9		
Volvo Penta	$275.0		
Yanmar Diesel America Corporation	$18.9		

[a] Annual sales of listed companies include revenues received from the sale of all products sold by these companies, not just revenues received from the sales of diesel marine engines.
[b] Companies in **bold** dominate the diesel engine market for recreational vehicles.
[c] NA means Not Available.

Less precise information is available about recreational boat builders than is available about engine manufacturers. Several sources were used, including trade associations, business directories, and Internet sites when identifying entities that build and/or sell recreational boats. We have also worked with an independent contractor to assist in the characterization of this segment of the industry. Finally, we have also obtained a list of nearly 1,700 boat builders known to the U.S. Coast Guard to produce boats using recreational gasoline and diesel engines. At least 1,200 of these companies install gasoline-fueled engines and would therefore be subject to the proposed evaporative emission standards. More that 90 percent of the companies identified to date would be considered small businesses as defined by SBA size standards for NAICS code 336612 (less than 500 employees). Table 2.1-7 provides a sample of recreational boat manufacturers known to EPA.

Table 2.1-7
Annual Sales and Employment for a Sample of Recreational Boat Manufacturers Identified by EPA, 2000/2001 [28,29,30]

Company	Annual Sales[a] ($$10^6$)	Employment
Bayliner Marine Corporation	$450.0	2,500
Beneteau USA Limited	$1.7	10
Boston Whaler, Inc.	$6.0	600
Brunswick Marine Group	$483.0	2,900
Carver Boat Corporation	$149.8	1,300
Catalina Yachts	$35.0	250
Correct Craft, Inc.	$35.0	250
Crestliner, Inc.	$50.0	350
Fiberglass Unlimited	$1.0	16
Fountain Powerboats, Inc.	$57.5	390
Four Winns, Inc. LLC	$46.6	500
Genmar Industries	$869.0	6,500
Glastron Boats	$58.0	650
Godfrey Marine	$51.4	550
Grady-White Boats, Inc.	$55.0	500
Hood Yacht Systems	NA[b]	NA[b]
Lowe Boats	$43.8	380
Lund Boat Company	$60.4	525
Magnum Marine Corporation	$6.9	60
Mariah Boats, Inc.	$31.7	275
MasterCraft Boat Company	$87.0	500
Morgan Marine	$37.1	400
Ocean Yachts, Inc.	$14.6	150
Old Town Canoe Company	$11.5	100
Palmer Johnson, Inc.	$23.0	200
Porta-Bote International	$3.6	32
Regal Marine Industries, Inc.	$85.0	700
S2 Yachts, Inc.	$78.0	600
Sabre Corporation	$18.4	160
Sea Ark Boats, Inc.	$6.0	100
Seaswirl Boats, Inc.	$28.8	250
Skeeter Boats, Inc.	$45.0	200
Smoker-Craft Boats, Inc.	$52.0	400
Sport-Craft Boats, Inc.	$23.0	200
Sunbird Boat Company, Inc.	$28.8	250
Tracker Marine, LLP	$57.0	2,400

[a] Annual sales of listed companies include revenues received from the sale of all products sold by these companies, not just revenues received from the sales of recreational boats.
[b] NA means Not Available.

2.1.4 Markets

This section examines select historical market statistics for inboard and sterndrive boats and engines. It presents domestic quantities, values, and unit prices for both boat types as well as shipment data for inboard and sterndrive engines. Also presented are quantities and values of exports and imports of both inboard and sterndrive boats and engines. The section concludes with the current trends of the marine industry. EPA focuses on these two boat configurations because they are available with diesel engines.

2.1.4.1 Quantity and Price Data

Quantities of shipments produced domestically, real values of shipments, and unit price data are presented in Tables 2.1-8 through 2.1-10 for inboard runabouts, inboard cruisers, and sterndrive boats equipped with SI and CI engines (disaggregated data were not available by engine type). Real unit price data are calculated by simply dividing real value of shipments by the quantity of shipments produced. Also provided are domestic shipment data for inboard and sterndrive engines in Table 2.1-11 (price data were not available). While a fraction of inboard boats are equipped with diesel engines (approximately 18 percent), recall that only 1 to 2 percent of sterndrive boats contain diesel engines and that sterndrives with diesel engines are more expensive than those operating with SI engines. Also note that virtually all diesel engines in inboard boats are placed in cruisers. Only 1 to 2 percent of inboard runabouts contain CI engines. Because these three boat categories may contain diesel engines, their market data are discussed here.

An overall examination of the data for all three boat types shows that the quantity of shipments, real value of shipments, and real unit values all increased over the 1980 to 2000 time period. Comparing across these boat types shows that the average annual growth rates are highest for quantities and shipment values for inboard runabouts (9.5 percent for the quantity of shipments and close to 12 percent for the real value of shipments). The average growth rates for these same variables are lowest for sterndrive boats (the quantity of shipments grew at an average annual rate of under 4 percent and the average annual growth rate for the value of shipments was 5 percent). Also notable is that the unit price of inboard runabouts increased, on average, at a lower rate than for inboard cruisers and sterndrives. Though the average annual growth rates are positive across the variables presented, there is definite evidence of dips in the quantity of shipments and real value of shipments for inboard cruisers, and in all three variables for sterndrive boats. These trends are not existent for inboard runabouts. Before examining the historical data presented for inboard cruisers and sterndrives, a closer examination at inboard runabouts is warranted.

Table 2.1-8
Recreational Inboard Runabout Boats - Domestic Quantity of Shipments, Value of Shipments, and Unit Values, 1980 - 2000 (1996$) [31,32]

Year	Quantity of Shipments (units)	Real Value of Shipments ($$10^3$)	Real Unit Value ($)
1980	2,900	$52,226	$18,009
1981	2,950	$55,860	$18,935
1982	3,200	$63,030	$19,697
1983	3,900	$71,217	$18,261
1984	4,500	$84,727	$18,828
1985	4,500	$92,238	$20,497
1986	5,300	$113,964	$21,503
1987	6,600	$137,669	$20,859
1988	7,400	$163,263	$22,063
1989	9,100	$215,846	$23,719
1990	7,500	$152,414	$20,322
1991	6,200	$129,380	$20,868
1992	6,400	$126,358	$19,743
1993	6,800	$141,809	$20,854
1994	7,200	$148,725	$20,656
1995	6,900	$150,673	$21,837
1996	6,000	$126,234	$21,039
1997	6,100	$133,733	$21,923
1998	6,900	$155,707	$22,566
1999	12,100	$293,742	$24,276
2000	13,600	$342,465	$25,181
Avg. Annual Growth Rate	9.5%	11.9%	1.9%

Of the three boat types presented here, domestic shipments and the real value of domestic shipments grew at a higher annual rate, on average, for inboard runabouts. In 1980, just under 3,000 inboard runabouts were being manufactured and distributed in the U.S. The real value of these boats (in 1996 dollars) was over $52 million, with the average inboard runabout equal to a real value of $18,000. By 1990, both the quantity of shipments and the real value of shipments more than doubled. Unit prices increased, but only by 12 percent. In 2000, quantity of shipments, shipment values, and unit values hit their peak. U.S. shipments of inboard runabouts were equal to 13,600, real value of shipments equaled over $342 million, and the real value was just over $25,000.

Table 2.1-9
Recreational Inboard Cruiser Boats - Domestic Quantity of Shipments, Value of Shipments, and Unit Values, 1980 - 2000 (1996$) [33,34]

Year	Quantity of Shipments (units)	Real Value of Shipments ($$10^3$)	Real Unit Value ($)
1980	5,300	$802,253	$151,368
1981	5,450	$861,890	$158,145
1982	5,125	$854,167	$166,667
1983	7,485	$1,060,700	$141,710
1984	10,780	$1,604,094	$148,803
1985	12,200	$1,811,865	$148,514
1986	12,700	$1,894,840	$149,200
1987	13,100	$2,135,718	$163,032
1988	13,500	$2,355,750	$174,500
1989	12,300	$2,299,952	$186,988
1990	7,500	$1,589,672	$211,956
1991	3,600	$742,680	$206,300
1992	3,550	$675,032	$190,150
1993	3,375	$696,830	$206,468
1994	4,200	$927,793	$220,903
1995	5,460	$1,193,367	$218,565
1996	5,350	$1,215,268	$227,153
1997	6,300	$1,636,375	$259,742
1998	6,600	$1,631,720	$247,230
1999	7,000	$1,713,733	$244,819
2000	8,000	$2,123,768	$265,471
Avg. Annual Growth Rate	5.0%	7.9%	3.1%

Inboard cruisers are larger boats and hence have higher value of shipments and average unit value measures. An examination of Table 2.1-9 shows that this market has grown over the 1980 to 2000 time period. Evidence of growth in this market can be seen by examining the average annual growth rates. The real average price of an inboard cruiser was equal to slightly more than $151,000 in 1980, but by the year 2000, prices reached a peak of $265,471 (a net price increase of 75 percent). Real shipment values also showed a large increase starting at $802 million in 1980 and rising to over $2.1 billion in 2000. The reason for the large price increase is evident because the rise in the quantity of shipments from 1980 to 2000 was not as dramatic as the rise in the real value of shipments. The net increase in the quantity of shipments for the 1980 to 2000 time period was 50 percent.

During the mid to late 1980s, the quantity and real shipment values of inboard cruisers steadily increased to reach their peak. In 1983, 7,485 inboard cruisers were manufactured with a total real value of $1.6 billion. By 1988, shipments rose to 13,500 and the real value of shipments exceeded $2.35 billion. The average value of this boat type in this same year was $174,500. This surge in the market for inboard cruisers was followed by a large decline in the quantities and values of shipments. By 1993, the domestic quantity of inboard cruisers fell to its lowest level at 3,375 and real value of shipments was close to its lowest level at just under $700 million.

Table 2.1-10
Recreational Sterndrive Boats - Domestic Quantity of Shipments, Value of Shipments, and Unit Values, 1980 - 2000 (1996$) [35,36]

Year	Quantity of Shipments (units)	Real Value of Shipments ($$10^3$)	Real Unit Value ($)
1980	56,000	$1,080,702	$19,298
1981	51,000	$1,052,492	$20,637
1982	55,000	$1,039,167	$18,894
1983	79,000	$1,412,841	$17,884
1984	108,000	$2,031,008	$18,806
1985	115,000	$2,247,784	$19,546
1986	120,000	$2,481,280	$20,677
1987	144,000	$3,141,231	$21,814
1988	148,000	$3,230,840	$21,830
1989	133,000	$2,836,265	$21,325
1990	97,000	$2,062,421	$21,262
1991	73,000	$1,436,559	$20,553
1992	75,000	$1,347,147	$19,251
1993	75,000	$1,322,872	$17,580
1994	90,000	$1,738,313	$17,271
1995	93,000	$1,827,867	$18,920
1996	64,500	$1,925,248	$19,138
1997	92,000	$2,027,969	$29,264
1998	91,000	$2,046,755	$21,829
1999	79,600	$1,956,644	$22,063
2000	78,400	$2,106,395	$24,122
Avg. Annual Growth Rate	3.7%	5.0%	2.0%

The annual domestic quantities of sterndrive boat shipments far exceed the quantities of inboard runabouts and inboard cruisers combined. They are mostly equipped with gasoline engines and are in a similar price range as inboard runabouts. A closer examination of Table 2.1-10 shows that this market peaked and dipped during the same years as the inboard cruiser market. This general expansion of the market for recreational boats in the late 80s was due to higher economic growth for the U.S. In 1988, shipments of sterndrives were equal to 148,000 (an 87 percent increase over the year 1983 quantity) and shipment values were equal to over $3.2 billion (a 128 percent increase in the real shipment value in 1983). Also notable is that though unit values of sterndrives are far less than those for inboard cruisers, the real value of shipments are very close for these boat types (approximately $2.1 billion in the year 2000). The value of the market for inboard runabouts is far smaller at a value of $342 million in 2000.

Table 2.1-11 below provides the quantity of shipments of inboard and sterndrive engines combined. These data also combine gasoline and diesel engines. What is clear from this table is that the shipment quantities tend to reflect the peaks and dips seen in the data for sterndrives and inboard cruisers. Domestic engine shipments rose to their highest value in 1988 at a total of 211,900. They then fell over the remainder of the 1980s and early 1990s to quantities in the low 90 thousands. In the mid 1990s there was a slight rise in engine shipments to a total of 120,000 but in the year 2000, the quantity fell to just over 105,000.

Table 2.1-11
U.S. Shipments of Inboard and Sterndrive Engines, 1980 - 2001 [37]

Year	Quantity of Shipments	Year	Quantity of Shipments
1980	87,750	1991	92,400
1981	81,500	1992	94,600
1982	85,650	1993	94,700
1983	104,125	1994	114,000
1984	148,000	1995	120,000
1985	155,000	1996	120,000
1986	161,900	1997	116,100
1987	210,800	1998	104,500
1988	211,900	1999	108,500
1989	190,700	2000	110,400
1990	134,100	2001	105,800

2.1.4.2 Foreign Trade

Tables 2.1-12 and 2.1-13 present trade data for inboard and sterndrive boats. Over the 1992 to 2000 time frame, import values of these boat types grew. A large increase in the value of inboard cruiser imports was evident from 1999 to 2000. Though they initially are larger, export values for these boat types do not show the same rising trend. For both boat types, export values dipped in the early 1990s and then steadily rose through the remainder of the decade. Inboard export value never recovered to its 1992 level, but sterndrive exports did. In fact, the 2000 value of sterndrive exports exceeded its value in 1992.

Further comparisons can be made between exports and imports of each boat type. As the data in these tables show, inboard import values exceeded their export values during the latter half of the 1990s. This was not always the case, as prior to 1996, export values were greater. In 1992, the value of inboard imports was only equal to 16 percent of the value of exports but by 1995, they caught up to exports and equaled 92 percent of inboard export values. In 2000, inboard exports were equal to a fraction of their imports (37 percent).

Table 2.1-12
Import Values[a] ($\$10^3$) of Inboard and Sterndrive Boats, 1992 - 2000 [38,39]

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Inboard Runabouts	8,957	16,781	21,069	56,199	135,800	221,497	301,226	348,107	303,910
Inboard Cruisers[b]	32,859	87,997	113,858	143,620	142,007	90,184	113,173	151,170	220,214
Inboards Total	41,816	104,778	134,927	199,819	277,807	311,681	414,399	499,277	524,124
Sterndrive Runabouts	10,900	7,965	9,479	15,224	12,090	11,637	22,494	27,894	30,139
Sterndrive Cruisers[c]	10,976	10,302	18,042	14,779	15,955	15,414	42,599	53,653	70,725
Sterndrives Total	21,876	18,267	27,521	30,003	28,045	27,051	65,093	81,547	100,864

[a] Import values are in nominal U.S. dollars.
[b] Data for inboard cruisers are for those over 24 feet in length.
[c] Data for sterndrive cruisers are for those over 20 feet in length.

Table 2.1-13
U.S. Export Values* ($\$10^3$) of Inboard and Sterndrive Boats, 1992 - 2000 [40,41]

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Inboards	261,474	184,673	163,284	217,443	189,825	222,976	213,111	197,260	198,257
Sterndrives	189,463	127,382	135,229	186,230	191,327	199,364	198,675	236,326	198,349

* Export values are in nominal U.S. dollars.

In the case of sterndrives, import values remained below the value of sterndrive exports over the 1992 to 2000 time period. In 1992, imports were equal to approximately 12 percent of export values. The value of imports did approach exports through the decade and by 2000, they were equal to about 50 percent of the value of exports. What is notable is a large jump in the value of sterndrive import values between the years 1997 and 1998. Imports rose from approximately $27 million to over $65 million in the span of this year. Sterndrive export values generally increased through the year 1999 when they hit their peak at $236 million, however in the year 2000, they fell to just below $200 million. Still, export values for sterndrives were twice the value of their imports in this year.

Tables 2.1-14 and 2.1-15 present foreign trade data for inboard diesel and sterndrive engines. Import data for inboard diesel engines were disaggregated by varying ranges of horsepower (ranging from less than 150 to over 1000 horsepower) while inboard export data are only available for diesel engines below 200 horsepower. Sterndrive engine data were not available in disaggregated form. An examination of Table 2.1-14 shows that the total import value of inboard diesel engines declined and rose over the 1990s. In the early part of the 1990s, imports of inboard diesel engines steadily declined in value, but then rose dramatically in 1995. This anomalous year was followed by a decline in import value which remained relatively constant until it again rose in 2000. For sterndrive engines, import values grew dramatically in the beginning of the 1990s as well. They then dipped during the mid 1990s only to rise again at the end of the decade to its highest value.

Though Table 2.1-14 only provides inboard import data for diesels, it is clear that the value of these engine imports exceed the value of sterndrive engine imports. We can infer that fewer sterndrive engines were imported relative to inboard engines. Note however, that inboard engines may also be used for boats with sterndrive engine configurations, which may partially explain why the import values for inboard engines are much higher.

Export data for the various types of inboard diesel engines were not available, therefore we are unable to make direct comparisons across the total import and export values of these engines. Some comparison can be made between the import values of inboard diesel engines below or equal to 150 horsepower and export values of inboard diesel engines under 200 horsepower since these generally refer to the same set of engines. A comparison of the these values shows roughly equal values of imports and exports of this engine type in the 1990s. Overall, export values are slightly higher. Sterndrive engine import and export values can be directly compared as these measures represent all foreign trade of this engine type to and from the U.S. From these tables, we can see that export values of sterndrive engines far exceeded import values in the beginning of the 1990s. However the value of imports for this engine type approached its export value by 1995. For the latter half of the 1990s, export values remained higher but the difference between export and import values remained smaller.

Table 2.1-14
U.S. Import Values* ($\$10^3$) of Inboard Diesel Engines and Sterndrive Engines, 1992 - 2000 [42,43]

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Inboard Diesels									
≤ 150HP	17,270	14,230	10,104	8,765	10,050	6,933	9,244	13,992	15,084
150-199HP	4,901	4,983	5,384	5,539	5,701	7,915	6,528	6,114	6,916
200-312HP	9,035	9,805	9,153	10,721	7,102	8,851	10,355	13,032	8,756
313-499HP	4,910	4,288	7,625	7,796	7,634	9,624	15,609	21,332	38,506
500-999HP	5,365	5,994	8,418	14,257	15,174	13,494	9,808	10,836	12,725
≥ 1000HP	72,606	40,611	18,577	24,680	39,965	31,486	33,777	29,002	43,698
Inboard Total	114,087	79,911	59,261	293,878	85,626	78,303	85,321	94,308	125,685
Sterndrive Engines									
Total	3,221	5,947	19,045	25,401	21,586	15,457	17,525	25,434	43,489

* Import values are in nominal U.S. dollars.

Table 2.1-15
U.S. Export Values* ($\$10^3$) of Diesel Inboard Engines Under 200 HP and Sterndrive Engines, 1992 - 2000 [44,45]

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Inboard Engines	11,174	11,332	8,962	15,263	13,976	20,201	18,665	19,123	23,543
Sterndrive Engines	25,186	24,164	25,024	28,386	26,980	23,734	17,089	24,430	30,427

* Export values are in nominal U.S. dollars.

2.2 Large SI Engines and Industrial Equipment

This section gives a general characterization of the Large SI industry. Large SI engines are nonroad spark-ignition engines that have rated power higher than 25 horsepower (19 kW) and that are not recreational engines or marine propulsion engines. They are typically derivatives of automotive engines, but use less advanced technology and operate on LPG and CNG as well as gasoline. Large SI engines are used in a wide variety of commercial uses. Because it is not practical to present detailed information on all of these applications in this section, we focus primarily on forklifts. This is reasonable because they are the dominant application for Large SI engines. Also, as explained in greater detail in Section 9.7 of Chapter 9, the detailed economic impact analysis performed for this sector focuses on forklifts. Other information presented in this section describes some general characteristics of the Large SI sector.

2.2.1 The Supply Side

This section provides a description of the types of industrial equipment that may contain Large SI engines, the major inputs used to manufacture this equipment, and the costs of production.

2.2.1.1 Product Types and Populations

Large SI engines are used in a wide variety of applications, including forklifts, generators, pumps, leaf blowers, sprayers, compressors, other material handling equipment, and agricultural production. Table 6.2.2-1 in Chapter 6 presents our estimates of the 2000 U.S. population of the various Large SI equipment applications. We estimated populations of engine and equipment models using historical sales information adjusted according to survival and scrappage rates.

A 1996 study of the forklift market estimated that there were 491,321 engine-powered forklifts in use in the United States in 1996 (Classes 4, 5, and 6; see below for an explanation of these classes).[46] That study estimated that 80 percent of this population used LPG (commonly referred to as propane because propane is its primary constituent), with the rest running on either gasoline or diesel fuel. If that 20 percent of that population are split evenly between gasoline and diesel fuels, as we estimate, this means that the number of spark-ignition forklifts in 1996 was about 442,000, or that about 90 percent of all forklifts were spark-ignition. As noted in Table 6.2.2.1, we estimate that about 95 percent of those spark-ignition forklifts are run LPG or CNG, with the rest being run on gasoline. The high percentage of propane systems for forklifts can be largely attributed to expenses related to maintaining fuel supplies. LPG cylinders can be readily exchanged with minimal infrastructure cost. Installing and maintaining underground tanks for storing gasoline has always been a significant expense, which has become increasingly costly due to the new requirements for replacing underground tanks.

With regard to non-forklift applications, the split between LPG and gasoline is not as clear. Large SI engines today are typically sold without fuel systems, which makes it difficult to assess the distribution of engine sales by fuel type. Also, engines are often retrofitted for a different fuel after the initial sale, making it still more difficult to estimate the prevalence of the different fuels. Natural gas, a third option, is less common in Large SI engines even though natural gas and LPG fuel systems are very similar. Natural gas supply systems typically offer the advantage of pipeline service, but the cost of installing high-pressure refueling equipment is an obstacle to increased use of natural gas. Table 6.6.2.1 contains our estimates of the use of LPG and CNG for non-forklift applications; the rest are estimated to use gasoline. We estimate 100 percent LPG/CNG use for oil field equipment, gas compressors, and refrigeration/AC. For construction, general industrial, and other nonroad equipment, there may be a mix of central and noncentral fueling; we therefore believe that estimating an even mix of LPG and gasoline for these engines is most appropriate.

We estimate very low or no LPG/CNG use for agricultural and lawncare equipment. Lawn and garden equipment is usually not centrally fueled and therefore operates almost exclusively on gasoline, which is more readily available. Agriculture equipment is predominantly powered by diesel engines. Most agriculture operators have storage tanks for diesel fuel. Those who use spark-ignition engines in addition to, or instead of, the diesel models, would likely invest in gasoline storage tanks as well, resulting in little or no use of LPG or natural gas for those applications. An estimated distribution of fuel types for the individual applications are listed in Table 6.2.2-1.

Large SI engines also vary considerably by size. Most of these engines are smaller than 100 horsepower, with the lower limit of the engine category at 25 horsepower. On an annual sales basis, 34 percent of Large SI engines are less than 50 horsepower, and 80 percent are less than 100 horsepower. Only about 20 percent are larger than 100 horsepower, with the largest about 250 horsepower.

2.2.1.2 Engine Design and Operation

Most engines operate at a wide variety of speeds and loads, such that operation at rated power (full-speed and full-load) is rare. To take into account the effect of operating at idle and partial load conditions, a load factor indicates the degree to which average engine operation is scaled back from full power. For example, at a 0.3 (or 30 percent) load factor, an engine rated at 100 hp would be producing an average of 30 hp over the course of normal operation. For many nonroad applications, this can vary widely (and quickly) between 0 and 100 percent of full power. Table 6.2.2-1 shows the load factors that apply to each nonroad equipment application.

Table 6.2.2-1 also shows annual operating hours that apply to the various applications. These figures represent the operating levels that apply through the median lifetime of equipment.

2.2.1.3 Liquid-Cooled , Automotive-Derived Engines

The majority of Large SI engines are industrial versions of automotive engines and are liquid-cooled. However, in the absence of emission standards there has been only limited transfer of emission-control technology from automotive to industrial engines, and most of these are equipped with only very basic emission control technology if any.

Producing an industrial version of an automotive engine typically involves fitting a common engine block with less expensive systems and components appropriate for nonroad use. Manufacturers remove most of the sophisticated systems in place for the high-performance, low-emission automotive engines to be able to produce the industrial engine at a lower cost. For example, while cars have used electronic fuel systems for many years, almost all industrial Large SI engines still rely on mechanical fuel systems. Chapter 3 describes the baseline and projected engine technologies in greater detail.

2.2.1.4 Air-Cooled Engines

Some manufacturers produce Large SI engines exclusively for industrial use. Most of these are air-cooled. Air-cooled engines with less than one liter total displacement are typically very similar to the engines used in lawn and garden applications. Total sales of air-cooled engines over one liter have been about 9,000 per year, 85 percent of which are rated under 50 hp. While these engines can use the same emission-control technologies as water-cooled engines, they have unique constraints on how well they control emissions. Air-cooling doesn’t cool the engine block as uniformly as water-cooling. This uneven heating can lead to cylinder-to-cylinder variations that make it difficult to optimize fuel and air intake variables consistently. Uneven heating can also distort cylinders to the point that piston rings don’t consistently seal the combustion chamber. Finally, the limited cooling capacity requires that air-cooled engines stay at fuel-rich conditions when operating near full power.

While air-cooled engines account for about 9 percent of Large SI engine sales, their use is concentrated in a few specialized applications. Almost all of these are portable (non-motive) applications with engine operation at constant speeds (the speed setting may be adjustable, but operation at any given time is at a single speed). Many applications, such as concrete saws and chippers, expose the engine to high concentrations of ambient particles that may reduce an engine’s lifetime. These particles could also form deposits on radiators, making water-cooling less effective.

2.2.1.5 Forklift Truck Manufacturing

As noted above, forklifts are the most common application of Large SI engines. Forklifts are self-propelled trucks equipped with platforms that can be raised and lowered. These trucks are used for lifting, stacking, retrieving, and transporting materials and are typically powered by either LPG, gasoline, diesel, or an electric motor. It is estimated that 80 percent of the forklift trucks in these classes operate on LPG.[47] The industry classifies forklifts in six categories, and the types of forklifts with Large SI engines are those classified as Class 4, 5, and 6. They represent those forklift truck classes that may be affected by the emissions control program. Descriptions of Class 4, 5, and 6 forklifts are as follows[48]:

- **Class 4**. Internal Combustion (IC) Engine Trucks - fork, counterbalanced, cushion tire, rider trucks;
- **Class 5**. IC Engine Trucks - fork, counterbalanced, pneumatic tire, rider trucks; and
- **Class 6**. Electric and IC Engine Tractors - sit down rider, draw bar pull.

The major difference between Class 4 and Class 5 forklifts is the type of tire installed. Pneumatic tires allow forklift trucks to be operated on varied terrain, while cushion tires are more suitable for flat floor surfaces. All of these forklifts allow for the operator to sit down, thus reducing operator fatigue or strain. Generally speaking, forklifts may differ in their design, maximum lift capacity, location of the lift operator, type of tires installed, and by the type of fuel used.

The costs of producing forklift trucks fall into three major categories: capital expenditures, labor costs, and the costs of materials. Capital expenditures include the manufacturer's costs of equipment and its installation; labor costs include the producer's costs associated with employees wages and benefits; and the costs of materials are the costs of tangible and intangible inputs such as internal combustion (IC) engines, steel for the truck frame, tires, rubber hosing and belting, counterbalances, and energy. Table 2.2-1 shows the historical production costs for the industrial truck, tractor, trailer, and stacker machinery manufacturing industry which includes forklift manufacturers. This industry is identified by Standard Industrial Code (SIC) 3537 and the North American Industrial Classification System (NAICS) Code 333924.

U.S. Department of Commerce statistics, set out in Table 2.2-1, show that the average value of shipments (VOS) for this industry over the 1992 to 1999 time period is equal to approximately $4.7 billion, with the highest value of shipments occurring in 1998. The cost of materials for this industry is equal to an average of almost $3 billion (64 percent of VOS). The average cost of labor is approximately $746 million (16 percent of VOS), while capital expenditures are equal to an average value of $93 million (2 percent of VOS). Examination of this data clearly shows that capital expenditures represent the smallest share of the value of shipments while the cost of materials represents the largest share.

Table 2.2-1
Value of Shipments (VOS) and Production Costs for the SIC and NAICS Codes that Include Forklift Manufacturers*, 1992 - 1999 [49,50,51,52,53,54,55]

		VOS	Payroll		Cost of Materials		Total Capital Expenditures	
Year	Industry Code	($\$10^6$)	($\$10^6$)	% of VOS	($\$10^6$)	% of VOS	($\$10^6$)	% of VOS
1992	SIC 3537	$2,754	$499	18%	$1,701	62%	$58	2%
1993	SIC 3537	$3,200	$592	19%	$1,984	62%	$43	1%
1994	SIC 3537	$4,054	$628	15%	$2,700	67%	$71	2%
1995	SIC 3537	$4,970	$723	15%	$3,251	65%	$94	2%
1996	SIC 3537	$4,866	$742	15%	$3,076	63%	$107	2%
1997	NAICS 333924	$5,538	$894	16%	$3,612	65%	$140	3%
1998	NAICS 333924	$6,248	$944	15%	$4,112	66%	$104	2%
1999	NAICS 333924	$5,597	$942	17%	$3,429	61%	$127	2%
	Average	$4,653	$746	16%	$2,983	64%	$93	2%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars.

2.2.2 The Demand Side

This section provides information about the uses and consumers of Large SI engines and forklift trucks. The various industrial sectors in which forklifts are used and the substitute products for forklifts are also discussed.

Generally speaking, industrial SI equipment is considered a final good while Large SI engines are referred to as intermediate goods. This is because the engines are manufactured to be used as inputs to the production of industrial SI equipment. Consumers in the marketplace demand industrial equipment which may contain Large SI engines, therefore their demand for Large SI engines is derived from their demand for industrial equipment.

Manufacturers of industrial equipment have three options to obtain the SI engines they use for equipment production. Their first options is to produce the SI engines used in their final products. The second option is to purchase a partially finished engine and add on the fuel system and perform the engine calibration in-house. The third options is to purchase a completed engine and “drop” it in their equipment without modification. When equipment companies purchase Large SI engines as an input to their production, they are considered the immediate consumers of Large SI engines. However, if equipment manufacturers choose to produce Large SI engines as inputs for their production of equipment, they have vertically integrated the production of a vital input, SI engines, into their overall production process. Though they consume the engines in the production of industrial equipment, they are, in this case, the suppliers of these engines via the final product.

In the case of forklifts, engines are commonly purchased from outside companies. However, the design and assembly of these engines may be completed in-house (i.e., adding the fuel system and calibrating the engine). Sometimes the forklift manufacturer is the designer of the engines, but in other cases, the forklift manufacturer may rely on its parent company to work on engine design while it focuses exclusively on forklift production. This secondary arrangement is common in large companies which may contain a subsidiary producer of forklift trucks. Because engine designs may be specific, contractual arrangements may be made between engine manufacturers and forklift producers so as to keep the supply of engines consistent.

2.2.2.1 Uses of Forklifts

The main function of forklift trucks is to lift and transport materials. Class 4, 5, and 6 forklifts are used in indoor settings, such as warehouses and stock rooms or in some outdoor settings. Table 2.2-2 shows the population of forklift trucks by industry sector for the year 1995, the most recent year for which industry data is available. The manufacturing sector uses the largest share of forklifts followed next by wholesale trade. Together, these two industry sectors accounted for over 60 percent of the U.S. total forklift population in 1995. This estimate is based on industry shipments and allows for scrappage of older units.

Table 2.2-2
1995 Class 4, 5, and 6 Forklift Population by Industry Sector[56]

Industry Sector	Population	Percent Share (%)
Manufacturing	196,985	40.3%
Wholesale Trade	100,721	20.6%
Transportation, Communication, and Utilities	68,785	14.1%
Services	46,675	9.5%
Retail Trade	32,919	6.7%
Construction	29,497	6.0%
Other	13,757	2.8%
Total	489,339	100%

2.2.2.2 Substitution Possibilities for Forklifts

The most common substitute for Class 4, 5, and 6 IC engine forklifts are electric motor forklifts, which fall into Classes 1, 2, and 3. Descriptions of these forklifts are as follows[57]:

- **Class 1**. Electric Motor Rider Trucks;
- **Class 2**. Electric Motor Narrow Isle Trucks; and

- **Class 3**. Electric Motor Hand Trucks.

Electric-powered forklifts are also used for lifting, transporting, and stacking of materials, but they differ in design and lift capacity from Class 4, 5, and 6 lift trucks. Design differences may lead a consumer to choose one type of forklift over another. For example, narrow isle trucks are commonly found in warehouses that are designed to use less floor space and rely more on vertical stacking. Rider-type forklift trucks are used when significant amounts of material must be moved or where operator fatigue may be an issue. Hand trucks are used for lighter loads and are operated using a handle.[58] Generally, electric forklifts have lower material-handing capacity.

One advantage of Class 1, 2, and 3 forklifts is that they do not produce exhaust fumes while in operation, thus making them well suited to indoor operations. However, electric forklifts rely on batteries that must be recharged which may lead to times where forklifts are not available. Changing out spent batteries to reduce recharge time is not generally practical because these batteries are expensive (as much as $10,000 or more each) and can weigh 1,000 lbs. While electric forklifts can operate for about 8 hours on a charge, LPG forklifts can operate for about 12 hours before refueling. Consequently, electric forklifts may be a practical alternative only in some applications.

Aside from electric powered forklifts, other modes of transporting materials may be considered. For lighter loads, non-motorized hand pallet trucks and stacker machinery may be acceptable substitutes. They are less expensive but have low load capacities. These types of equipment also rely more heavily on manual labor.

2.2.2.3 Customer Concerns

As illustrated in Table 6.6.2.1, most Large SI engines are used in industrial applications. These industrial customers have historically been most concerned about the cost of the engine and equipment, and about reliability. In many cases, equipment users value uniform and familiar technology because these characteristics simplify engine maintenance. As described in Chapter 5, equipment users have largely ignored the potential for improving fuel economy when they make their purchase decisions. As a result most Large SI engines being sold today have relatively simple carburetor technology that is similar to automotive technology of the early 1960s.

Another user concern relates to emissions. A large number of these engines are operated indoors or in other areas with restricted airflow much of the time. For these applications, customers generally want engines with lower CO emissions. Consequently, most engines used in these applications are fueled with LPG or CNG. However, calibration or maintenance problems in the field can cause dangerously high CO levels in these engines. Occasionally customers purchase engines equipped with exhaust catalysts to protect operators from exposure to high emission levels.

2.2.3 Industry Organization

It is important to gain an understanding of how the Large SI equipment and engine industries may be affected by the emission control program. One way to determine how increase costs may affect the market is to examine the organization of each industry. This section provides data to measure the competitive nature of the forklift and Large SI engine industries and lists manufacturers of these equipment and engines. It should be noted that while forklift manufacturers will be affected by changing engine designs, only those companies that certify their engines with EPA will be directly regulated.

This section does not contain detailed information on non-forklift application. While these other sectors will be affected by the control program, it is not practical to report detailed information for each.

2.2.3.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in production. This condition is most likely to hold if the industry has a large number of buyers and sellers, the products sold and inputs used are homogeneous, and entry and exit of firms is unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firm is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and the Herfindahl-Hirschman index (HHI) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the six digit NAICS code level for the year 1997, the most recent year available. Table 2.2-3 provides the four- and eight-firm concentration ratios (CR4 and CR8, respectively), and the Herfindahl-Hirschman index for the industrial truck, tractor, trailer, and stacker machinery manufacturing industry, the industry that includes producers of forklifts. This industry is represented by NAICS code 333924. Concentration ratios are provided in percentage terms while HHI are based on a scale formulated by the Department of Justice.

The criteria for evaluating the HHI are based on the 1992 Department of Justice Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries have more ability to influence market prices. Based on these criteria, the industry that produces forklifts can be modeled as perfectly competitive for the purposes of the economic impact analysis, since their HHI is 503.

Table 2.2-3
Measures of Market Concentration for the NAICS Code that Includes Forklift Manufacturers, 1997 [59]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 333924	38.5	52.3	503	$5,538.33	434

2.2.3.2 Large SI Engine and Forklift Manufacturers

Using data from Power Systems Research for the period 1994-96, we have identified seven principal manufacturers of Large SI engines. These are listed in Table 2.2-4, along with their average annual sales volume. This table shows that sales volumes are relatively evenly distributed among these seven manufacturers. The figures for “other” manufacturers presents aggregated data from four additional companies: Volkswagen, Westerbeke, Hercules, and Chrysler. While the market has changed over recent years, with some manufacturers dropping out of the market, General Motors, Mitsubishi Motors, Ford Power Products, and Nissan Industrial Engines continue to have roughly equal shares and represent between 60 and 70 percent of the annual sales of these engines in the United States.

Table 2.2-4
Engine Sales by Manufacturer (1994-1996)

Manufacturer	Average Annual Sales	Distribution
General Motors	19,500	19%
Mitsubishi Motors	15,600	15%
Ford Power Products	14,000	14%
Nissan Industrial Engines	13,800	13%
Wis-Con Total Power	12,100	12%
Toyota	11,800	12%
Mazda	8,200	8%
Other	7,200	6%
Total	102,300	100%

Source: Power Systems Research Database

The degree to which engine manufacturers offer integrated engine and equipment models is an important factor in determining how companies address the need to redesign their products. Companies that use their own engine models to produce equipment can coordinate the engine design changes with the appropriate changes in their equipment models. The principal integrated manufacturers (Nissan, Mitsubishi, and Toyota) all produce forklifts. About 40 percent of Large SI equipment sales are from integrated manufacturers.

Other forklift manufacturers have also been responsible for varying degrees of engine design. Engine design expertise among these companies is so prevalent that some forklift manufacturers may assume responsibility for certifying their engines, even though they buy the engines mostly assembled from other manufacturers.

EPA has identified at least fourteen forklift manufacturers that use Large SI engines. The majority of these companies produce Class 4 and 5 forklifts, though there are a handful that manufacture Class 6 forklifts. Table 2.2-5 provides a listing of the forklift manufacturers and their total annual sales (including sales abroad) for the most current year for which data were available (2000 or 2001). The table shows that the companies range in size based on their annual sales.

Table 2.2-5
Annual Sales for Forklift Manufacturing Companies, 2000/2001 [60,61,62,63]

Company	Annual Sales ($\$10^6$)
NACCO Materials Handling Group (owns Hyster and Yale)	$1,292
Clark Material Handling Company	$539
Mitsubishi Caterpillar Forklift America, Inc.	$172
Nissan Forklift Corporation, North America	$86
Toyota Industrial Equipment Manufacturing	$83
Hyundai Construction Equipment - Material Handling Division	$80
TCM Manufacturing USA	$50
Komatsu Forklift USA, Inc.	$30
Kalmar AC, Inc.	$27
Linde Lift Truck Corporation	$26
Drexel Industries, Inc.	$26
Tailift USA, Inc.	$10
Blue Giant	$9
Daewoo Heavy Industries America	$5

2.2.4 Markets

This section examines the historical market statistics for the forklift manufacturing industry. Historical data on the quantity of domestic shipments and some price data of IC engine forklifts are provided. The quantity and values of exports and imports of non-electric forklift trucks are presented as well.

2.2.4.1 Quantity and Price Data

Historical market data on the quantity of U.S. shipments of Class 4, 5, and 6 forklifts are provided in Table 2.2-6 and were obtained from the Industrial Truck Association Membership Handbook (2002). As this table shows, there has been an overall increasing trend in the quantity of forklifts produced in the U.S. with an overall net increase of 118 percent from 1980 to 2000 and an average increase of just under 7 percent per year. During the 1990s, shipments increased from almost 48,000 in 1990 to approximately 73,000 in 1995, but then dipped in 1996 to just above 60,000. Since 1996, the general increasing trend in the quantity of SI engine forklifts manufactured in the U.S. continued with a relatively small dip in 1999. For the purpose of this economic impact analysis, we used 65,000 forklifts as our baseline quantity of forklifts produced in 2000, based on production data for the past 10 years. For future year projections, we used the growth rates contained in our NONROAD model.

Table 2.2-6
U.S. Shipments of Internal Combustion
Class 4, 5, and 6 Forklifts, 1980 - 2000 [64]

Year	Quantity of Shipments	Year	Quantity of Shipments
1980	39,448	1991	38,406
1981	31,885	1992	46,183
1982	18,553	1993	48,947
1983	26,245	1994	65,027
1984	45,338	1995	72,685
1985	47,844	1996	60,287
1986	46,195	1997	64,946
1987	47,945	1998	80,554
1988	48,535	1999	74,994
1989	55,104	2000	85,993
1990	47,702	Average Annual Growth Rate = 6.7%	

Forklift truck prices can vary a great deal depending on their class, the manufacturer, the model type, and selected options. Pricing data on various Class 4 and 5 forklift models were obtained from the Handbook of New and Used Equipment Values - IC Lift Trucks (Equipment Watch, 2001). Current retail prices for various IC forklifts with no options for the year 2001 varied from a low of $17,000 up to well over $100,000 for high end models. However, most models were priced in the range of $25,000 to $50,000.

2.2.4.2 Foreign Trade

Export and import values and quantities for non-electric forklifts presented in Table 2.2-7 show increasing trends since 1989. Based on this information, the U.S. is a net importer of forklifts as its value and quantity of imports exceeds it value and quantity of exports. Note, however, that U.S. domestic production of forklifts far outweighs the quantity it imports. A closer examination of the export value and quantity data show that while U.S. exports generally increased over the 1989 to 2001 time period, there was a sharp decline in export quantity and value in 1996. Exports of forklifts went from a total value of $194.3 million in 1995 to about $91 million in 1996 (a similar decline is evident in the quantity of forklifts). Since 1996, both the value and quantity of exports has increased with a slight dip occurring in 2001. U.S. imports of forklifts has also shown a general increase in both value and quantity, however again, in 2001 a slight dip is evident.

The main importers of non-electric forklifts, related trucks, and parts of forklifts to the U.S. are Japan, Canada, and the United Kingdom and the main countries the U.S. exports its forklifts to are Canada, Mexico, and the United Kingdom.[65]

Table 2.2-7
Import and Export Quantities and Values* for Non-Electric Self-Propelled Forklift and Other Trucks, 1989 - 2001 [66]

Year	Export Value ($$10^6$)	Export Quantity	Import Value ($$10^6$)	Import Quantity
1989	$113	7,065	NA	NA
1990	$142	7,651	NA	NA
1991	$148	8,302	NA	NA
1992	$146	9,511	NA	NA
1993	$144	12,762	NA	NA
1994	$196	11,277	$301	19,496
1995	$194	10,131	$389	22,824
1996	$91	4,963	$375	19,214
1997	$146	8,670	$459	21,820
1998	$162	9,890	$611	29,251
1999	$150	11,526	$574	26,741
2000	$190	16,208	$612	30,751
2001	$168	12,768	$507	23,381
Average	$153	10,056	$294**	14,883**

[a] Values are in nominal dollars.
[b] Average is computed for the years 1994 through 2001.

2.3 Snowmobile Market

Snowmobiles are normally one or two passenger vehicles that are used to transverse over snow-covered terrain. They have a track in the rear similar to that of a bulldozer and runners (similar to skis) in the front for steering. Snowmobiles are used primarily for recreational purposes. However, a small number of them are produced and used for utility purposes, such as search and rescue operations. Annual sales of snowmobiles in the U. S. have varied dramatically over the years. Over 140.6 million units were sold in the U. S. in 2001.[67]

2.3.1 The Supply Side

This section provides a description of snowmobiles and their engines, the major inputs used to manufacture this equipment, and the costs of production.

2.3.1.1 Product Types

There are several types of snowmobiles on the market. Snowmobiles types range from children's models with very low horsepower to high-powered machines with engine sizes approaching 1000 displacement cc. Snowmobiles are designed to appeal to a variety of consumers including those who wish to cover rough mountainous terrain, those who seek speed, those who wish to tour the countryside and the novice snowmobiler. Snowmobiles are offered in one-seat and two-seat models and in luxury and low-cost varieties. Snowmobile manufacturers seek to appeal to a wide range of potential snowmobile riders. This section will describe a few of the components of the models on the market. There are a variety of engine options including two-stroke or four-stroke, air or water cooled, and various engine displacements. Options include electric start, reverse, specialized paints, and other items. For a more complete description of typical snowmobile attributes see Section 9.4.

2.3.1.2 Engine Design and Populations

The vast majority of snowmobiles sold in the U.S. are powered by two-stroke engines currently. Engine displacements range from 60 cc for an entry-level youth model to 998 cc for a high-performance model. Based upon PSR snowmobile production data, snowmobiles produced have been trending towards higher engine sizes with the average engine size increasing over 17 percent between the period 1990 and 2000. In 1996 over 44 percent of the snowmobiles produced had engine sizes less than 500 cc displacement. In 2000, this percentage had dropped to 23 percent. In general the larger the engine size, the more powerful for the 2-stroke engines that dominate the snowmobile market today. The average engine size in 2002 was 570 cc displacement.[68]

The number of models produced for a given engine size for the four major snowmobile manufacturers is shown in Table 2.3-1.

Table 2.3-1
Engine Displacement for Major Snowmobile Manufacturers in the U.S. Market in 2000[69]

Manufacturers	≤300cc	≤500cc	<700cc	700-1000cc
Arctic Cat, Inc.	852	14,233	41,253	8,317
Bombardier (Ski Doo)	2,638	23,507	20,017	11,973
Polaris Industries	2,533	21,585	34,067	14,276
Yamaha	0	10,615	16,483	6,085
Total	6,023	69,940	111,820	40,651

* Production data were taken from OELINK Database owned by Power Systems Research.

2.3.1.3 Two-Stroke vs Four-Stroke Cycle Engine Usage

The majority of snowmobiles are equipped with 2-stroke engines. For the 2003 models currently available for sale, nine 4-stroke models are available. Each of the manufacturers offers 4-stroke models in their current sales inventory. For more details see Section 9.4.

2.3.1.4 Production Costs of Snowmobiles

Production costs for snowmobiles are not readily available. In lieu of cost of production data for snowmobiles specifically, a discussion of the cost of production data for NAICS 366999 Other Transportation Equipment Manufacturing is presented. This category includes snowmobiles, ATVs, golf carts, and other miscellaneous transportation equipment. As Table 2.3-2 shows, the average value of shipments (VOS) for these industries over the 1992 to 2000 time period is equal to approximately 4.5 billion dollars, with the highest value of shipments occurring in 2000. The cost of materials for this industry is equal to an average of about 3 billion dollars (65 percent of VOS). The average cost of labor is approximately 549 million (12 percent of VOS), while capital expenditures are equal to an average value of 97 million (2 percent of VOS). Examination of these data clearly shows that capital expenditures and payroll represent the smallest shares of the value of shipments while the cost of materials represents the largest share.

Table 2.3-2
Value of Shipments (VOS) and Production Costs for the SIC and NAICS Codes that Includes Snowmobile Manufacturers, 1992 - 2000 [70,71,72,73,74]

		VOS	Payroll		Cost of Materials		New Capital Expenditures	
Year	Industry Code	($$10^6$)	($$10^6$)	% of VOS	($$10^6$)	% of VOS	($$10^6$)	% of VOS
1992	SIC 3799	3,087	449	15%	1,969	64%	62	2%
1993	SIC 3799	3,807	514	14%	2,422	64%	86	2%
1994	SIC 3799	3,947	469	12%	2,611	66%	98	2%
1995	SIC 3799	4,539	512	11%	3,056	67%	86	2%
1996	SIC 3799	5,179	570	11%	3,368	65%	103	2%
1997	NAICS 336999	4,437	496	11%	2,803	63%	97	2%
1998	NAICS 336999	5,033	578	11%	3,236	64%	122	2%
1999	NAICS 336999	5,645	643	11%	3,766	67%	106	2%
2000	NAICS 336999	6,245	714	11%	4,195	67%	117	2%
	Average	4,568	549	12%	3,047	65%	97	2%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars

2.3.2 The Demand Side

This section provides information on the uses of snowmobiles, various substitute products on the market, and information concerning consumers who purchase snowmobiles.

2.3.2.1 Uses of Snowmobiles

There are a variety of snowmobile types currently produced and tailored to a variety of riding styles. The majority of the overall snowmobile market is made up of high performance machines. These snowmobiles have fairly high powered engines and are very light, giving them good acceleration speed and handling. The performance sled come in several styles. Cross country sleds are designed for aggressive trail and cross country riding. Mountain sleds have longer tracks and wider runner stance for optimum performance in mountainous terrain. Finally, muscle sleds are designed for top speeds (in excess of 120 miles per hour) over flat terrain such as frozen lakes. Performance snowmobiles are generally designed for a single rider.

The second major style of snowmobile is designed for casual riding over groomed trails. These touring sleds are designed for one or two riders and tend to have lower powered engines than performance snowmobiles. The emphasis in this market segment is more on comfort and convenience. As such, these sled feature more comfortable rides than performance machines and tend to have features such as electric start, reverse, and electric warming hand grips.

The last and smallest segment of the snowmobile market is the utility sled segment. Utility snowmobiles are designed for pulling loads and for use in heavy snow. Thus the engines are designed more for producing torque at low engine speeds, which typically corresponds to a reduced maximum speed of the snowmobiles. Utility snowmobiles are common in search and rescue operations.

A typical snowmobile lasts thirteen years and travels approximately 17,000 miles over its lifetime. The average snowmobile is used 57 hours per year.[75]

2.3.2.2 Substitution Possibilities

A number of substitute products to snowmobiles exist. Consumers can substitute across off-road recreational vehicles. However, ATVs and off-highway vehicles may not be used safely in the snow. Snow coaches are a substitute motorized product. Consumers may be interested in engaging in outdoor activities, but may instead consider doing a non-motorized activity. For example, consumers who are interested in being outside in the snow may engage in skiing or sledding. Recreational indoor activity of many types are substitute possibilities for snowmobile riding.

2.3.2.3 Customer Demographics and Customer Concerns

Based upon ISMA data, the average snowmobile owner is 42 years old, and had an average annual income of $68,000 in 2001. The average snowmobile rider has 18 years experience in riding. The majority of snowmobile owners are married. Approximately 63 percent of riders trailer their snowmobiles to go riding.[76]

Good performance is very important to snowmobilers. This is especially true for the performance segment of the market, where high power and low weight are crucial for the enjoyment of the performance snowmobile enthusiast. The performance snowmobile segment is driven by a constant demand for more power and lower weight. In the touring segment of the market, performance in terms of power and weight is somewhat less important but still significant. In all snowmobile market segments, durability and reliability are very important to the customer.

The price of a snowmobile produced by the four major manufacturers currently ranges from about $3,700 for entry level models to around $12,000 for some high performance models. The average snowmobile price in 2001 was $6,360. Some of the high performance snowmobiles produced by the small manufacturers can approach $20,000, but this is an extremely small niche market. Since snowmobiles are a discretionary purchase, price is a factor in the consumers decision to purchase.

2.3.3 Industry Organization

Because there are costs associated with the emission control program, it is important to determine how the snowmobile industry may be affected. Industry organization is an important factor which affects how a market may react to regulatory costs. This section provides a description of the organization of the snowmobile industry.

2.3.3.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in production. This condition is most likely to hold if the industry has a large number of buyers and sellers, the products sold and inputs used are homogeneous, and entry and exit of firms is unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firm is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and the Herfindahl-Hirschman index (HHI) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the six digit NAICS code level for the year 1997, the most recent year available. Table 2.3-3 provides the four- and eight-firm concentration ratios (CR4 and CR8, respectively), and the Herfindahl-Hirschman index for the NAICS code 336999, Other Transportation Equipment Manufacturing, the industry category that includes producers of snowmobiles. Note that the concentration ratio is reported in percentage terms while the HHI is based on a scale developed by the Department of Justice. For this industry the CR4 was 50.7 percent and the CR8 was 75.3 percent.

The criteria for evaluating the HHI are based on the 1992 Department of Justice Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries have more ability to influence market prices. Based on these criteria, the NAICS category that includes firms that produce snowmobiles can be considered unconcentrated or more competitive.

Table 2.3-3
Measures of Market Concentration for the NAICS Code that Includes NAICS 336999 Manufacturers, 1997 [77]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 336999	50.7	75.3	885.2	$4,436,679	349

However, it is important to recognize that four producers dominate the snowmobile industry or produce 99 percent of the worldwide snowmobiles produced and sold. This information suggests that snowmobile manufacturing is highly concentrated with four manufacturers dominating the market. However, when one considers firm behavior within the industry and the availability of numerous product substitutes, the picture alters somewhat. While snowmobile manufacturing is concentrated, snowmobiles represent a small fraction of total recreational products available in the market place.

Market structure is important to assessing the potential impacts of a regulation on an industry because it determines the behavior of producers and consumers within the industry. Economists often estimate concentration ratios for the subject market or industry to assess the competitiveness. More (less) concentrated markets are considered to be less (more) competitive. The extremes are defined by perfect competition (many buyers/seller with no influence over price) and monopoly (one seller with control over setting price). Between these two extremes are varying degrees of imperfect competition, or oligopoly, that depend upon different assumptions of strategic behavior among sellers within the market or industry. The competitiveness will depend upon the definition of the subject market or industry with those being more (less) broadly defined demonstrating more (less) competition. For example, the "snowmobile" market is dominated by four major producers and may be considered less competitive. However, there are likely to be many substitutes for snowmobiles when considering the broader "recreational vehicles" or "recreational activities" markets. These substitutes increase the competitive nature of the market or industry. In previous regulatory analysis, the Agency has modeled the imperfectly competitive nature of pharmaceuticals (product differentiation) and cement (regional barriers to entry) where there were commonly accepted and researched approaches. Rather than add uncertainy to model outcomes by speculating on the strategic interactions of producers here, we chose to model the markets as perfectly competitive. Generally speaking, this assumption will tend to understate the price and output changes associated with regulation and may overstate the profit loss of producers; however, the extent of the bias is unknown and direction may vary by producer.[78]

2.3.3.2 Snowmobile Manufacturers

Manufacturers of snowmobile were formerly classified under the SIC code 3799 and are now classified under NAICS code 336999, Other Transportation Equipment Manufacturing. The

Small Business Administration (SBA) uses SIC/NAICS categories to classify businesses as large or small, depending on the number of employees or sales criteria. Snowmobile manufacturers have the NAICS sub-classification 3369993414 and must have fewer than 500 employees to be considered a small business by SBA. Snowmobile wholesale companies may also be impacted by this regulation. Wholesale dealers of snowmobiles are categorized as NAICS classification 421110 - Automobile and Other Motor Vehicle Wholesales, and are considered small business if they have fewer than 100 employees.

There are four major manufacturers of snowmobiles that account for almost the entire U.S. market. These manufacturers are Arctic Cat, Bombardier (Ski Doo), Polaris and Yamaha. Polaris is the largest snowmobile manufacturer by sales volume, followed by Arctic Cat, Bombardier, and Yamaha. There are less than five snowmobile manufacturers that combined make up significantly less than one percent of the U.S. snowmobile market. These snowmobile manufacturers specialize in high performance snowmobiles and other unique designs (such as stand-up snowmobiles).

Bombardier and Yamaha produce the engines used in the snowmobiles they sell. In contrast, Polaris and Arctic Cat purchase engines for the snowmobiles they sell. Arctic Cat typically purchases Suzuki engines, while Polaris purchases engines made by Fuji Corporation.

2.3.4 Snowmobile Retailers and Rental Firms

In contrast to the small number of manufacturers producing snowmobiles, there are over 1,500 registered snowmobile dealers in the United States according to ISMA data. Approximately the same number operate in Canada and Scandinavia. These firms typically do not sell snowmobiles exclusively, but also sell other recreational vehicle products such as ATVs and motorcycles. Snowmobile retailers are included in NAICS category 441229 - All Other Motor Vehicle Dealers, and are considered small business if annual sales revenues are less than $6.0 million. In additional to retailers, rental firms exist that purchase snowmobiles to rent to the occasional snowmobile rider. These firms are included in NAICS category 532292 - Recreational Goods Rental, and are considered small business if the firm experiences sales less than $6.0 million. Potentially, both retailers and rental firms may be impacted by the regulation to the extent that the price of the snowmobiles the firms sell or rent increase.

2.3.5 Markets

This section examines the historical market data for the snowmobile industry. Historical data on the quantity of domestic shipments and price data of snowmobiles are provided.

2.3.5.1 Quantity and Price Data

Historical market data on the quantity of snowmobiles sold in the U.S. are provided in Table 2.3-4. Data were obtained from ISMA.[79] As this table shows, there has been an overall increasing trend in the quantity of snowmobiles sold in the U.S. with an average annual increase of 6 percent from 1990 to 2001. However, annual sales declined in 1991 and 1998 through 2000. Sales of snowmobiles increased more than 76 percent between the years 1990 and 2001. Retail dollars sales increased, on average, by 11 percent annually from 1990 to 2001. Snowmobile retail dollars per unit have also increased, showing an annual average increase of 5 percent for the same period.

Table 2.3-4
U.S. Units Sold, Retail Dollars and Retail Dollars Per Unit
Snowmobiles, 1990 - 2001 [80]

Year	Unit Sales	% Change Unit Sales	Retail Dollars ($$10^6$)	% Change Retail Dollars	Retail Dollars/ Unit	% Change Retail Dollars/Unit
1990	80,000	---	$300.0	---	$3,750	---
1991	78,000	(3%)	$323.7	8%	$4,150	11%
1992	81,946	5%	$356.0	10%	$4,344	5%
1993	87,809	7%	$403.9	13%	$4,600	6%
1994	114,057	30%	$558.9	38%	$4,900	7%
1995	148,207	30%	$791.3	42%	$5,339	9%
1996	168,509	14%	$905.2	14%	$5,372	1%
1997	170,325	1%	$1,005.8	11%	$5,905	10%
1998	162826	(4%)	$975.1	3%	$5,988	1%
1999	147867	(9%)	$882.8	9%	$5,970	0%
2000	136,601	(8%)	$821.0	7%	$6,000	1%
2001	140,629	3%	$894.4	9%	$6,360	6 %
11-year Annual Average	137,889	6%	$747	11%	$5,698	5%
Change 1990 to 2001		76%		198%		70%

*Dollar values and percent changes of dollar values presented are nominal values.

2.3.5.2 Foreign Trade

In general, export and import data are not available for the snowmobile market. Data for SIC 3799 are available from the International Trade Commission. These data are presented on Table 2.4-6, Import and Export Quantities and Values for ATVs, 1989-2001, in Section 2.4, All-Terrain Vehicles, below. However, SIC 3799 includes snowmobiles, ATVs, golf carts and other transportation equipment. Thus the trade data is not specific to snowmobiles. World wide sales data for snowmobiles are presented in Table 2.3-5. During 2000 approximately 40 percent of total worldwide production was produced by Bombardier and Yamaha, foreign companies with the remainder of 60 percent produced by Arctic Cat and Polaris, domestic manufacturers.

Table 2.3-5
Worldwide Production, Sales, and Inventories of Snowmobiles 1990 - 2001[81]

Year	Worldwide Production (10^3 units)	Worldwide Retail Sales (10^3 units)	Worldwide Inventory (10^3 units)
1990	174.9	163.4	55.5
1991	157.2	153.0	59.7
1992	116.3	150.0	27.9
1993	146.0	158.0	16.0
1994	185.0	181.0	18.6
1995	231.5	227.4	22.6
1996	260.9	252.3	31.1
1997	273.7	260.7	44.2
1998	270.7	257.9	56.9
1999	231.7	230.9	57.7
2000	205.0	208.3	54.4
2001	190.3	208.5	36.1

2.4 All-Terrain Vehicles

All Terrain Vehicles (ATVs) are normally one-passenger open vehicles that are used for recreational and other purposes requiring the ability to traverse over most types of terrain. Most modern ATVs have four-wheels, and have evolved from three-wheeled designs that were first introduced in the 1970s. According to data provided by the Motorcycle Industry Council (MIC), production of ATVs sold in the U.S. has averaged about 390,000 units between 1996 and 2001. However, ATV sales have increased during that time to more than 880,000 units in 2001. ATVs therefore constitute the largest single category of non-highway recreational vehicles, though it is difficult to calculate the total vehicle population at any given point in time since many states do not require registration of ATVs.

2.4.1 The Supply Side

This section provides a description of ATVs and their engines, the major inputs used to manufacture this equipment, and the costs of production.

2.4.1.1 Product Types

There are several types of ATVs on the market. This section will describe a few of the components of the models on the market. There are a variety of engine options including two-stroke or four-stroke, air or water cooled, and various engine displacements. Options also include 5-speed manual or automatic transmissions.

2.4.1.2 Engine Design and Populations

The majority of ATVs sold in the U.S. are powered by single-cylinder, four-stroke cycle engines of less than 40 horsepower, operating under a wide variety of operating conditions and load factors. Engine displacements range from 50cc for an entry-level youth model to 660cc for a high-performance adult model, but more than three-fourths of them fall in the 200-500cc range.

In the year 2000, ATV manufacturers used 225,246 engines between 200cc and 300cc displacement (see Table 2.4-1). Of the engines produced, 64 percent were less than 400cc displacement and 84 percent were less than 500cc displacement . Over the past four years, production of engines with greater than 500cc displacement has increased from approximately 5 percent in 1996 to 16 percent in 2000.

Table 2.4-1
Engine Displacement for Major ATV Manufacturers in the U.S. Market in 2000[82]

Manufacturers	**<200cc**	**200 - 300cc**	**300 - 400cc**	**400 - 500cc**	**200 - 700cc**
Arctic Cat, Inc.	0	14,758	4,896	10,869	0
Honda	2,429	119,661	7,561	65,933	13,583
Kawasaki Motors	0	44,169	6,780	0	0
Polaris Industries	0	21579	54,834	6,689	62,144
Suzuki	0	9,346	0	1,740	0
Yamaha	7,635	15,733	26,977	21,743	0
Total	10,064	225,246	101,048	106,980	75,727

2.4.1.3 Two-Stroke vs Four-Stroke Cycle Engine Usage

Approximately 80 percent of all ATVs produced for U.S. consumption use four-stroke cycle engines. Of the six major manufacturers, only Polaris, Suzuki and Yamaha used two-stroke cycle engines at all. The remainder of the two-stroke engines in ATVs sold in U.S. are found in entry-level or youth models, which are imported from the Far East or assembled in this country from imported parts. In general, two-stroke engines are less expensive to produce than four-stroke engines, thus providing a marketing advantage in the youth and entry-level categories. We estimate that two-strokes make up roughly twenty percent of the market when the imported youth models are included.

2.4.1.4 Production Costs of ATVs

As Table 2.4-2 shows, the average value of shipments (VOS) for this industry over the 1992 to 1999 time period is equal to approximately 4.6 billion dollars, with the highest value of shipments occurring in 1999. The cost of materials for this industry is equal to an average of about 3 billion dollars (65 percent of VOS). The average cost of labor is approximately 549 million (12 percent of VOS), while capital expenditures are equal to an average value of 97 million (2 percent of VOS). Examination of these data clearly shows that capital expenditures and payroll represent the smallest shares of the value of shipments while the cost of materials represents the largest share.

Table 2.4-2
Value of Shipments (VOS) and Production Costs for the SIC and NAICS Codes that Includes ATV Manufacturers, 1992 - 2000 [83,84,85,86,87]

		VOS	Payroll		Cost of Materials		New Capital Expenditures	
Year	Industry Code	($$10^6$)	($$10^6$)	% of VOS	($$10^6$)	% of VOS	($$10^6$)	% of VOS
1992	SIC 3799	3,087	449	15%	1,969	64%	62	2%
1993	SIC 3799	3,807	514	14%	2,422	64%	86	2%
1994	SIC 3799	3,947	469	12%	2,611	66%	98	2%
1995	SIC 3799	4,539	512	11%	3,056	67%	86	2%
1996	SIC 3799	5,179	570	11%	3,368	65%	103	2%
1997	NAICS 336999	4,437	496	11%	2,803	63%	97	2%
1998	NAICS 336999	5,033	578	11%	3,236	64%	122	2%
1999	NAICS 336999	5,645	643	11%	3,766	67%	106	2%
2000	NAICS 336999	6,245	714	11%	4,195	67%	117	2%
	Average	4,568	549	12%	3,047	65%	97	2%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars.

2.4.2 The Demand Side

This section provides information on the uses of ATVs, various substitute products on the market, and the consumers who purchase ATVs.

2.4.2.1 Uses of ATVs

As noted above, ATVs are used for recreational and other purposes. They are mainly used for, riding on trails. Examples of non-recreational uses are for hauling and towing on farms, ranches or in commercial applications. Some ATVs are sold with attachments that allow them to take on some of the functions of a garden tractor or snow blower. ATVs are also used for competitive purposes, although not to the same extent as off-highway motorcycles.

2.4.2.2 Alternate Uses of ATV Engines

Although a few ATV engine lines have been used in other applications, such as some smaller on- and off-highway motorcycles, manufacturers have stated that ATV engines are normally designed only for use in ATVs. ATV engines may share certain components with motorcycles, snowmobiles and Personal Water Craft (PWC), but many major components such as pistons, cylinders and crankcases differ within given engine displacement categories.

2.4.2.3 Substitution Possibilities

Consumers can substitute across off-road recreational vehicles. An off-highway motorcycle as a substitute would allow the consumer to enjoy the same off-road recreation that they would receive with an ATV. Consumers may be interested in engaging in outdoor activities, but may instead consider doing a non-motorized activity. For example, consumers who are interested in being outside may engage in hiking, running, or riding a bicycle. These non-motorized options would allow the consumer to participate in outdoor activity, hence they may be considered substitutes for less intensive off-highway pastime.

2.4.2.4 Customer Concerns

Except for the competitive segment of the market, performance seems to be somewhat less important to ATV purchasers than it is to purchasers of snowmobiles or off-highway motorcycles. Most youth models, which form a significant portion of the market, are normally equipped with governors or other speed-limiting devices. Performance can be important for some of the higher-end adult models, but handling is also an important consideration, particularly when riding in dense wooded areas. Durability and reliability are also important to the customer, but perhaps not as important as price.

The price of an ATV can range from about $1,200 for an entry-level youth model to around $7,000 or more for a large, high performance machine. ATVs, like other recreational vehicles, are basically discretionary purchases, although utility may enter into the equation more often than in the case of off-highway motorcycles or snowmobiles. Cost is an important factor, particularly in the youth or entry-level segments of the market, and significant cost increases could cause people to spend their discretionary funds in other areas.

2.4.3 Industry Organization

Because there are costs associated with the emission control program, it is important to determine how the ATV industry may be affected. Industry organization is an important factor which affects how a market may react to regulatory costs. This section provides a description of the organization of the motorcycle industry.

2.4.3.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in production. This condition is most likely to hold if the industry has a large number of buyers and sellers, the products sold and inputs used are homogeneous, and entry and exit of firms is unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firm is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and the Herfindahl-Hirschman index (HHI) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the six digit NAICS code level for the year 1997, the most recent year available. Table 2.4-3 provides the four- and eight-firm concentration ratios (CR4 and CR8, respectively), and the Herfindahl-Hirschman index for the NAICS code 336999l, Other Transportation Equipment Manufacturing, the industry category that includes producers of ATVs. Note that the concentration ratio is reported in percentage terms while the HHI is based on a scale developed by the Department of Justice. For this industry the CR4 was 50.7 percent and the CR8 was 75.3 percent.

The criteria for evaluating the HHI are based on the 1992 Department of Justice Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries have more ability to influence market prices. Based on these criteria, the NAICS category that includes firms that produce ATVs can be considered unconcentrated or more competitive.

Table 2.4-3
Measures of Market Concentration for the NAICS Code that Includes ATV Manufacturers, 1997 [88]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 336999	50.7	75.3	885.2	$4,436,679	349

2.4.3.2 ATV Manufacturers

Manufacturers of ATVs were formerly classified under the Standard Industrial Classification (SIC)code 3799 and the North American Industrial Classification System (NAICS) code 336999, Other Transportation Equipment Manufacturing. These codes are used by the Small Business Administration (SBA) uses SIC/NAICS categories to classify businesses as large or small, depending on the number of employees or sales criteria. ATV manufacturers have the NAICS sub-classification 3369993101 and must have fewer than 500 employees to be considered a small business by SBA. In addition to manufacturers, there are a number of importers of ATVs, classified under NAICS code 42111, the code that also includes importers of automobiles, trucks, motorcycles and motor homes. To be classified as a small business by SBA for this NAICS code, an importer must have fewer than 100 employees.

Using data including the Power Systems Research (PSR) Database, Dun & Bradstreet (D&B) Market Identifiers Online Database, and information from the MIC identified 16 manufacturers and 17 importers of ATVs. ATV producers and importers are listed in Table 2.4-4. Six large manufacturers, Honda, Polaris, Kawasaki, Yamaha, Suzuki, and Arctic Cat accounted for approximately 98 percent of all U.S. ATV production in calendar year 2000.

Four of the six major ATV manufacturers, Honda, Kawasaki, Yamaha and Suzuki, are primarily automobile and/or on-highway motorcycle manufacturers who also produce ATVs, off-highway motorcycles, snowmobiles, personal water craft (PWC) and other non-highway vehicles. Polaris and Arctic Cat manufacture snowmobile, in addition to producing ATVs. Polaris also produces on-highway motorcycles and Arctic Cat produces PWC.

The 10 other manufacturers account for the remaining two percent of U.S. production in 2000. Only three of these are non-U.S.-owned. Of these remaining producers, five are classified as large businesses, and five as small businesses. Bombardier is a large Canadian snowmobile manufacturer that has recently entered the ATV market. Cannondale is a large American bicycle manufacturer that has recently begun production of ATVs as well. Hyosung and Tai Ling are large Far Eastern manufacturers, who also manufacture motorcycles and motor scooters (in the case of Hyosung). Roadmaster/Flexible Flyer is primarily a large bicycle and toy manufacturer but it also produces youth ATVs that are sold in large discount stores.

There are also some 17 firms that import ATVs. Thirteen of these are U.S.-owned. Dun and Bradstreet data on the numbers of employees are available for four of these companies, and indicate that these are small businesses according to the SBA definition. Since none of these had more than 40 employees and two had less than 20 employees, it seems safe to assume that the others are also small businesses according to the SBA definition. The 17 importers and 5 small manufacturers either import completed ATVs or assemble them in this country from imported parts.

Table 2.4-4
ATV Manufacturers/Importers

Firm Name	Type
ATK	IMPORTER
COSMOPOLITAN MOTORS	IMPORTER
D.R.R. INC.	IMPORTER
E-TON DISTRIBUTION LP	IMPORTER
HOFFMAN GROUP INC.	IMPORTER
J & J SALES	IMPORTER
JEHM POWERSPORTS	IMPORTER
KASEA MOTORSPORTS	IMPORTER
MANCO PRODUCTS	IMPORTER
MOTORRAD OF NORTH AMERICA	IMPORTER
PANDA MOTORSPORTS	IMPORTER
POWERGROUP INTERNATIONAL ALPHASPORTS	IMPORTER
REINMECH MOTOR COMPANY, LTD	IMPORTER
TRANSNATIONAL OUTDOOR POWER LLC	IMPORTER
TWS-USA, INC	IMPORTER
ULTIMAX LCC	IMPORTER
UNITED MOTORS OF AMERICA, INC	IMPORTER
AMERICAN SUNDIRO	MANUFACTURER
ARCTIC CAT, INC.	MANUFACTURER
BOMBARDIER	MANUFACTURER
CANNONDALE CORP - BEDFORD	MANUFACTURER
HONDA AMERICAN MANUFACTURING	MANUFACTURER
HYOSUNG MOTORS AND MACHINERY	MANUFACTURER
INTERNATIONAL POWERCRAFT	MANUFACTURER
KAWASAKI MOTORS CORPORATION	MANUFACTURER
KEEN PERCEPTION INDUSTRIES	MANUFACTURER
MOSS	MANUFACTURER
PANDA MOTORSPORTS	MANUFACTURER
POLARIS INDUSTRIES	MANUFACTURER
ROADMASTER /FLEXIBLE FLYER	MANUFACTURER
SUZUKI	MANUFACTURER
TAI LING MOTOR COMPANY	MANUFACTURER
YAMAHA MOTOR MANUFACTURING CORP.	MANUFACTURER

2.4.3.3 Engine Manufacturers

Four of the major ATV producers, Honda, Kawasaki, Yamaha and Suzuki, manufacture both engine and equipment. In addition to producing engines for itself, Suzuki manufactures engines for Arctic Cat, and in fact owns a significant amount of Arctic Cat common stock. Hyosung Motors and Machinery and the Tai Ling Motor Company also use Suzuki engines in their ATVs. Although Polaris produces some of its own engines, a substantial number are supplied by Fuji Heavy Industries, primarily an auto and truck manufacturer, and its U.S. subsidiary, Robin Industries. Polaris owns a substantial amount of Robin common stock.

Other engine manufacturers include Rotax, a subsidiary of Bombardier Inc., a large Canadian company. Bombardier/Rotax also produces engines for a wide variety of other applications, including snowmobiles, motorcycles, ATVs, personal water craft (PWC), utility vehicles and aircraft. A few small ATV manufacturers use Briggs or Kohler utility engines, but these are covered by EPA’s Small Spark Ignition (SI) Engine regulations and are not included in this analysis.

2.4.4 Markets

This section examines the historical market data for the ATV industry. Historical data on the quantity of domestic shipments and price data of ATVs are provided. The quantity and values of imports and exports for ATVs are presented as well.

2.4.4.1 Quantity and Price Data

Historical market data on the quantity of ATVs sold in the U.S. are provided in Table 2.4-5. Data were obtained from the Motorcycle Industry Council (MIC). As this table shows, there has been an overall increasing trend in the quantity of ATVs sold in the U.S. with an average annual increase of 17 percent from 1990 to 2001. Sales of ATVs increased more than 600% between the years 1990 and 2001. Retail dollars increased, on average, by 22 percent from 1990 to 2001. This is due to the huge increase in production. Retail dollars per unit has also increased, showing an annual average increase of 5 percent for the same period. There was a steady rise of the retail dollars/unit over this time period.

Table 2.4-5
U.S. Units Sold, Retail Dollars and Retail Dollars Per Unit ATVs, 1990 - 2001 [89]

Year	Unit Sales	% Change Unit Sales	Retail Dollars ($$10^3$)	% Change Retail Dollars	Retail Dollars/ Unit	% Change Retail Dollars/Unit
1990	134,619		$393.20		$2,921	
1991	125,056	(7%)	$371.32	(5%)	$2,969	2%
1992	144,332	15%	$449.42	21%	$3,114	5%
1993	162,307	12%	$563.18	25%	$3,470	11%
1994	189,328	17%	$770.52	37%	$4,070	17%
1995	277,787	48%	$1,282.47	66%	$4,617	13%
1996	317,876	14%	$1,530.97	19%	$4,816	4%
1997	359,397	13%	$1,759.77	15%	$4,896	2%
1998	429,414	19%	$2,155.02	22%	$5,019	3%
1999	545,932	27%	$2,805.70	30%	$5,139	2%
2000	648,645	19%	$3,343.15	19%	$5,154	0.3%
2001	880,000	12%	$3,734.91	12%	$5,123	-0.6%
Annual Average	383,154	17%	$1,596.64	22%	$4,276	5%

2.4.4.2 Foreign Trade

Export and import values and quantities for ATVs are presented in Table 2.4-6. This table shows that the export values started out on in an increasing trend for the first three years. Then in 1992, export value dropped by 64 percent and fluctuated between $73 million and $95 million, with the exception of the year 1997. Import quantity decreased until 1992 then remained between 34 thousand and 45 thousand through 2001. The import value decreased each year from 1989 to 1993, it dropped again in 1995 and maintained an increasing trend from 1996 to 2001. The import quantity generally decreased from 1989 to 1993 and started a general rebounding trend. Note that the data presented relates to SIC 3799 and includes ATVs, snowmobiles, golf carts and other transportation equipment.

Table 2.4-6*
Import and Export Quantities and Values for ATVs, 1989 - 2001 [90]

Year	Export Value ($$10^3$)	Export Quantity (10^3)	Import Value ($$10^3$)	Import Quantity (10^3)
1989	$169,881	161	$223,425	2,548
1990	$196,344	95	$156,239	2,486
1991	$209,003	75	$50,877	2,838
1992	$134,356	35	$31,786	1,854
1993	$75,876	40	$9,907	8
1994	$72,787	45	$13,549	11
1995	$85,976	43	$7,351	17
1996	$92,806	42	$9,272	19
1997	$136,357	45	$13,478	41
1998	$85,742	34	$19,174	37
1999	$91,335	42	$32,755	113
2000	$94,783	40	$48,433	178
2001	$89,381	42	$89,786	156
Average	$118,048	56	$54,310	793

*Values shown relate to SIC 3799, which includes ATVs, snowmobiles, golf carts, and other transportation products.

2.5 Off-Highway Motorcycles

Off-highway motorcycles, commonly referred to as “dirt bikes,” are recreational vehicles designed specifically for use on unpaved surfaces. As such, they all have certain characteristics in common, such as a large amount of clearance between the fenders and the wheels, tires with aggressive knobby tread designs, and a lack of some of the equipment typically found on highway motorcycles (e.g., lights, horns, turn signals, and often mufflers). Thus they normally can not be licensed for on-highway use. There are a limited number of motorcycles, known as dual-purpose motorcycles, that can be used for both on- and off-highway purposes. These can be licensed for highway use, and so fall under the current highway motorcycle regulations, assuming that they are powered by engines of 50cc or larger displacement. Off-highway motorcycles are used for recreational riding, but substantial numbers are also used for competition purposes. Some in fact can be used for little else, e.g., machines that are designed for observed trials competition, which have no seats in the conventional sense of the term, and engine characteristics that are totally unlike those of most other motorcycles. Only a few thousand observed trials competition bikes are produced each year. Vehicles designed solely for competition are exempt from this rule. EPA's noise regulations also exempt any off-highway motorcycle that is designed and marketed solely for use in closed-course competition.

2.5.1 The Supply Side

This section provides a description of off-road motorcycles and engines, the major inputs used to manufacture this equipment, and the costs of production.

The motorcycle manufacturing process generally begins with the delivery of motorcycle engines and transmissions, from engine plants to the motorcycle assembly plant. At the plant, the engines and transmissions are matched to designated vehicles on the assembly line. Motorcycle engines are produced with 1 to 8 cylinders, with various configurations. Multi-cylinder engines are manufactured in three basic configurations: in-line, opposed, and V-type. Each of these refer to the position of one bank of cylinders in relation to the other. Motorcycles engines can be air or water cooled; 2-stroke or 4-stroke; carbureted or fuel-injected. Engines may be manufactured with variances in other design characteristics, including the number and placement of carburetors, cams, and valves.

2.5.1.1 Product Types and Populations

The number of off-highway motorcycles produced for sale in the U.S. averaged about 71,415 units between 1990 and 2001. As is the case with ATVs, off-highway motorcycle production increased considerably in later years, to more than 195,000 units in 2001 according to the Motorcycle Industry Council (MIC). Since many states do not require registration of off-highway motorcycles, it is difficult to estimate a total population of these vehicles operational at any given time.

As noted above, off-highway motorcycles can be used for recreational purposes or for competition. EPA defines vehicles that are "used solely for competition" as those with features (not easily removable from the vehicle) that would make the vehicle's use in other recreational activities unsafe, impractical, or highly unlikely.

Certain types of off-highway motorcycles are designed and marketed for closed-course competition. These are commonly known as "motocross bikes." Some 12-14 percent of off-highway motorcycles produced from 1996 to 2000 were motocross bikes. Other sources have estimated motocross bikes to be closer to 30 percent of off-highway sales.[91] Other types of competition motorcycles are the observed trials machines mentioned above, which emphasize handling ability rather than speed, and the so-called "enduro bikes." Enduro bikes are designed for cross-country type racing, rather than closed-course competition. As such, they require some of the equipment normally found on non-racing machines, such as spark arresters (required by U.S. Forest Service regulations) and at least minimal lighting packages.

Whether for competition or recreational use, off-highway motorcycles are operated under transient conditions that include a wide variety of speeds and load factors.

2.5.1.2 Engine Design and Operation

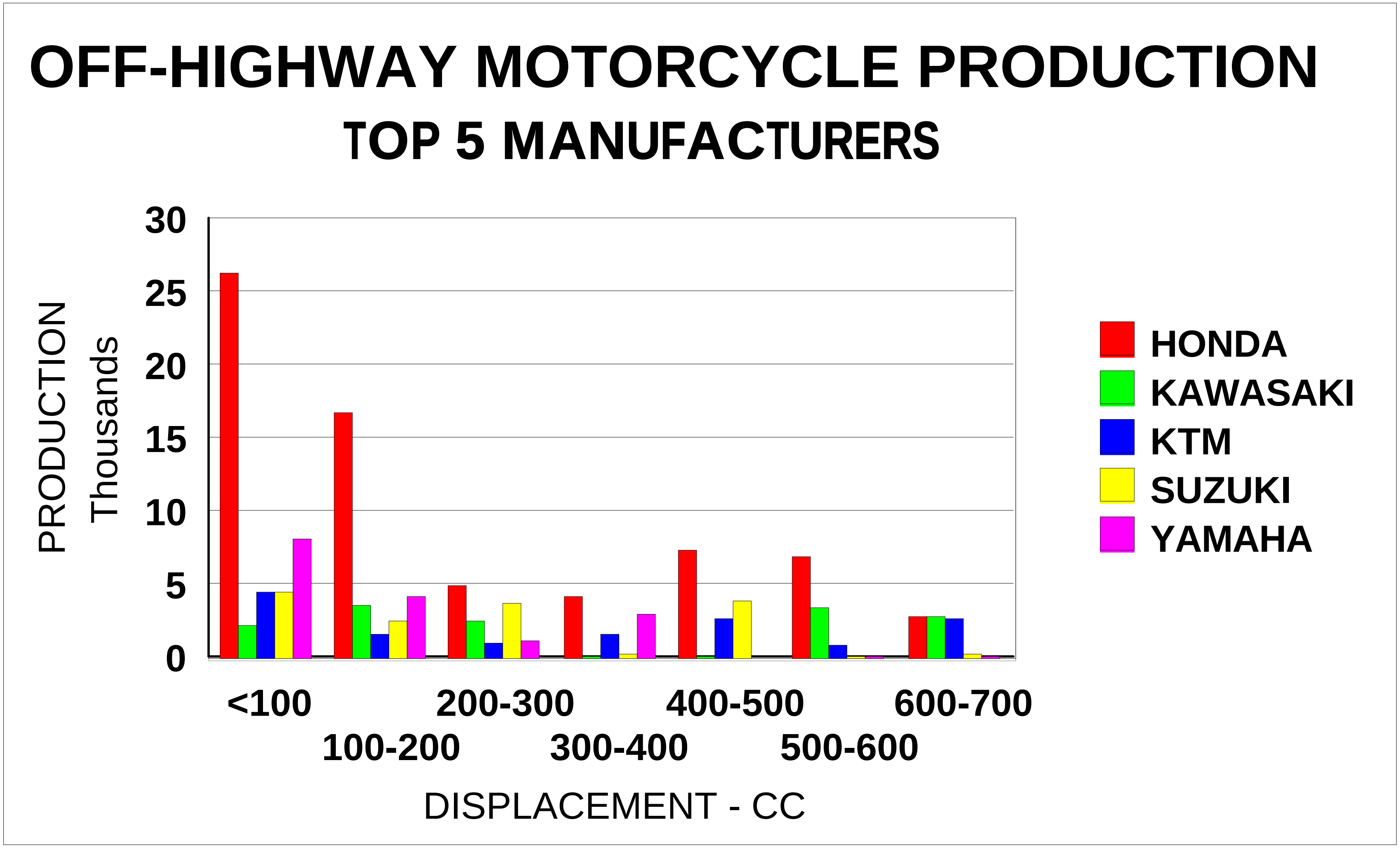
The off-road segment of the motorcycle market is dominated by vehicles with relatively small engines. Off-highway motorcycle engines have traditionally been about two-thirds smaller and less powerful than those used in on-highway cycles. In 1990 and 1998, approximately 88 percent of the off-highway motorcycles in use had an engine displacement less than 350cc. See Table 2.5-1.

Table 2.5-1
Quantities of Off-road Motorcycles By Engine Displacement
1990 and 1998 [92]

Engine Displacement	1990 Number of Motorcycles	1990 % of Total	1998 Number of Motorcycles	1998 % of Total
Under 125cc	306,000	40.8	367,200	30.7
125-349cc	346,500	46.2	680,500	56.9
350-499cc	30,000	4.0	34,700	2.9
450-749cc	67,500	9.0	113,600	9.5
Total	750,000	100	1,196,000	100

In the year 2000, about 68 percent of the models produced were less than 300cc displacement, and half of these were 100cc or less. Percentages by engine displacement for the top five producers are approximately the same as for the industry as a whole. The distribution of engine sizes for these producers tends to be somewhat skewed, with a larger fraction of off-highway motorcycles falling into the lower displacement ranges (see Figure 2.5-1). Unlike on-highway motorcycles, our contractor found no off-highway engines larger than 700cc are currently produced.

Figure 2.5-1 [93]



2.5.1.3 Two-Stroke vs Four-Stroke Cycle Engine Usage

Based on the PSR database, slightly more than half of the off-highway motorcycles produced for sale in the United States are powered by four-stroke cycle engines. However, estimates from the Motorcycle Industry Council (MIC) place the percentage of two-stroke sales at more than 60 percent. The percentage of two-strokes varies considerably by manufacturer. Honda, which accounts for more than 45 percent of this production, is predominantly a four-stroke manufacturer. Four-strokes comprise about two-thirds of its production. For Yamaha, the percentage is about 57 percent. The remainder of the foreign and domestic producers manufacture more two-stroke engines than four-strokes. For the other top-five producers, KTM, Kawasaki, and Suzuki, the percentage of two-stroke engines varies from 58 to 72 percent, and can be even higher (up to 100 percent) for some of the remaining manufacturers.

Two-stroke engines are normally used in two primary applications: (1) racing machines, because they tend to have a higher power-to-weight ratio than four-stroke engines (this is important for competition, especially in the smaller displacement classes), and (2) youth model or entry-level motorcycles, because two-strokes are cheaper to produce than four-strokes. Since youth or entry-level motorcycles also tend to have smaller displacement engines, the higher power-to-weight ratio of the two-stroke tends to provide slightly better performance. However, there has been a growing tendency in recent years for manufacturers to bring out more new four-stroke engines, particularly in the higher displacement ranges. This is also true in their competition lines.

2.5.1.4 Use of Engines in Other Applications

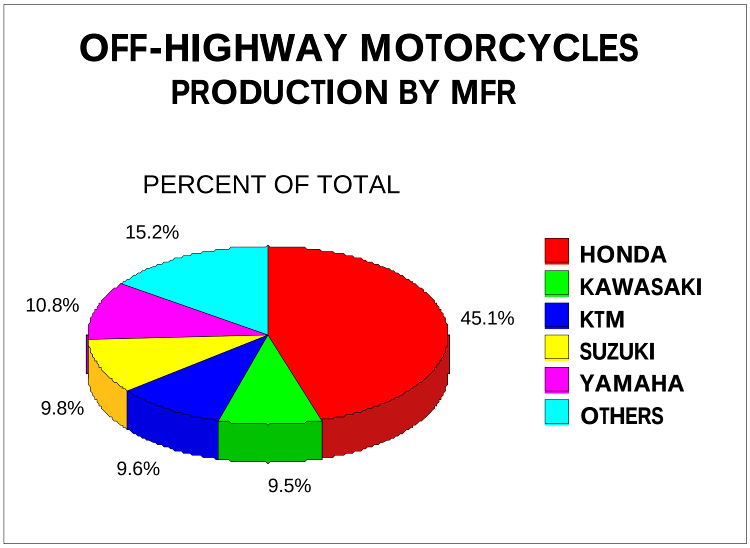
Only a few engine lines, primarily among the top five producers, are used in both off-highway and on-highway motorcycles. Part of the reason for this is because over half of the off-highway bikes use two-stroke engines, whereas almost no two-stroke engines are found in on-highway motorcycles. Also, as noted above, off-highway motorcycles generally have much smaller displacement engines than their on-highway counterparts. Off-highway motorcycle engines are closer in terms of engine size to ATV engines. However, ATVs also use predominantly four-stroke engines and these are not as likely to be highly-tuned for performance as are many off-highway motorcycle engines.

2.5.1.5 Off-Road Motorcycle Manufacturers

Motorcycle manufacturers are classified under the Standard Industrial Classification (SIC) code 3751 and under the North American Industry Classification System (NAICS) code 336991, Motorcycle, Bicycle and Parts Manufacturers. Motorcycle manufacturers have the subcode 3369913, which includes manufacturers of scooters, mopeds, and sidecars. To be classified as a small business by the Small Business Administration (SBA) size standards, the manufacturer must have fewer than 500 employees. Motorcycle importers are classified by subcode 4211101, which also includes automobile importers, and has an SBA size cutoff of 100 employees to be considered a small business.

Twenty five companies manufacture off-highway motorcycles. The five largest manufacturers, Honda, Kawasaki, Yamaha, Suzuki, and KTM. accounted for approximately 85 percent of all production sold in the U.S. in calendar year 2000. These companies manufacture automobiles and/or on-highway motorcycles, motorscooters, ATVs, Personal Water Crafts (PWC), as well as off-highway motorcycles. Honda is by far the largest producer of off-highway motorcycles, with over 45 percent of the total production for sale in the U.S. Figure 2.5-2 shows the market shares for the top five and the other producers, and Table 2.5-2 presents a list of the manufacturers of off-highway motorcycles.[94]

Figure 2.5-2



Source: ICF Consulting, Docket A-2000-01, Document II-A-84.

Of the 25 firms that manufacture off-highway motorcycles for the U.S. market, six are U.S. manufacturers. With the exception of Cannondale, which is primarily a bicycle manufacturer, all of these companies produce only motorcycles. Italy has five manufacturers. One of these, Cagiva, is mainly a producer of on-highway motorcycles. Piaggio is primarily a motorscooter manufacturer; Betamotor makes motorscooters and trials bikes. Lem and Polini manufacture youth motorcycles. Spanish manufacturers of off-highway motorcycles that are imported to the U.S. include Gas Gas Motos, primarily an observed trials bike manufacturer, and Montesa, which is owned by Honda. Other manufacturing companies whose products are imported into the U.S. market are also found in Austria, Belarus, Ireland, Korea, Sweden, Taiwan, and the United Kingdom. KTM, an Austrian company with a U.S. branch, is one of the five major producers for the U.S. market.

The 20 other manufacturers accounted for the remaining 15 percent of production for sale in the U.S. Six of these firms, accounting for approximately 3 percent of total production for the U.S. market, are located in this country. Dun and Bradstreet employee data are available for four of the six U.S. manufacturers, indicating that these are small businesses according to the SBA definition.

Our contractor has also identified 16 off-highway motorcycle importers. Eight of these are U.S.-owned. Dun and Bradstreet data are available for five of the eight U.S. importers, indicating that they are small businesses though it seems likely that all eight are small businesses.

Table 2.5-2
U.S. Off-Highway Motorcycle Manufacturers/Importers [95]

Firm Name	Type
ACTION POLINI	IMPORTER
BETA USA	IMPORTER
CODY RACING PRODUCTS	IMPORTER
COSMOPOLITAN MOTORS INC.	IMPORTER
CRE IMPORTS/E-LINE ACCESSORIES	IMPORTER
GAS GAS NORTH AMERICA	IMPORTER
HUSQVARNA USA	IMPORTER
KASEA MOTORSPORTS	IMPORTER
KTM SPORTMOTORCYCLE USA, INC.	IMPORTER
MIDWEST MOTOR VEHICLES, INC.	IMPORTER
TRANSNATIONAL OUTDOOR POWER, LLC	IMPORTER
TRYALS SHOP	IMPORTER
TWS-USA INC.	IMPORTER
U.S. MONTESA	IMPORTER
UNITED MOTORS OF AMERICA	IMPORTER
VOR MOTORCYCLES USA	IMPORTER
AMERICAN DIRT BIKE INC. (U.S.)	MANUFACTURER
ATK MOTORCYCLES (U.S.)	MANUFACTURER
BETAMOTOR SPA (ITALY)	MANUFACTURER
CAGIVA MOTORCYCLE SPA (ITALY)	MANUFACTURER
CANNONDALE CORP - BEDFORD (U.S.)	MANUFACTURER
CCM MOTORCYCLES LTD (U.K.)	MANUFACTURER
COBRA MOTORCYCLE MFG. (U.S.)	MANUFACTURER
GAS GAS MOTOS SPA (SPAIN)	MANUFACTURER
HM MOTORCYCLES (U.S.)	MANUFACTURER
HONDA MOTORCYCLES (JAPAN)	MANUFACTURER
HUSABERG MOTOR AB (SWEDEN)	MANUFACTURER
HYOSUNG MOTORS AND MACHINERY (KOREA)	MANUFACTURER

KAWASAKI HEAVY INDUSTRIES (JAPAN)	MANUFACTURER
KTM SPORT MOTORCYCLE AG (AUSTRIA)	MANUFACTURER
LEM MOTOR SAS (ITALY)	MANUFACTURER
MADFAST MOTORCYCLES (IRELAND)	MANUFACTURER
MINSK MOTOVELOZAVOD (BELARUS)	MANUFACTURER
MONTESA-HONDA ESPANA, SA (SPAIN)	MANUFACTURER
PIAGGIO GROUP (ITALY)	MANUFACTURER
POLINI (ITALY)	MANUFACTURER
REV! MOTORCYCLES (U.S.)	MANUFACTURER
SUZUKI (JAPAN)	MANUFACTURER
TAI LING MOTOR COMPANY LTD. (TAIWAN)	MANUFACTURER
VOR MOTORI (ITALY)	MANUFACTURER
YAMAHA MOTOR COMPANY LTD. (JAPAN)	MANUFACTURER

2.5.1.6 Engine Manufacturers

For the majority of off-highway motorcycles, the vehicle manufacturer is also the engine manufacturer. However, a few motorcycle manufacturers use engines produced by other firms. ATK Motorcycles and CCM Motorcycles Ltd. use Bombardier/Rotax engines, while the Tai Ling Motor Company uses Suzuki engines. The Spanish manufacturer, Gas Gas Motos, noted primarily for its observed trials machines, produces some of its own engines and buys others from Cagiva, a large Italian manufacturer. One U.S. manufacturer, Rokon, markets a low-production trail motorcycle resembling a large motorscooter. This vehicle type is intended for hunters and fishermen. Rokon uses industrial-type engines made by Honda and other manufacturers which are regulated under the EPA Small SI regulations. Therefore, Rokon is not included here.

As Table 2.5-3 shows the average value of shipments (VOS) for this industry over the 1992 to 1999 time period is equal to approximately 2.8 billion dollars, with the highest value of shipments occurring in 1998. The cost of materials for this industry is equal to an average of almost 1.6 billion dollars (57 percent of VOS). The average cost of labor is approximately 347 million (19 percent of VOS), while capital expenditures are equal to an average value of 26.7 million (1 percent of VOS). Examination of this data clearly shows that capital expenditures represent the smallest share of the value of shipments while the cost of materials represents the largest share.

Table 2.5-3
Value of Shipments (VOS) and Production Costs for the SIC and NAICS Codes that Include Off-Highway Motorcycle Manufacturers, 1992 - 1999 [96,97,98,99]

		VOS	Payroll		Cost of Materials		Total Capital Expenditures	
Year	Industry Code	($$10^6$)	($$10^6$)	% of VOS	($$10^6$)	% of VOS	($$10^6$)	% of VOS
1992	SIC 3751	1,878.9	301.7	16%	1,146.2	61%	10.6	1%
1993	SIC 3751	1,878.3	409.3	22%	1,362.0	73%	13.0	1%
1994	SIC 3537	2,632.1	482.6	18%	1,488.6	57%	14.2	1%
1995	SIC 3537	2,832.9	502.6	18%	1,541.6	54%	15.4	1%
1996	SIC 3537	3,094.0	565.1	18%	1,673.9	54%	17.9	1%
1997	NAICS 336991	3,382.6	662.3	20%	1,802.3	53%	19.5	1%
1998	NAICS 336991	3,343.8	620.3	19%	1,740.7	52%	9.6	0
1999	NAICS 336991	3,066.1	576.1	19%	1,611.3	53%	7.2	0
	Average	2,776.8	347.1	19%	1,559.1	57%	26.7	1%

* Value of Shipments, Payroll, Cost of Materials, and Total Capital Expenditures are in nominal U.S. dollars

2.5.2 The Demand Side

This section provides information on the uses of off-highway motorcycles, the various substitute products on the market, and the consumers who purchase off-highway motorcycles.

2.5.2.1 Uses of Off-Highway Motorcycles

Motorcycles are used for a for a variety of purposes, including recreation, touring, commuting, and on- and off-road racing. There are generally three motorcycle model types, on-highway, dual(both on highway and off-highway), and off-highway. On-highway motorcycles are certified by the manufacture as being in compliance with the Federal Motor Vehicle Safety Standards (FMVSS), and are designed for use on public roads. On-highway motorcycles include scooters, but excludes mopeds (limited speed motor-driven cycles under 50cc, with or without fully operative pedals). Dual motorcycles are certified by the manufacturer as being in compliance with FMVSS, and are designed with the capability for use on public roads, as well as off-highway recreational use. Off-highway motorcycles are not certified by the manufacturer to be in compliance with FMVSS for on-highway use. This category includes competition motorcycles. Table 2.5-4 show that off-highway motorcycles represents nearly 15% of the total population in 1998 and nearly 18% in 1998.

Table 2.5-4
Estimated Population By Model Type
1990 and 1998 [100]

MODEL TYPE	1990 NUMBER OF MOTORCYCLES	1998 NUMBER OF MOTORCYCLES
On-Highway	3,650,000 (72.3%)	4,809,000 (73%)
Dual	660,000 (13%)	565,000 (8.6%)
Off-Highway	750,000 (14.8%)	1,196,000 (18.2%)
Total	5,060,000 (100%)	6,570,000 (100%)

2.5.2.2 Substitution Possibilities

Consumers can substitute across off-road recreational vehicles. As a substitute, an ATV would allow the consumer to enjoy the same off-road recreation that they would receive with an off-highway motorcycle. Consumers may be interested in engaging in outdoor activities, but may instead consider doing a non-motorized activity. For example, consumers who are interested in being outside may engaging in hiking, running, or riding a bicycle. These non-motorized options will also allow the consumer to participate in outdoor activity, but they may be considered substitutes for less intensive off-highway past times. Indeed, any type of recreational activity may be viewed as a substitute for off-highway motorcycle usage.

2.5.3 Industry Organization

Because there are costs associated with the emission control program, it is important to determine how the off-highway motorcycle industry may be affected. Industry organization is an important factor which affects how an industry may react to regulatory costs. This section provides a description of the organization of the motorcycle industry.

2.5.3.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in production. This condition is most likely to hold if the industry has a large number of buyers and sellers, the products sold and inputs used are homogeneous, and entry and exit of firms is unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firm is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and the Herfindahl-Hirschman index (HHI) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the six digit NAICS code level for the year 1997, the most recent year available. Table 2.5-5 provides the four- and eight-firm concentration ratios (CR4 and CR8, respectively), and the Herfindahl-Hirschman index for the Motorcycle, Bicycle, and Parts Manufacturing industry, the industry that includes producers of off-highway motorcycles. This industry is represented by NAICS code 336991. For this industry the CR4 was 67.5 percent and the CR8 was 76.7 percent.

The criteria for evaluating the HHI are based on the 1992 Department of Justice Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries have more ability to influence market prices. Though the HHI measure for this industry is high, we have chosen to model is as a perfectly competitive market. We have made this choice based on the number of recreational substitute available for off-highway motorcycles.

Table 2.5-5
Measures of Market Concentration for the
NAICS Code that Includes Off-Highway Motorcycle Manufacturers, 1997 [101]

Description	CR4	CR8	HHI	VOS ($\$10^6$)	Number of Companies
NAICS 336991	67.5	76.7	2,036.5	$3,382,689	373

2.5.3.2 Motorcycle Manufacturers

As mentioned above, motorcycles are included under Standard Industrial Classification (SIC) 3751. The U.S. motorcycle industry is relatively small compared to other industries such as the automobile industry. There are over 40 U.S. firms (Table 2.5-2) engaged in the manufacture and/or distribution of off-highway motorcycles. Six of these firms accounted for 90 percent of the new motorcycle units produced in the United States in 2000. Table 2.5-6 shows the ranking and market share for the major producers in the industry for 1999 and 2000.

Table 2.5-6
Motorcycle Manufacturers by Market Share 1999-2000 [102]

BRAND	1999 RANK	1999 MARKET SHARE	2000 RANK	2000 MARKET SHARE
Honda	2	24.1%	1	25.0%
Harley-Davidson	1	25.5%	2	23.0%
Yamaha	3	17.8%	3	19.3%
Suzuki	5	10.8%	4	11.2%
Kawasaki	4	11.8%	5	10.2%
BMW	6	1.9%	6	1.7%
All Others	--	8.1%	--	9.6%

In the off-highway segment, the top five manufacturers were Honda , Kawasaki, KTM, Suzuki, and Yamaha. Table 2.5-7 shows the market share among the major producers. U.S. off-highway motorcycle production by the top five firms steadily rose over the 1996 to 2000 time period, with a slight dip in 1999.

Table 2.5-7
Off-Highway Motorcycle Units Manufactured by the Top Five Firms 1996-1999 [103]

Company	1996	1997	1998	1999	2000	1996-2000 TOTAL	1996-2000 MARKET SHARE
Honda	45,694	51,281	56,678	53,706	68,924	276,283	48.0%
Suzuki	17,022	19,200	18,694	10,617	11,039	76,572	13.3%
Yamaha	23,862	29,231	25,230	26,079	20,406	124,808	21.7%
Kawasaki	12,687	12,147	13,249	12,885	14,560	66,528	11.5%
KTM	2,778	3,146	3,783	7,236	14,747	31,690	5.5%
Total	102,043	116,005	117,634	110,523	129, 676	575,881	100%

2.5.3.3 Small Businesses

The motorcycle companies listed in Table 2.5-2 can be grouped into small and large business categories using the Small Business Administration (SBA) general size standard definitions for NAICS codes. The SBA defines a small business in terms of the employment or annual sales of the owning entity and these thresholds vary by industry. Based on the size standard for NAICS 336991, several of the motorcycle producers are considered small businesses.

2.5.4 Markets

This section examines the historical market statistics for the off-highway motorcycle manufacturing industry. Historical data on the quantity of domestic shipments and price data of off-highway motorcycles are provided. The quantity and values of imports and exports for motorcycles are presented as well.

2.5.4.1 Quantity and Price Data

Historical market data on the quantity of U.S. unit sales of off-highway motorcycles are provided in Table 2.5-8. Data were obtained from the Motorcycle Industry Council (MIC). As this table shows, there has been an overall increasing trend in the quantity of off-highway motorcycles sold in the U.S. with an overall net increase of 290 percent and the retail value of off-highway motorcycle increased by nearly 40 percent from 1990 to 2000.

Table 2.5-8
U.S. Units Sold, Retail Dollars and
Retail Dollars Per Unit Off-Highway Motorcycles, 1990 - 2001 [104]

Year	Unit Sales	Retail Dollars	Retail Dollars/Unit
1990	39,221	$63,745,225	$1,625
1991	37,363	$63,670,177	$1,704
1992	39,345	$68,038,926	$1,729
1993	39,863	$75,033,960	$1,882
1994	40,991	$84,844,505	$2,070
1995	40,791	$94,125,405	$2,308
1996	45,266	$111,001,200	$2,452
1997	49,168	$119,041,853	$2,421
1998	59,930	$133,062,004	$2,220
1999	77,875	$170,303,959	$2,187
2000	120,501	$279,984,888	$2,324
2001	195,250	$334,983,201	$2,253

* Values are in nominal dollars.

2.5.4.2 Foreign Trade

Export and import values and quantities for off -highway motorcycle are presented in Table 2.2-9. These data show increasing trends for export and import values since 1989. Note these data reflect imports and exports for SIC 3751, motorcycles, bicycles, and parts.

Table 2.5-9
Import and Export Quantities and Values for Off-Highway Motorcycles, 1989 - 2001[105]

Year	Export Value (1,000 Dollars)	Export Quantity (1,000 Dollars)	Import Value (1,000 Dollars)	Import Quantity (1,000 Units)
1989	$244,722	$319	$1,325,309	32,829
1990	$419,911	$480	$1,216,239	37,164
1991	$615,439	$796	$1,370,364	40,850
1992	$671,331	$846	$1,574,380	37,823
1993	$702,831	$1,053	$1,758,664	42,767
1994	$711,053	$739	$1,800,564	40,322
1995	$850,229	$721	$2,178,559	43,937
1996	$906,040	$626	$2,046,358	41,868
1997	$976,494	$692	$2,117,154	48,622
1998	$918,277	$662	$2,445,434	45,565
1999	$738,152	$823	$2,993,162	43,008
2000	$798,357	$673	$3,898,859	37,846
2001	$967,947	$480	$3,895,486	26,592
Average	$732,368	$685	$2,201,579	39,938

* Values are in nominal dollars and reflect values for SIC 3751 Motorcycles, Bicycles, and Parts.

Chapter 2 References

1. “Recreational Boating Industry Characterization,” ICF Consulting, Contract No. 68-C-98-170, WAN 0-5, August, 1999, Docket A-2000-01, Document II-A-9.

2. Boating Industry Magazine, “1997 Annual Industry Reviews: The Boating Business”, January 1998. Docket A-2000-01, Document IV-A-116.

3. Dun & Bradstreet. 2001.

4. National Marine Manufacturers Association - http://www.nmma.org. Docket A-2000-01, Document IV-A-51.

5. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Docket A-2000-01, Document IV-A-53.

6. U.S. EPA. 1999. Economic Impact Analysis of the Proposed Boat Manufacturing NESHAP. Air Quality Strategies and Standards Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. EPA-452/R-99-005. November.

7. U.S. Department of Commerce. 2001. *1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58.

8. U.S. Department of Commerce. 2000. *1998 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-59.

9. U.S. Department of Commerce. 1999. *1997 Economic Census - Boat Building* Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-64.

10. U.S. Department of Commerce. 1998. *1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-65.

11. U.S. Department of Commerce. 1997. *1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

12. U.S. Department of Commerce. 1996. *1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

13. U.S. Department of Commerce. 1995. *1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-

2000-01, Document IV-A-68.

14. U.S. Department of Commerce. 2001. *1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58.

15. U.S. Department of Commerce. 2000. *1998 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-59.

16. U.S. Department of Commerce. 1999. *1997 Economic Census - Other Engine Equipment Manufacturing*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-62.

17. U.S. Department of Commerce. 1998. *1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-65.

18. U.S. Department of Commerce. 1997. *1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

19. U.S. Department of Commerce. 1996. *1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

20. U.S. Department of Commerce. 1995. *1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-68.

21. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/. Docket A-2000-01, Document IV-A-50.

22. National Marine Manufacturing Association. Boating 1998 - Facts and Figures at a Glance. http://63.236.237.146/facts/boatingstats/boating98.html.. Docket A-2000-01, Document IV-A-52.

23. U.S. Department of Commerce. 2001. *1997 Economic Census - Concentration Ratios in Manufacturing*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

24. U.S. Department of Commerce. 2001. *1997 Economic Census - Concentration Ratios in Manufacturing*. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

25. Wards Business Directory. 2001.

26. Dun & Bradstreet. 2001.

27. American Business Directory. 2000.

28. Wards Business Directory. 2001.

29. Dun & Bradstreet. 2001.

30. American Business Directory. 2000.

31. National Marine Manufacturing Association. *U.S. Recreational Boating Domestic Shipment Statistics, 1970 - 1998*. http://63.236.237.146/facts/history.pdf.. Docket A-2000-01, Document IV-A-49.

32. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/. Docket A-2000-01, Document IV-A-50.

33. National Marine Manufacturing Association. *U.S. Recreational Boating Domestic Shipment Statistics, 1970 - 1998*. http://63.236.237.146/facts/history.pdf. Docket A-2000-01, Document IV-A-49.

34. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/. Docket A-2000-01, Document IV-A-50.

35. National Marine Manufacturing Association. *U.S. Recreational Boating Domestic Shipment Statistics, 1970 - 1998*. http://63.236.237.146/facts/history.pdf. Docket A-2000-01, Document IV-A-49.

36. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/. Docket A-2000-01, Document IV-A-50.

37. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/. Docket A-2000-01, Document IV-A-50.

38. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Table 4 - Product Analysis: Inboard Boats, Imports. Docket A-2000-01, Document IV-A-53.

39. National Marine Manufacturing Association. 2002. Supplemental Tables for Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Sterndrive Boats, Imports. Docket A-2000-01, Document IV-A-54.

40. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Table 4 - Product Analysis: Inboard Boats,

Exports. Docket A-2000-01, Document IV-A-53.

41. National Marine Manufacturing Association. 2002. Supplemental Tables for Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Sterndrive Boats, Exports. Docket A-2000-01, Document IV-A-54.

42. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Table 3 - Inboard Engines - Imports. Docket A-2000-01, Document IV-A-53.

43. National Marine Manufacturing Association. 2002. Supplemental Tables for Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Sterndrive Engines, Imports. Docket A-2000-01, Document IV-A-54.

44. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Table 3 - Inboard Engines - Imports. Docket A-2000-01, Document IV-A-53.

45. National Marine Manufacturing Association. 2002. Supplemental Tables for Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Sterndrive Engines, Exports. Docket A-2000-01, Document IV-A-54.

46.“The Role of Propane in the Fork Lift/Industrial Truck Market: A Study of its Status, Threats, and Opportunities,” Robert E. Myers for the National Propane Gas Association, December 1996, Docket A-98-01, Document II-D-2. Docket A-2000-01, Document II-A-86.

47. See footnote 46.

48. Industrial Truck Association. 2002. Membership Handbook. A copy of the relevant pages can be found in Docket A-2000-01, Document No. IV-A-188.

49. U.S. Department of Commerce. 2001. 1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58.

50. U.S. Department of Commerce. 2000. 1998 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-59.

51. U.S. Department of Commerce. 1999. 1997 Economic Census - Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-63.

52. U.S. Department of Commerce. 1998. 1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-

01, Document IV-A-65.

53. U.S. Department of Commerce. 1997. 1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

54. U.S. Department of Commerce. 1996. 1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

55. U.S. Department of Commerce. 1995. 1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-68.

56. See footnote 46.

57. See footnote 48.

58. U.S. International Trade Commission. 1996. Industry and Trade Summary: Forklift Trucks and Related Vehicles. Washington, DC. Docket A-2000-01, Document IV-A-189

59. U.S Department of Commerce. 2001. 1997 Economic Census - Concentration Ratios in Manufacturing. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

60. See footnote 48.

61. American Business Information. 2002. American Business Directory Electronic Database.

62. Dun & Bradstreet. 2002. Dun and Bradstreet Market Identifiers Electronic Database.

63. Ward's Business Directory, 53rd edition.

64. See footnote 48.

65. See footnote 13.

66. International Trade Commission. 2002. ITCDataWeb. Docket A-2000-01, Document IV-A-187.

67. International Snowmobile Association . www.snowmobile.org. June 2002. Docket A-2000-01, Document IV-A-128 and IV-A-136.

68. Production data were taken from OELINK Database owned by Power Systems Research.

69. Production data were taken from OELINK Database owned by Power Systems Research.

70. U.S. Department of Commerce. 2002. Statistics for Industry Groups and Industries: 2000. Annual Survey of Manufacturers Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-117.

71. U.S. Department of Commerce. 1998. 1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-65.

72. U.S. Department of Commerce. 1997. 1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

73. U.S. Department of Commerce. 1996. 1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

74. U.S. Department of Commerce. 1995. 1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-68.

75. Memo to Docket A-98-01 from Linc Wehrly, regarding Emission Modeling for Recreational Vehicles. Docket A-2000-01, Document II-B-19.

76. International Snowmobile Manufacturers Association. www.snowmobile.org. June. Docket A-2000-01, Documents IV-A-112 and Docket A-2000-01, Document IV-A-136.

77. US Department of Commerce. 1997 Economic Census - Concentration Ratio in Manufacturing. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

78. USEPA. June 1998. "Regulatory Impact Analysis of Cement Kiln Dust Rulemaking." Final report prepared by Research Triangle Institute for Office of Air Quality Planning and Standards, RTP, North Carolina. See also USEPA. July 1996. "Economic Analysis of Air Pollution Regulations: Portland Cement." Final report prepared by Research Triangle Institute for Office of Air Quality Planning and Standards, RTP, North Carolina.

79. International Snowmobile Manufacturers Association. www.snowmobile.org. June 2002. Docket A-2000-01, Document IV-A-128 and IV-A-136.

80. International Snowmobile Manufacturers Association. www.snowmobile.org. June 2002. Docket A-2000-01, Document IV-A-128 and IV-A-136.

81. International Snowmobile Manufacturers Association. www.snowmobile.org. June 2002. Docket A-2000-01, Document IV-A-128 and IV-A-136.

82. ICF Consulting. 2001. Industry Characterization of Non-Road Recreational Vehicles, Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, September 13, 2001. Docket A-2000-01, Document II-A-84.

83. U.S. Department of Commerce. 2002. Statistics for Industry Groups and Industries: 2000. Annual Survey of Manufacturers Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-117.

84. U.S. Department of Commerce. 1998. 1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-65.

85. U.S. Department of Commerce. 1997. 1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

86. U.S. Department of Commerce. 1996. 1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

87. U.S. Department of Commerce. 1995. 1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-68.

88. US Department of Commerce. 1997 Economic Census - Concentration Ratio in Manufacturing. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

89. Motorcycle Industry Council, Inc. 2002. Docket A-2000-01, Document No. IV-A-138.

90. International Trade Commission. 2002. ITC Data Web. Docket A-2000-01, Document IV-A-193.

91. U.S. Environmental Protection Agency, Office of Transportation and Air Quality, 2001. Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines. Ann Arbor, MI. EPA 420-D-01-004. Docket A-2000-01, Document III-B-02 . This document is available on our website, www.epa.gov/otaq/regs/nonroad/proposal

92. ICF Consulting. 2001. Industry Characterization of Non-Road Recreational Vehicles, Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, September 13, 2001. Docket A-2000-01, Document II-A-84.

93. ICF Consulting. 2001. Industry Characterization of Non-Road Recreational Vehicles, Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, September 13, 2001. Docket A-2000-01, Document II-A-84.

94. ICF Consulting. 2001. Industry Characterization of Non-Road Recreational Vehicles, Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, September 13, 2001. Docket A-2000-01, Document II-A-84.

95. ICF Consulting. 2001. Industry Characterization of Non-Road Recreational Vehicles, Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, September 13, 2001. Docket A-2000-01, Document II-A-84.

96.U.S. Department of Commerce. 1998. 1996 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-65.

97.U.S. Department of Commerce. 1997. 1995 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-66.

98.U.S. Department of Commerce. 1996. 1994 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-67.

99.U.S. Department of Commerce. 1995. 1993 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-68.

100.See footnote 90.

101.US Department of Commerce. 1997 Economic Census - Concentration Ratio in Manufacturing. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-57.

102.See footnote 90.

103.See footnote 90.

104. Motorcycle Industry Council, Inc. 2002. Docket A-2000-01, Document No. IV-A-138.

105.International Trade Commission. 2002. ITC Data Web. Docket A-2000-01, Document IV-A-193.

Chapter 3: Technology

This chapter describes the current state of spark-ignition technology for engines, evaporative emission technology, and compression-ignition technology for marine engines, as well as the emission control technologies expected to be available for manufacturers. Chapter 4 presents the technical analysis of the feasibility of the standards.

3.1 Introduction to Spark-Ignition Engine Technology

The two most common types of engines are gasoline-fueled engines and diesel-fueled engines. These engines have very different combustion mechanisms. Gasoline-fueled engines initiate combustion using spark plugs, while diesel fueled engines initiate combustion by compressing the fuel and air to high pressures. Thus these two types of engines are often more generally referred to as "spark-ignition" and "compression-ignition" (or SI and CI) engines, and include similar engines that used other fuels. SI engines include engines fueled with liquefied petroleum gas (LPG) and compressed natural gas (CNG).

3.1.1 Four-Stroke Engines

Four-stroke engines are used in many different applications. Virtually all automobiles and many trucks are powered by four-stroke SI engines. Four-stroke engines are also very common in motorcycles, all-terrain vehicles (ATVs), boats, airplanes, and numerous nonroad applications such as lawn mowers, lawn and garden tractors, and generators, to name just a few.

A “four-stroke” engine gets it’s name from the fact that the piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, power, and exhaust. Two of the strokes are downward (intake & power) and two of the strokes are upward (compression & exhaust). Valves in the combustion chamber open and close to route gases into and out of the combustion chamber or create compression.

The first step of the cycle is for an intake valve in the combustion chamber to open during the “intake” stroke allowing a mixture of air and fuel to be drawn into the cylinder while an exhaust valve is closed and the piston moves down the cylinder. The piston moves from top dead center (TDC) or the highest piston position to bottom dead center (BDC) or lowest piston position. This creates a vacuum or suction in the cylinder, which draws air and fuel past the open intake valve into the combustion chamber.

The intake valve then closes and the momentum of the crankshaft causes the piston to move back up the cylinder from BDC to TDC, compressing the air and fuel mixture. This is the “compression” stroke. As the piston nears TDC, at the very end of the compression stroke, the air and fuel mixture is ignited by a spark from a spark plug and begins to burn. As the air and fuel mixture burns, increasing temperature and pressure cause the piston to move back down the cylinder, transmitting power to the crankshaft. This is referred to as the “power” stroke. The last stroke in the four-stroke cycle is the “exhaust” stroke. At the bottom of the power stroke, an exhaust valve opens in the combustion chamber and as the piston moves back up the cylinder, the burnt gases are pushed out through the exhaust valve to the exhaust manifold, and the cycle is complete.

3.1.2 Two-Stroke Engines

Two-stroke SI engines are widely used in nonroad applications, especially for recreational vehicles, such as snowmobiles, off-highway motorcycles and ATVs. 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 recreational vehicles: high power-to-weight ratios; simplicity; ease of starting; and lower manufacturing costs. However, they also have much higher emission rates.

Another difference between two- and four-stroke engines is how the engines are lubricated. Four-stroke engines use the crankcase as a sump for lubricating oil. Oil is distributed throughout the engine by a pump through a series of small channels. Because the crankcase in a two-stroke engine serves as the pump for the scavenging process, it is not possible to use it as an oil sump as is the case for four-stroke engines. Otherwise, gasoline would mix with the oil and dilute it. Instead, lubrication for two-stroke engines is provided by mixing specially-formulated two-stroke oil with the incoming charge of air and fuel mixture. The oil is either mixed with the gasoline in the fuel tank, or metered into the gasoline as it is consumed, using a small metering pump. As the gasoline/oil mixture passes through the carburetor, it is atomized into fine droplets and mixed with air. The gasoline quickly vaporizes, while the less volatile oil forms a fine mist of fine droplets. Some of these droplets contact the crankshaft, piston pin, and cylinder walls, providing lubrication. Most of the oil droplets, however, pass out of the crankcase and into the cylinder with the rest of the incoming charge.

In a two-stroke engine, combustion occurs in every revolution of the crankshaft. Two-stroke engines eliminate the intake and exhaust strokes, leaving only compression and power strokes. This is due to the fact that two-stroke engines do not use intake and exhaust valves. Instead, they have openings, referred to as “ports,” in the sides of the cylinder walls. There are typically three ports in the cylinder; an intake port that brings the air-fuel mixture into the crankcase; a transfer port that channels the air and fuel mixture from the crankcase to the combustion chamber; and an exhaust port that allows burned gases to leave the cylinder and flow into the exhaust manifold. Two-stroke engines route incoming air and fuel mixture first into the crankcase, then into the cylinder via the transfer port. This is fundamentally different from a four-stroke engine which delivers the air and fuel mixture directly to the combustion chamber.

With a two-stroke engine, as the piston approaches the bottom of the power stroke, it uncovers exhaust ports in the wall of the cylinder. The high pressure burned combustion gases blow into the exhaust manifold. At the same time, downward piston movement compresses the fresh air and fuel mixture charge in the crankcase. As the piston gets closer to the bottom of the power stroke, the transfer ports are uncovered, and fresh mixture of air and fuel are forced into the cylinder while the exhaust ports are still open. Exhaust gas is “scavenged” or forced into the exhaust by the pressure of the incoming charge of fresh air and fuel. In the process, however, some mixing between the exhaust gas and the fresh charge of air and fuel takes place, so that some of the fresh charge is also emitted in the exhaust. Losing part of the fuel out of the exhaust during scavenging causes the very high hydrocarbon emission characteristics of two-stroke engines.

At this point, the power, exhaust, and transfer events have been completed. When the piston begins to move up, its bottom edge uncovers the intake port. Vacuum draws fresh air and fuel into the crankcase. As the piston continues upward, the transfer port and exhaust ports are closed. Compression begins as soon as the exhaust port is blocked. When the piston nears TDC, the spark plug fires and the cycle begins again.

3.1.3 - Engine Calibration

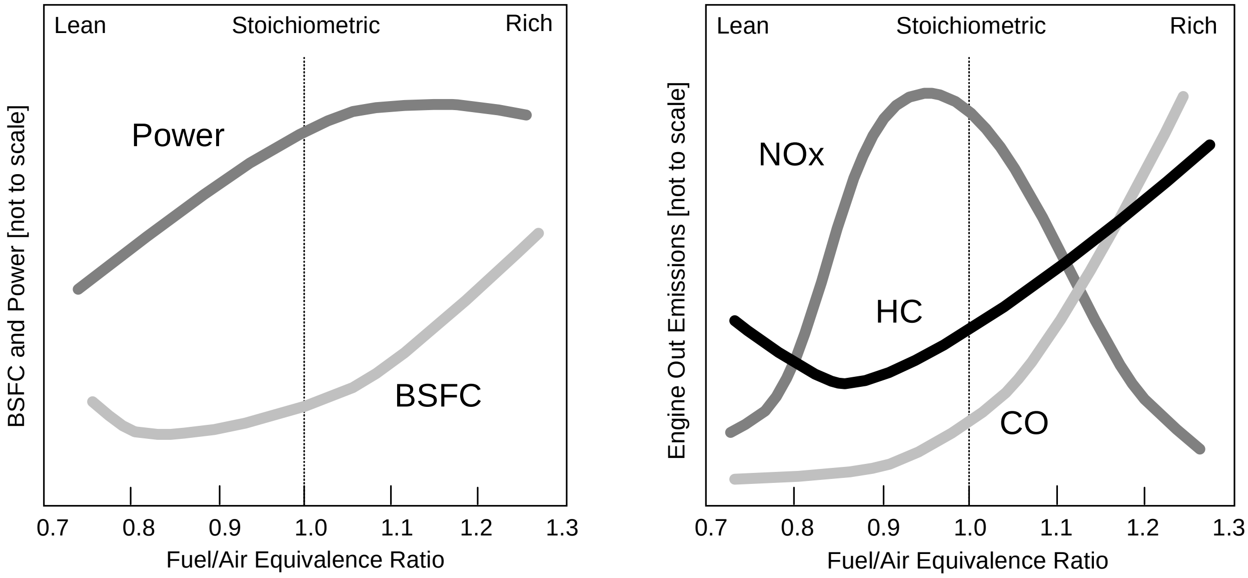
For most current SI engines, the two primary variables that manufacturers can control to reduce emissions are the air and fuel mixture (henceforth referred to as air-fuel ratio) and the spark timing. For highway motorcycles, these two variables are the most common methods for controlling exhaust emissions. However, for many nonroad engines and vehicles, the absence of emission standards have resulted in air-fuel ratio and spark timing calibrations optimized for engine performance and durability rather than for low emissions.

3.1.3.1 Air-fuel ratio

The calibration of the air-fuel mixture affects power, fuel consumption (referred to as Brake Specific Fuel Consumption (BSFC)), and emissions for SI engines. The effects of changing the air-fuel mixture are shown in Figure 3.1-1.[1] Traditionally, in most nonroad SI applications, manufacturers have calibrated their fuel systems for rich operation for two main advantages. First, by running the engine rich, manufacturers can reduce the risk of lean misfire due to imperfect mixing of the fuel and air and variations in the air-fuel mixture from cylinder to cylinder. Second, by making extra fuel available for combustion, it is possible to get more power from the engine. At the same time, since a rich mixture lacks sufficient oxygen for full combustion, it results in increased fuel consumption rates and higher HC and CO emissions. As can be seen from the figure, the best fuel consumption rates occur when the engine is running lean.

With the use of more advanced fuel systems, manufacturers would be able to improve control of the air-fuel mixture in the cylinder. This improved control allows for leaner operation without increasing the risk of lean misfire. This reduces HC and CO emissions and fuel consumption. Leaner air-fuel mixtures, however, increase NOx emissions due to the higher temperatures and increased supply of oxygen.

Figure 3.1-1: Effects of Air-fuel Ratio on Power, Fuel Consumption, and Emissions



3.1.3.2 Spark-timing:

For each engine speed and air-fuel mixture, there is an optimum spark-timing that results in peak torque. If the spark is advanced to an earlier point in the cycle, more combustion occurs during the compression stroke. If the spark is retarded to a later point in the cycle, peak cylinder pressure is decreased because too much combustion occurs later in the expansion stroke when it generates little torque on the crankshaft. Timing retard may be used as a strategy for reducing NOx emissions, because it suppresses peak cylinder temperatures that lead to high NOx levels. Timing retard also results in higher exhaust gas temperatures, because less mechanical work is extracted from the available energy. This may have the benefit of warming catalyst material to more quickly reach the temperatures needed to operate effectively during light-load operation.[2] Some automotive engine designs rely on timing retard at start-up to reduce cold-start emissions.

Advancing the spark-timing at higher speeds gives the fuel more time to burn. Retarding the spark timing at lower speeds and loads avoids misfire. With a mechanically controlled engine, a fly-weight or manifold vacuum system adjusts the timing. Mechanical controls, however, limit the manufacturer to a single timing curve when calibrating the engine. This means that the timing is not completely optimized for most modes of operation.

3.1.3.3 - Fuel Metering

Fuel injection has proven to be an effective and durable strategy for controlling emissions and reducing fuel consumption from highway gasoline engines. Comparable upgrades are also available for gaseous fuels. This section describes a variety of technologies available to improve fuel metering.

Throttle-body gasoline injection: A throttle-body system uses the same intake manifold as a carbureted engine. However, the throttle body replaces the carburetor.   By injecting the fuel into the intake air stream, the fuel is better atomized than if it were drawn through with a venturi. This results in better mixing and more efficient combustion. In addition, the fuel can be more precisely metered to achieve benefits for fuel economy, performance, and emission control.

Throttle-body designs have the drawback of potentially large cylinder-to-cylinder variations. Like a carburetor, TBI injects the fuel into the intake air at a single location upstream of all the cylinders. Because the air-fuel mixture travels different routes to each cylinder, the amount of fuel that reaches each cylinder will vary. Manufacturers account for this variation in their design and may make compromises such as injecting extra fuel to ensure that the cylinder with the leanest mixture will not misfire. These compromises affect emissions and fuel consumption.

Multi-port gasoline injection: As the name suggests, multi-port fuel injection means that a fuel injector is placed at each of the intake ports. A quantity of fuel is injected each time the intake valve opens for each cylinder. This allows manufacturers to more precisely control the amount of fuel injected for each combustion event. This control increases the manufacturer’s ability to optimize the air-fuel ratio for emissions, performance, and fuel consumption. Because of these benefits, multi-port injection is has been widely used in automotive applications for over 15 years.

Sequential injection has further improved these systems by more carefully timing the injection event with the intake valve opening. This improves fuel atomization and air-fuel mixing, which further improves performance and control of emissions.

A newer development to improve injector performance is air-assisted fuel injection. By injecting high pressure air along with the fuel spray, greater atomization of the fuel droplets can occur. Air-assisted fuel injection is especially helpful in improving engine performance and reducing emissions at low engine speeds. In addition, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold. On a highway 3.8-liter engine with sequential fuel injection, the air assist was shown to reduce HC emissions by 27 percent during cold-start operating conditions. At wide-open-throttle with an air-fuel ratio of 17, the HC reduction was 43 percent when compared with a standard injector.[3]

3.1.4 - Alternate Fuels

Gaseous-fuel engines

Engines operating on LPG or natural gas carry compressed fuel that is gaseous at atmospheric pressure. The technical challenges for gasoline related to an extended time to vaporize the fuel don't apply to gaseous-fuel engines. Typically, a mixer introduces the fuel into the intake system. Manufacturers are pursuing new designs to inject the fuel directly into the intake manifold. This improves control of the air-fuel ratio and the combustion event, similar to the improvements in gasoline injection technology.

3.2 - Exhaust Emissions and Control Technologies

3.2.1 - Current Two-Stroke Engines

As discussed above, two-stroke engines are typically found in applications where light weight, low cost, simplistic design, easy starting, and high power-to-weight ratio are desirable attributes. Of the engines and vehicles and covered by this rulemaking, the engines found in recreational vehicles tend to have a high percentage of two-stroke engines. For example, almost all snowmobiles use two-stroke engines, while 40 percent of off-highway motorcycles are equipped with two-strokes. Approximately 20 percent of all ATVs use two-stroke engines.

California ARB has had exhaust emission standards for off-highway motorcycles and ATVs since 1996. However, the regulations allow the sales and use of non-certified vehicles within the state. Thus, recreational vehicles equipped with two-stroke engines have essentially been unregulated. As a result, two-stroke engines used in recreational vehicles are typically designed for optimized performance and durability rather than low emissions. Current two-stroke engines emit extremely high levels of HC and CO emissions. The scavenging of unburned fuel into the exhaust contributes to the bulk of the HC emissions. Up to 30 percent[j] of the air and fuel mixture (along with lubricating oil) can pass unburned from the combustion chamber to the exhaust, resulting not only in high levels of HC, but also in high levels of particulate matter (PM). As discussed above, two-stroke engines lubricate the engine by mixing specially-formulated two-stroke oil with gasoline. As the gasoline/oil mixture passes through the carburetor, it is atomized into fine droplets and mixed with air. The gasoline quickly vaporizes, while the less volatile oil forms a fine mist of fine droplets. Some of these droplets contact the crankshaft, piston pin, and cylinder walls, providing lubrication. Most of the oil droplets, however, pass out of the crankcase and into the cylinder with the rest of the incoming charge. Much of this oil mist will be trapped in the cylinder and burned along with the gasoline vapor. Since lubricating oil is less combustible than gasoline, some of the oil will survive the combustion process in the cylinder and be passed into the exhaust. In the hot exhaust, the oil may vaporize, however, as the exhaust cools and through mixing with air after it is emitted, the oil vapor recondenses into very fine droplets or particles and enter the atmosphere as PM.

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[j] Hare et al, 1974; Batoni, 1978; Nuti and Martorano, 1985

Another major source of unburned HC emissions from two-stroke engines is due to misfire or partial combustion at light loads. Under light load conditions such as idle, the flow of fresh air and fuel into the cylinder is reduced, and substantial amounts of exhaust gas are retained in the cylinder. This high fraction of residual gas leads to incomplete combustion or misfire, which is the source of the "popping" sound produced by two-stroke engines at idle and light loads. These unstable combustion events are major sources of unburned HC at idle and light load conditions.[k]

High CO levels from two-stroke engines are a result of operating the engine at rich air and fuel mixture levels to promote engine cooling and enhance performance. Two-stroke engines typically have very low levels of NOx emissions due to relatively cool combustion temperatures. Two-stroke engines have cooler combustion temperatures as a result of two phenomenon: rich air and fuel mixture operation and internal exhaust gas recirculation. Two-stroke engines tend to operate with a rich air and fuel mixture to increase power and to help cool the engine. Because many two-stroke engines are air-cooled, the extra cooling provided by operating rich is a desirable engine control strategy. Combustion with a rich air and fuel mixture results in some incomplete combustion which means less efficient combustion and a lower combustion temperature. High combustion temperature is the main variable in producing NOx emissions. Two-stroke engines also tend to have a high levels of naturally occurring exhaust gas recirculation due to the scavenging process where some of the burned gases are drawn back into the cylinder rather than being emitted out into the exhaust. The addition of burned exhaust gas into the fresh charge of air and fuel mixture in the combustion chamber also results in less complete or efficient combustion, which lowers combustion temperatures and reduces NOx emissions.

HC emissions for recreational vehicle two-stroke engines are approximately 25 times higher than for recreational vehicle four-stroke emissions. CO levels are roughly the same for both types of engines, while NOx levels are 1.5 times lower than four-stroke engine levels. Table 3.2-1 shows two-stroke emission results for several off-highway motorcycles and ATVs tested by and for EPA in grams per kilometer (g/km). Table 3.2-2 shows two-stroke emission results from snowmobiles in grams per horsepower-hour (g/hp-hr).

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[k] Tsuchiya et al, 1983; Abraham and Prakash, 1992; Aoyama et al, 1977

Table 3.2-1
Baseline Two-Stroke Emissions From Off-Highway Motorcycles & ATVs (g/km)

MC or ATV	Manufacturer	Model	Model Year	Eng. Displ.	HC	CO	NOx
ATV	Suzuki	LT80	1998	80 cc	7.66	24.23	0.047
ATV	Polaris	Scrambler 80	2001	90 cc	38.12	25.08	0.057
ATV	Polaris	Trailblazer	2000	250 cc	18.91	44.71	0.040
MC	KTM	125SX	2001	125 cc	33.71	31.01	0.008
MC	KTM	125SX	2001	125 cc	61.41	32.43	0.011
MC	KTM	200EXC	2001	200 cc	53.09	39.89	0.025
MC	Honda	n/a	1993	200 cc	8.00	16.00	0.010
MC	Honda	n/a	1993	200 cc	26.00	28.00	1.010
MC	Honda	n/a	1995	249 cc	12.00	21.00	0.010
MC	Honda	CR250R	1997	249 cc	17.47	36.62	0.004
MC	Honda	n/a	1998	249 cc	23.00	36.00	0.010
MC	KTM	250SX	2001	249 cc	62.89	49.29	0.011
MC	KTM	250EXC	2001	249 cc	59.13	40.54	0.016
MC	KTM	300EXC	2001	298 cc	47.39	45.29	0.0124
Average					33.56	33.51	0.091

Table 3.2-2
Baseline Two-Stroke Emissions From Snowmobiles (g/hp-hr)

Source	Eng. Displ.	HC	CO	NOx	PM
Carroll 1999 (SwRI) YNP	480 cc	115	375	0.69	0.7
White et al. 1997	488 cc	150	420	0.42	1.1
White et al. 1997	440 cc	160	370	0.50	3.4
Hare & Springer 1974	436 cc	89	142	1.40	6.1
Hare & Springer 1974	335 cc	120	235	1.80	2.5
Hare & Springer 1974	247 cc	200	63	3.40	2.6
Wright & White 1998	440 cc	130	380	0.42	n/a
Wright & White 1998	503 cc	105	400	0.73	n/a
ISMA #1	600 cc	110	218	0.86	n/a
ISMA #2	440 cc	95	312	1.62	n/a
ISMA #3	600 cc	106	196	1.30	n/a
ISMA #4	900 cc	95	215	0.84	n/a
ISMA #5	698 cc	92	298	0.34	n/a
ISMA #6	597 cc	100	328	0.30	n/a
ISMA #7	695 cc	88	345	0.24	n/a
ISMA #8	485 cc	148	385	0.56	n/a
ISMA #9	340 cc	104	297	0.84	n/a
ISMA #10	440 cc	95	294	0.56	n/a
ISMA #11	600 cc	94	262	0.81	n/a
ISMA #12	700 cc	102	355	0.69	n/a
ISMA #13	593 cc	67	288	0.57	n/a
ISMA #14	494 cc	105	400	0.43	n/a
ISMA #15	699 cc	92	276	0.50	n/a
Average		111	298	0.86	2.7

3.2.2 - Clean Two-Stroke Technologies

Technologies available for reducing two-stroke emissions can be grouped into several categories: calibration improvements; combustion chamber modifications; improved scavenging characteristics; advanced fuel metering systems; and exhaust aftertreatment technologies.

3.2.2.1 - Calibration Improvements

The vast majority of two-stroke engines used in recreational vehicles use a carburetor as the means of metering the air and fuel that is supplied to the engine. The carburetion system supplies a controlled mixture of air and fuel to the engine, taking into consideration engine temperature and load and speed, while trying to optimize engine performance and fuel economy. A carburetor is a mechanical fuel atomizing device. It uses the venturi or Bernoulli’s principle, which is based on pressure differences, to draw fuel into the air stream from a small reservoir (known as the “bowl”). A venturi is a restriction formed in the carburetor throat. As air passes through the venturi, it causes an increase in air velocity and creates a vacuum or low pressure. The fuel in the bowl is under atmospheric pressure. The higher pressure fuel will flow to the lower pressure (vacuum) created in the airstream by the venturi. The fuel is atomized (broken into small droplets) as it enters the airstream.

As discussed above in section 3.1.3.1, the calibration of the air-fuel mixture affects power, fuel consumption, and emissions. Traditionally, in most recreational vehicles using two-stroke engines, manufacturers have calibrated their fuel systems for rich operation for two main advantages. First, by running the engine rich, manufacturers can reduce the risk of lean misfire due to imperfect mixing of the fuel and air and variations in the air-fuel mixture from cylinder to cylinder. Second, by making extra fuel available for combustion, it is possible to get more power from the engine. At the same time, since a rich mixture lacks sufficient oxygen for full combustion, it results in increased fuel consumption rates and higher HC and CO emissions.

One means of reducing HC and CO emissions from two-stroke engines is to calibrate the air-fuel ratio for lower emissions. This means leaning the air-fuel mixture, so that there is more oxygen available to oxidize HC and CO. This strategy appears simplistic, but the manufacturer has to not only optimize the air-fuel ratio for emissions, but also allow acceptable performance and engine cooling. This means that the air-fuel ratio must not be leaned to the point of causing lean misfire or substantially reduced power. However, since it is common for manufacturers to set-up their carburetors to operate overly rich, there is opportunity for better optimization of carburetor air-fuel settings to account for performance, engine cooling and lower emissions.

3.2.2.2 - Combustion Chamber Modifications

For two-stroke engines, if modifications are made to air-fuel calibrations that result in leaner operation, one of the main concerns is that the combustion temperature will increase and result in engine damage. It is fairly common for two-stroke engines to seize the piston in the cylinder if they operate at too high of combustion temperatures. Piston seizure results when combustion chamber temperatures become excessive and the piston heats-up and expands until it becomes lodged or seizes in the cylinder. Depending on the level of enleanment used to control HC and CO emissions, it may be necessary to also incorporate modifications to the combustion chamber. Combustion chamber and piston configuration can be improved to induce more swirl and squish or turbulent motions during the compression stroke, as well as control the flow direction of the air and fuel mixture as it enters the combustion chamber to minimize short-circuiting (unburned fuel leaving thru the exhaust port). Increasing turbulence in the combustion chamber improves thermal efficiency by increasing the rate of burning in the chamber, which results in lower combustion temperatures. Improved combustion chamber and piston configurations can also minimize the formation of pocket or dead zones in the cylinder volume where unburned gases can become trapped. Many engine designs induce turbulence into the combustion chamber by increasing the velocity of the incoming air-fuel mixture and having it enter the chamber in a swirling motion (known as “swirl”).

3.2.2.3 - Improved Scavenging Characteristics

As discussed above, the exhaust and intake events for two-stroke engines overlap extensively, resulting in considerable amounts of unburned gasoline and lubricating oil passing through the engine and out the exhaust into the atmosphere. As the piston moves downward uncovering the exhaust port, a fresh charge of air and fuel enters the combustion chamber under pressure from the transfer port and pushes the burned gases from the previous combustion event out into the exhaust. Since the burned gases are pushed out of the chamber by the intake mixture, some of the fresh air and fuel mixture being introduced into the chamber are also lost through the exhaust port. The ideal situation would be to retain all of the fresh charge in the cylinder while exhausting all of the burned gases from the last cycle. This is difficult in most current two-stroke engine designs, since the cylinder ports and piston timing are generally designed for high scavenging efficiency, in order to achieve maximum power and a smoother idle, which results in higher scavenging losses and emissions. It is possible to reconfigure the cylinder ports to fine tune the scavenging characteristics for lower emissions, but this involves significant trade-offs with engine performance. There are, however, several techniques that can be employed to improve scavenging losses.

Exhaust charge control technology modifies the exhaust flow by introducing one-way control valves in the exhaust, or by making use of the exhaust pressure pulse wave. In order to get increased power out of a two-stroke engine, it is imperative that the engine combust as much air and fuel as possible. Scavenging losses from two-stroke engines (called “short-circuiting”) allow a large percentage of the air and fuel to leave the combustion chamber before they can be combusted. Two-stroke engines used in recreational vehicles all tend to use an exhaust system equipped with an “expansion chamber.” An expansion chamber is typically made of two cones, one diverging and the other converging, with a short straight section of pipe between the two cones. As the exhaust pulse leaves the exhaust port and enters the exhaust pipe, it travels through the diverging cone and expands. The expanded pulse travels through the straight section of pipe and then meets the converging cone. Upon hitting the converging cone, the exhaust pulse wave becomes a sonic wave and travels back into the combustion chamber, pushing some of the burnt exhaust gases and fresh charge of air and fuel that escaped originally.

As part of the Society of Automotive Engineers (SAE) Clean Snowmobile Challenge 2001, a college competition which encourages the development clean snowmobile technologies, Colorado State University (CSU) developed a two-stroke snowmobile engine using a supercharged “reverse uniflow” design. The reverse uniflow design incorporates an exhaust port and a crankcase pressure activated intake valve. After the ignition of the charge occurs at TDC, the high combustion pressures and expanding gases force the piston downward. As the bottom of the piston covers the exhaust port, the pressure in the crankcase increases due to a decreasing volume. The increasing pressure is transmitted to the check-valve diaphragm. As the piston fully uncovers the exhaust port, the exhaust gases are expelled out of the port, and the cylinder pressure goes to approximately atmospheric pressure. Due to the larger pressure in the crankcase (and thus on the diaphragm) as compared to the cylinder, the check-valve opens and the supercharged intake begins to runs into the cylinder. As the intake air is entering the cylinder, expelling the exhaust gases out of the bottom ports, a fuel injector or carburetor provides fuel into the intake air stream. After the piston reaches BDC, and begins to move back upwards, the crankcase pressure decreases. Once the piston moves past the exhaust port, the crankcase pressure returns to approximately atmospheric pressure, and the check-valve completely closes. The piston continues up, compressing the air-fuel mixture until the point that ignition can once again occur, completing the cycle.

3.2.2.4 - Advanced Fuel Metering Systems

The most promising technology for reducing emissions from two-stroke engines are advanced fuel metering systems, otherwise known as fuel injection systems. For two-stroke engines, there are two types of fuel injection systems available. The first system is electronic fuel injection (EFI), similar to what exists on automobiles. This system consists of an electronic fuel injector, an electronic fuel pump, pressurized fuel lines and an electronic control unit (ECU) or computer. EFI also requires the use of various sensors to provide information to the ECU so that precise fuel control can be delivered. These sensors typically monitor temperature, throttle position and atmospheric pressure. The use of EFI can provide better atomization of the fuel and more precise fuel delivery than found with carburetors, which can reduce emissions. EFI systems also have the advantage of providing improved power and fuel economy, when compared to a carburetor. However, EFI does not address the high emission resulting from short-circuiting or scavenging losses.

The second type of fuel injection system, known as Direct Injection (DI), does address scavenging losses. DI systems are very similar to EFI systems, since both are electronically controlled systems. The main difference is that DI systems more fully atomize (i.e., break-down into very small droplets) the fuel, which can greatly improve combustion efficiency resulting in improved power and reduced emissions. DI engines pump only air into the cylinder, rather than air and fuel. Finely atomized fuel is then injected into the combustion chamber once all of the ports are closed. This eliminates the short-circuiting of fresh air and fuel into the exhaust port. The biggest problem with DI is that there is very little time for air to be pumped into the cylinder and fuel then injected after all of the ports have closed. This is overcome by the use of numerous engines sensors, a high-speed electronic control module, and software which uses sophisticated control algorithms.

DI systems have been in use for the past several years in some small motorcycle, scooter and marine applications, primarily for personal watercraft (PWC) and outboard engines. There are numerous variations of DI systems, but two primary approaches that are commercially available today: high pressure injection and air-assisted injection. There are a number of companies who have developed high pressure DI systems, but the most successful systems currently belong to FICHT and Yamaha. The FICHT system uses a special fuel injector that is able to inject fuel at very high pressure (e.g., over 250 psi). The fuel injector itself is essentially a piston that is operated by an electromagnet. Fuel enters the injector at low pressure from an electric fuel pump and is forced out of the injector nozzle at high pressure when the piston hammers down on the fuel. The Yamaha system uses a high pressure fuel pump to generate the high fuel pressure. The other DI approach that is most common in various engine applications is the air-assisted injection system which has been developed by Orbital. The Orbital system uses pressurized air to help inject the fuel into the combustion chamber. The system uses a small single cylinder reciprocating air compressor to assist in the injection of the fuel. All three systems are currently used in some marine applications by companies such as Kawasaki, Polaris, Sea-Doo, and Yamaha. The Orbital system is also currently used on some small motorcycle and scooter applications by Aprilla. Certification data from various engines certified with DI have shown HC and CO emission reductions of 60 to 75 percent from baseline emission levels.

There is at least one other injection technology that has had success in small two-stroke SI engines used in lawn and garden applications, such as trimmers and chainsaws. Compression Wave technology, referred to as Low Emission (LE) technology, developed by John Deere, uses a compressed air assisted fuel injection system, similar to the Orbital system, to reduce the unburned fuel charge during the scavenging process of the exhaust portion of the two-stroke cycle. The system has shown the ability to reduce HC and CO emissions by up to 75 percent from baseline levels. Although this technology has not yet been applied to any recreational vehicle engines, it appears to have significant potential, especially because of its simplistic design and low cost. For a detailed description of the LE technology, refer to the Nonroad Small SI regulatory support document.

3.2.2.5 - Exhaust Aftertreatment Technologies

There are two exhaust aftertreatment technologies that can provide additional emission reductions from two-stroke engines: thermal oxidation (e.g., secondary air) and oxidation catalyst. Thermal oxidation reduces HC and CO by promoting further oxidation of these species in the exhaust. The oxidation usually takes place in the exhaust port or pipe, and may require the injection of additional air to supply the needed oxygen. If the exhaust temperature can be maintained at a high enough temperature (e.g., 600 to 700°C) for a long enough period, substantial reductions in HC and CO can occur. Air injection at low rates into the exhaust system has been shown to reduce emissions by as much as 77 percent for HC and 64 percent for

CO.[l] However, this was effective only under high-power operating conditions, and the high exhaust temperatures required to achieve this oxidation substantially increased the skin temperature of the exhaust pipe, which can be a concern for off-highway motorcycle applications where the operators legs could come in contact with the pipe.

Like thermal oxidation, the oxidation catalyst is used to promote further oxidation of HC and CO emissions in the exhaust stream, and it also requires sufficient oxygen for the reaction to take place. Some of the requirements for a catalytic converter to be used in two-stroke engines include high HC conversion efficiency, resistance to thermal damage, resistance to poisoning from sulfur and phosphorus compounds in lubricating oil, and low light-off temperature. Additional requirements for catalysts to be used in recreational vehicle two-stroke engines include extreme vibration resistance, compactness, and light weight.

Application of catalytic converters to two-stroke engines presents a problem, because of the high concentrations of HC and CO in their exhaust. If combined with sufficient air, these high pollutant concentrations result in catalyst temperatures that can easily exceed the temperature limits of the catalyst. Therefore, the application of oxidation catalysts to two-stroke engines may first require engine modifications to reduce HC and CO and may also require secondary air be supplied to the exhaust in front of the catalyst.

Researchers of Graz University of Technology and the Industrial Technology Research Institute (ITRI) in Taiwan have published data on the application of catalytic converters in small two-stroke moped and motorcycle engines using catalytic converters. The Graz researchers focused on reducing emissions using catalysts, as well as by improving the thermodynamic characteristics of the engines, such as gas exchange and fuel handling systems, cylinder and piston geometry and configurations, and exhaust cooling systems. For HC and CO emissions, they found that an oxidation catalyst could reduce emissions by 88 to 96 percent. Researchers at ITRI successfully retrofitted a catalytic converter to a 125 cc two-stroke motorcycle engine, and demonstrated both effective emissions control and durability.[m] The Manufacturers of Emission Controls Association (MECA)in their publication titled “Emission Control of Two-and Three-wheel Vehicles,” published May 7, 1999, state that catalyst technology has clearly demonstrated the ability to achieve significant emissions reductions from two-stroke engines. MECA points to the success of two-stroke moped and motorcycle engines equipped with catalysts that have been operating for several years in Taiwan, Thailand, Austria, and Switzerland.

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[l] White, J.J., Carroll,J.N., Hare, C.T., and Lourenco, J.G. (1991), “Emission Control Strategies for Small Utility Engines,” SAE Paper No. 911807, Society of Automotive Engineers, Warrendale, PA, 1991.

[m] Hsien, P.H., Hwang, L.K., and Wang, H.W (1992), “Emission Reduction by Retrofitting a 125 cc Two-Stroke Motorcycle with Catalytic Converter,” SAE Paper No. 922175, Society of Automotive Engineers, Warrendale, PA, 1992.

3.2.3 - Current Four-Stroke Engines

Four-stroke engines are the most common type of engine today. Large nonroad SI engines are exclusively four-stroke. Recreational vehicles are also predominantly four-stroke. Four-stroke engines have considerably lower HC emissions than two-stroke engines, due to the fact that four-stroke engines do not experience short circuiting of raw fuel. CO emissions from four-stroke engines is very similar to two-stroke engines, since CO emissions are the result of inefficient combustion of the air-fuel mixture within the cylinder, typically resulting from rich operation. Since the combustion of fuel within the cylinder of a four-stroke engine is more efficient than that of a two-stroke engine, combustion temperatures are higher, which results in higher NOx emission levels.

The four-stroke engines covered under this rulemaking are typically either automotive engines (large nonroad SI) or motorcycle-like engines (including ATVs). Large nonroad SI engines, off-highway motorcycles, ATVs, and snowmobiles have been unregulated federally. Therefore, while they have relatively low HC emissions compared to two-stroke engines, they can still have high levels of CO (due to rich air-fuel calibration) and NOx. Table 3.2-3 shows baseline emission levels for four-stroke equipped off-highway motorcycles and ATVs.

Table 3.2-3
Baseline Four-Stroke Emissions From Off-Highway Motorcycles & ATVs (g/km)

MC or ATV	Manufacturer	Model	Model Year	Eng. Displ.	HC	CO	NOx
MC	Yamaha	WR250F	20001	249 cc	1.46	26.74	0.110
MC	Yamaha	WR400	1999	399 cc	1.07	20.95	0.112
MC	KTM	400EXC	2001	398 cc	1.17	28.61	0.050
MC	Husaberg	FE501	2001	499 cc	1.30	25.81	0.163
ATV	Kawasaki	Bayou	1989	280 cc	1.17	14.09	0.640
ATV	Honda	300EX	1997	298 cc	1.14	34.60	0.155
ATV	Polaris	Trail Boss	1998	325 cc	1.56	43.41	0.195
ATV	Yamaha	Banshee	1998	349 cc	0.98	19.44	0.190
ATV	Polaris	Sportsman H.O.	2001	499 cc	2.68	56.50	0.295
ATV	Arctic Cat	375 Automatic	2001	375 cc	1.70	49.70	0.190
ATV	Yamaha	Big Bear	2001	400 cc	2.30	41.41	0.170
ATV	Honda	Rancher	2001	400 cc	1.74	33.98	0.150
ATV	Bombardier	4X4 AWD	2001	500 cc	1.62	20.70	0.740
ATV	Polaris	Sportsman	2001	499 cc	1.56	19.21	0.420
ATV	Yamaha	Raptor	2001	660 cc	0.97	16.56	0.210
Average					1.40	28.33	0.245

3.2.4 - Clean Four-Stroke Technologies

The emission-control technologies for four-stroke engines are very similar to those used for two-stroke engines. HC and CO emissions from four-stroke engines are primarily the result of poor in-cylinder combustion. Higher levels of NOx emissions are the result of leaner air-fuel ratios and the resulting higher combustion temperatures. Combustion chamber modifications can help reduce HC emission levels, while using improved air-fuel ratio and spark timing calibrations, as discussed in sections 3.1.3.1 and 3.1.3.2, can further reduce HC emissions and lower CO emissions. The conversion from carburetor to EFI will also help reduce HC and CO emissions. The use of exhaust gas recirculation on Large SI engines can reduce NOx emissions, but is not necessarily needed for recreational vehicles, due to their relatively low NOx emission levels. The addition of secondary air into the exhaust can significantly reduce HC and CO emissions. Finally, the use catalytic converters can further reduce all three emissions.

3.2.4.1. - Combustion chamber design

Unburned fuel can be trapped momentarily in crevice volumes (especially the space between the piston and cylinder wall) before being released into the exhaust. Reducing crevice volumes decreases this amount of unburned fuel, which reduces HC emissions. One way to reduce crevice volumes is to design pistons with piston rings closer to the top of the piston. HC may be reduced by 3 to 10 percent by reducing crevice volumes, with negligible effects on NOx emissions.[4]

HC emissions also come from lubricating oil that leaks into the combustion chamber. The heavier hydrocarbons in the oil generally don't burn completely. Oil in the combustion chamber can also trap gaseous HC from the fuel and prevent it from burning. For engines using catalytic control, some components in lubricating oil can poison the catalyst and reduce its effectiveness, which would further increase emissions over time. To reduce oil consumption, manufacturers can tighten tolerances and improve surface finishes for cylinders and pistons, improve piston ring design and material, and improve exhaust valve stem seals to prevent excessive leakage of lubricating oil into the combustion chamber.

3.2.4.2 - Exhaust gas recirculation

Exhaust gas recirculation (EGR) has been in use in cars and trucks for many years. The recirculated gas acts as a diluent in the air-fuel mixture, slowing reaction rates and absorbing heat to reduce combustion temperatures. These lower temperatures can reduce the engine-out NOx formation rate by as much as 50 percent.[5] HC is increased slightly due to lower temperatures for HC burn-up during the late expansion and exhaust strokes.

Depending on the burn rate of the engine and the amount of recirculated gases, EGR can improve fuel consumption. Although EGR slows the burn rate, it can offset this effect with some benefits for engine efficiency. EGR reduces pumping work since the addition of recirculated gas increases intake pressure. Because the burned gas temperature is decreased, there is less heat loss to the exhaust and cylinder walls. In effect, EGR allows more of the chemical energy in the fuel to be converted to useable work.[6]

For catalyst systems with high conversion efficiencies, the benefit of using EGR becomes proportionally smaller. Also, including EGR as a design variable for optimizing the engine adds significantly to the development time needed to fully calibrate engine models.

3.2.4.3. - Secondary air

Secondary injection of air into exhaust ports or pipes after cold start (e.g., the first 40 to 60 seconds) when the engine is operating rich, coupled with spark retard, can promote combustion of unburned HC and CO in the exhaust manifold and increase the warm-up rate of the catalyst. By means of an electrical or mechanical pump, secondary air is injected into the exhaust system, preferably in close proximity of the exhaust valve. Together with the oxygen of the secondary air and the hot exhaust components of HC and CO, oxidation ahead of the catalyst can bring about an efficient increase in the exhaust temperature which helps the catalyst to heat up quicker. The exothermic reaction that occurs is dependent on several parameters (secondary air mass, location of secondary air injection, engine A/F ratio, engine air mass, ignition timing, manifold and headpipe construction, etc.), and ensuring reproducibility demands detailed individual application for each vehicle or engine design.

Secondary air injection was first used as an emission control technique in itself without a catalyst, and still is used for this purpose in many highway motorcycles and some off-highway motorcycles to meet federal and California emission standards. For motorcycles, air is usually provided or injected by a system of check valves which uses the normal pressure pulsations in the exhaust manifold to draw in air from outside, rather than by a pump.

3.2.4.4 - Catalytic Aftertreatment

Over the last several years, there have been tremendous advances in exhaust aftertreatment systems. Catalyst manufacturers are progressively moving to palladium (Pd) as the main precious metal in automotive catalyst applications. Improvements to catalyst thermal stability and washcoat technologies, the design of higher cell densities, and the use of two-layer washcoat applications are just some of the advances made in catalyst technology. There are two types of catalytic converters commonly used: oxidation and three-way. Oxidation catalysts use platinum and/or palladium to increase the rate of reaction between oxygen in the exhaust and unburned HC and CO. Ordinarily, this reaction would proceed very slowly at temperatures typical of engine exhaust. The effectiveness of the catalyst depends on its temperature, on the air-fuel ratio of the mixture, and on the mix of HC present. Highly reactive species such as formaldehyde and olefins are oxidized more effectively than less-reactive species. Short-chain paraffins such as methane, ethane, and propane are among the least reactive HC species, and are difficult to oxidize.

Three-way catalysts use a combination of platinum and/or palladium and rhodium. In addition to promoting oxidation of HC and CO, these metals also promote the reduction of NO to nitrogen and oxygen. For the NO reduction to occur efficiently, an overall rich or stoichiometric air-fuel ratio is required. The NOx efficiency drops rapidly as the air-fuel ratio becomes leaner than stoichiometric. If the air-fuel ratio can be maintained precisely at or just rich of stoichiometry, a three-way catalyst can simultaneously oxidize HC and CO and reduce NOx. The window of air-fuel ratios within which this is possible is very narrow and there is a trade-off between NOx and CO control even within this window. HC oxidation generally correlates with CO conversion, though changing air-fuel ratios tend to affect CO emissions much more than HC emissions.

There are several issues involved in designing catalytic control systems for the four-stroke engines covered by this rulemaking. The primary issues are the cost of the system, packaging constraints, and the durability of the catalyst. This section addresses these issues.

3.2.4.4.1. - System cost

Sales volumes of industrial and recreational equipment are small compared to automotive sales. Manufacturers therefore have a limited ability to recoup large R&D expenditures for Large SI and recreational engines. For this reason, we believe it is not appropriate to consider highly refined catalyst systems that are tailored specifically to nonroad applications. For Large SI engines, we have based the feasibility of the emission standards on the kind of catalysts that manufacturers have already begun to offer for these engines. These systems are currently produced in very low volumes, but the technology has been successfully adapted to Large SI engines. The cost of these systems will decrease substantially when catalysts become commonplace. Chapter 4 describes the estimated costs for a nonroad catalyst system.

3.2.4.4.2. - Packaging constraints

Large SI engines power a wide range of nonroad equipment. Some of these have no significant space constraints for adding a catalyst. In contrast, equipment designs such as forklifts have been fine-tuned over many years with a very compact fit. The same is even more true for recreational vehicles, such as ATVs and motorcycles.

Automotive catalyst designs typically have one or two catalyst units upstream of the muffler. This is a viable option for most nonroad equipment. However, if there is no available space to add a separate catalyst, it is possible to build a full catalyst/muffler combination that fits in the same space as the conventional muffler. With this packaging option, even compact applications should have little or no trouble integrating a catalyst into the equipment design. The hundreds of catalysts currently operating on forklifts and highway motorcycles clearly demonstrate this.

3.2.5 - Advanced Emission Controls

On February 10, 2000, EPA published new “Light-duty Tier 2" emissions standards for all passenger vehicles, including sport utility vehicles (SUVs), minivans, vans and pick-up trucks. The new standards will ensure that exhaust VOC emissions be reduced to less than 0.1 g/mi on average over the fleet, and that evaporative emissions be reduced by at least 50 percent. Onboard refueling vapor recovery requirements were also extended to medium-duty passenger vehicles. By 2020, these standards will reduce VOC emissions from light-duty vehicles by more than 25 percent of the projected baseline inventory. (See Chapter 4 for a more detailed discussion of the impact of the Light-duty Tier 2 final rule on VOC inventories.) To achieve these reductions, manufacturers will need to incorporate advanced emission controls, including: larger and improved close-coupled catalysts, optimized spark timing and fuel control, improved exhaust systems.

To reduce emissions gasoline-fueled vehicle manufacturers have designed their engines to achieve virtually complete combustion and have installed catalytic converters in the exhaust system. For these controls to work well for gasoline-fueled vehicles, it is necessary to maintain the mixture of air and fuel at a nearly stoichiometric ratio (that is, just enough air to completely burn the fuel). Poor air-fuel mixture can result in significantly higher emissions of incompletely combusted fuel. Current generation highway vehicles are able to maintain stoichiometry by using closed-loop electronic feedback control of the fuel systems. As part of these systems, technologies have been developed to closely meter the amount of fuel entering the combustion chamber to promote complete combustion. Sequential multi-point fuel injection delivers a more precise amount of fuel to each cylinder independently and at the appropriate time increasing engine efficiency and fuel economy. Electronic throttle control offers a faster response to engine operational changes than mechanical throttle control can achieve, but it is currently considered expensive and only used on some higher-price vehicles. The greatest gains in fuel control can be made through engine calibrations—the algorithms contained in the powertrain control module (PCM) software that control the operation of various engine and emission control components/systems. As microprocessor speed becomes faster, it is possible to perform quicker calculations and to increase response times for controlling engine parameters such as fuel rate and spark timing. Other advances in engine design have also been used to reduce engine-out emissions, including: the reduction of crevice volumes in the combustion chamber to prevent trapping of unburned fuel; “fast burn” combustion chamber designs that promote swirl and flame propagation; and multiple valves with variable-valve timing to reduce pumping losses and improve efficiency. These technologies are discussed in more detail in the RIA for the Light-duty Tier 2 final rule.[n]

As noted above, manufacturers are also using aftertreatment control devices to control emissions. New three-way catalysts for highway vehicles are so effective that once a TWC reaches its operating temperature, emissions are virtually undetectable.[o] Manufacturers are now working to improve the durability of the TWC and to reduce light-off time (that is, the amount of time necessary after starting the engine before the catalyst reaches its operating temperature and is effectively controlling VOCs and other pollutants). EPA expects that manufacturers will be able to design their catalyst systems so that they light off within less than thirty seconds of engine starting. Other potential exhaust aftertreatment systems that could further reduce cold-start emissions are thermally insulated catalysts, electrically heated catalysts, and HC adsorbers (or traps). Each of these technologies, which are discussed below, offer the potential for VOC reductions in the future. There are technological, implementation, and cost issues that still need to be addressed, and at this time, it appears that these technologies would not be a cost-effective means of reducing nonroad emissions on a nationwide basis.

Thermally insulated catalysts maintain sufficiently high catalyst temperatures by surrounding the catalyst with an insulating vacuum. Prototypes of this technology have

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[n] http://www.epa.gov/otaq/tr2home.htm#Documents. EPA 420-R-99-023

[o] McDonald, J., L. Jones, Demonstration of Tier 2 Emission Levels for Heavy Light-Duty Trucks, SAE 2000-01-1957.

demonstrated the ability to store heat for more than 12 hours.[p] Since ordinary catalysts typically cool down below their light-off temperature in less than one hour, this technology could reduce in-use emissions for vehicles that have multiple cold-starts in a single day. However, this technology would have less impact on emissions from vehicles that have only one or two cold-starts per day.

Electrically-heated catalysts reduce cold-start emissions by applying an electric current to the catalyst before the engine is started to get the catalyst up to its operating temperature more quickly.[q] These systems require a modified catalyst, as well as an upgraded battery and charging system. These can greatly reduce cold-start emissions, but could require the driver to wait until the catalyst is heated before the engine would start to achieve optimum performance.

Hydrocarbon adsorbers are designed to trap VOCs while the catalyst is cold and unable to sufficiently convert them. They accomplish this by utilizing an adsorbing material which holds onto the VOC molecules. Once the catalyst is warmed up, the trapped VOCs are automatically released from the adsorption material and are converted by the fully functioning downstream three-way catalyst. There are three principal methods for incorporating an adsorber into the exhaust system. The first is to coat the adsorber directly on the catalyst substrate. The advantage is that there are no changes to the exhaust system required, but the desorption process cannot be easily controlled and usually occurs before the catalyst has reached light-off temperature. The second method locates the adsorber in another exhaust pipe parallel with the main exhaust pipe, but in front of the catalyst and includes a series of valves that route the exhaust through the adsorber in the first few seconds after cold start, switching exhaust flow through the catalyst thereafter. Under this system, mechanisms to purge the adsorber are also required. The third method places the trap at the end of the exhaust system, in another exhaust pipe parallel to the muffler, because of the low thermal tolerance of adsorber material. Again a purging mechanism is required to purge the adsorbed VOCs back into the catalyst, but adsorber overheating is avoided. One manufacturer who incorporates a zeolite hydrocarbon adsorber in its California SULEV vehicle found that an electrically heated catalyst was necessary after the adsorber because the zeolite acts as a heat sink and nearly negates the cold start advantage of the adsorber. This approach has been demonstrated to effectively reduce cold start emissions.

3.2.5.1 Multiple valves and variable-valve timing

Four-stroke engines generally have two valves for each cylinder, one for intake of the air-fuel mixture and the other for exhaust of the combusted mixture. The duration and lift (distance the valve head is pushed away from its seat) of valve openings is constant regardless of engine speed. As engine speed increases, the aerodynamic resistance to pumping air in and out of the cylinder for intake and exhaust also increases. Automotive engines have started to use two

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[p] Burch, S.D., and J.P. Biel, SULEV and "Off-Cycle" Emissions Benefits of a Vacuum-Insulated Catalytic Convert, SAE 1999-01-0461.

[q] Laing, P.M., Development of an Alternator-Powered Electrically-Heated Catalyst System, SAE 941042.

intake and two exhaust valves to reduce pumping losses and improve their volumetric efficiency and useful power output. Some highway motorcycles have used multiple valves for years, especially the high-performance sport motorcycles.

In addition to gains in breathing, 4-valve designs allow the spark plug to be positioned closer to the center of the combustion chamber, which decreases the distance the flame must travel inside the chamber. This decreases the likelihood of flame-out conditions in the areas of the combustion chamber farthest from the spark plug. In addition, the two streams of incoming gas can be used to achieve greater mixing of air and fuel, further increasing combustion efficiency and lowering engine-out emissions.

Control of valve timing and lift take full advantage of the 4-valve configuration for even greater improvement in combustion efficiency.   Engines normally use fixed-valve timing and lift across all engine speeds. If the valve timing is optimized for low-speed torque, it may offer compromised performance under higher-speed operation. At light engine loads, for example, it is desirable to close the intake valve early to reduce pumping losses. Variable-valve timing can enhance both low-speed and high-speed performance with compromise. Variable-valve timing can allow for increased swirl and intake charge velocity, especially during low-load operating conditions where this is most problematic. By providing a strong swirl formation in the combustion chamber, the air-fuel mixture can mix sufficiently, resulting in a faster, more complete combustion, even under lean air-fuel conditions, thereby reducing emissions.

Variable-valve technology by itself may have somewhat limited effect on reducing emissions, but combining it with optimized spark plug location and exhaust gas recirculation can lead to substantial emission reductions.

3.3 - Evaporative Emissions

3.3.1 Sources of Evaporative Emissions

Evaporative emissions from nonroad SI equipment represents a small but significant part of their NMHC emissions. The significance of the emissions varies widely depending on the engine design and application. LPG-fueled equipment generally has very low evaporative emissions because of the tightly sealed fuel system. At the other extreme, carbureted gasoline-fueled equipment with open vented tanks can have very high evaporative emissions. Evaporative emissions can be grouped into five categories:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day, heating the fuel tank and venting gasoline vapors.

RUNNING LOSSES: The hot engine and exhaust system can vaporize gasoline when the engine is running.

HOT SOAK: The engine remains hot for a period of time after the engine is turned off and gasoline evaporation continues.

REFUELING: Gasoline vapors are always present in typical fuel tanks. These vapors are forced out when the tank is filled with liquid fuel.

PERMEATION: Gasoline molecules can saturate plastic fuel tanks and rubber hoses, resulting in a relatively constant rate of emissions as the fuel continues to permeate through these components.

Among the factors that affect emission rates are: (1) fuel metering (fuel injection or carburetor); (2) the degree to which fuel permeates fuel lines and fuel tanks; (3) the proximity of the fuel tank to the exhaust system or other heat sources; (4) whether the fuel system is sealed and the pressure at which fuel vapors are vented; and (5) fuel tank volume.

3.3.1.1 - Diurnal and Running Loss Emissions

In an open fuel tank, the vapor space is at atmospheric pressure (typically about 14.7 psi), and contains a mixture of fuel vapor and air. At all temperatures below the fuel's boiling point, the vapor pressure of the fuel is less than atmospheric pressure. This is also called the partial pressure of the fuel vapor. The partial pressure of the air is equal to the difference between atmospheric pressure and the fuel vapor pressure. For example, in an open-vented fuel tank at 60˚F, the vapor pressure of typical gasoline would be about 4.5 psi. In this example, the partial pressure of the air would be about 10.2 psi. Assuming that the vapor mixture behaves as an ideal gas, then the mole fractions (or volumetric fractions) of fuel vapor and air would be equal to their respective partial pressures divided by the total pressure; thus, the fuel would be 31 percent of the mixture (4.5/14.7) and the air would be 69 percent of the mixture (10.2/14.7).

Diurnal emissions occur when the fuel temperature increases, which increases the equilibrium vapor pressure of the fuel. For example, assume that the fuel in the previous example was heated to 90˚F, where the vapor pressure that same typical fuel would be about 8.0 psi. To maintain the vapor space at atmospheric pressure, the partial pressure of the air would need to decrease to 6.7 psi, which means that the vapor mixture must expand in volume. This forces some of the fuel-air mixture to be vented out of the tank. When the fuel later cools, the vapor pressure of the fuel decreases, contracting the mixture, and drawing fresh air in through the vent. When the fuel is heated again, another cycle of diurnal emissions occurs. It is important to note that this is generally not a rate-limited process. Although the evaporation of the fuel can be slow, it is generally fast enough to maintain the fuel tank in an essentially equilibrium state.

Consider a typical fuel use cycle beginning with a full tank. As fuel is used by the engine, and the liquid fuel volume decreases, air is drawn into the tank to replace the volume of the fuel. (Note: the decrease in liquid fuel could be offset to some degree by increasing fuel vapor pressure caused by increasing fuel temperature.) This would continue while the engine was running. If the engine was shut off and the tank was left overnight, the vapor pressure of the fuel would drop as the temperature of the fuel dropped. This would cause a small negative pressure within the tank that would cause it to fill with more air until the pressure equilibrated. The next day, the vapor pressure of the fuel would increase as the temperature of the fuel increased. This would cause a small positive pressure within the tank that would force a mixture of fuel vapor and air out. In poorly designed gasoline systems, where the exhaust is very close to the fuel tank, the fuel can actually begin to boil. When this happens, large amounts of gasoline vapor can be vented directly to the atmosphere. Southwest Research Institute measured emissions from several large nonroad gasoline engines and found them to vary from about 12 g/day up to almost 100 g/day. They also estimated that a typical large nonroad gasoline engine in the South Coast Air Basin (the area involved in their study) would have an evaporative emission rate of about 0.4 g/kW-hr.

3.3.1.2 - Hot Soak Emissions

Hot soak emissions occur after the engine is turned off, especially during the resulting temperature rise. For nonroad engines, the primary source of hot soak emissions is the evaporation of the fuel left in the carburetor bowl. Other sources can include increased permeation and evaporation of fuel from plastic or rubber fuel lines in the engine compartment.

3.3.1.3 - Refueling Emissions

Refueling emissions occur when the fuel vapors are forced out when the tank is filled with liquid fuel. At a given temperature, refueling emissions are proportional to the volume of the fuel dispensed into the tank. Every gallon of fuel put into the tank forces out one-gallon of the mixture of air and fuel vapors. Thus, refueling emissions are highest when the tank is near empty. Refueling emissions are also affected by the temperature of the fuel vapors. At low temperatures, the fuel vapor content of the vapor space that is replaced is lower than it is at higher temperatures.

3.3.1.4 - Permeation

The polymeric material (plastic or rubber) of which many gasoline fuel tanks and fuel hoses generally have a chemical composition much like that of gasoline. As a result, constant exposure of gasoline to these surfaces allows the material to continually absorb fuel. The outer surfaces of these materials are exposed to ambient air, so the gasoline molecules permeate through these fuel-system components and are emitted directly into the air. Permeation rates are relatively low, but emissions continue at a nearly constant rate, regardless of how much the vehicle or equipment is used. Permeation-related emissions can therefore add up to a significant fraction of the total emissions from gasoline powered vehicles.

3.3.2 Evaporative Emission Controls

Several emission-control technologies can be used to reduce evaporative emissions. The advantages and disadvantages of the various possible emission-control strategies are discussed below. Chapter 4 presents more detail on how we expect manufacturers to use these technologies to meet the emission standards for the individual applications.

3.3.2.1 - Sealed System with Pressure Relief

Evaporative emissions are formed when the fuel heats up, evaporates, and passes through a vent into the atmosphere. By closing that vent, evaporative emissions are prevented from escaping. However, as vapor is generated, pressure builds up in fuel tank. Once the fuel cools back down, the pressure subsides.

For forklifts, the primary application of Large SI engines, Underwriters Laboratories specifies that units operating in certain areas where fire risk is most significant must use pressurized fuel tanks. Underwriters Laboratories requires that trucks use self-closing fuel caps with tanks that stay sealed to prevent evaporative losses; venting is allowed for positive pressures above 3.5 psi or for vacuum pressures of at least 1.5 psi.[r] These existing requirements are designed to prevent evaporative losses for safety reasons. This same approach for other types of engines would similarly reduce emissions for air-quality reasons.

An alternative to using a pressure relief valve to hold vapors in the fuel tank would be to use a limited flow orifice. However, the orifice size may be so small that there would be a risk of fouling. In addition, an orifice designed for a maximum of 2 psi under worst case conditions may not be very effective at lower temperatures. One application where a limited flow orifice may be useful is if it is combined with an insulated fuel tank as discussed below.

3.3.2.2 - Insulated Fuel Tank

Another option for reducing diurnal emissions is insulating the fuel tank. Rather than capturing the vapors in the fuel tank, this strategy would minimize the fuel heating which therefore minimizes the vapor generation. However, significant evaporative emissions would still occur through the vent line due to diffusion even without temperature gradients. A limited-flow orifice could be used to minimize the to loss of vapor through the vent line due to diffusion. In this case, the orifice could be sized to prevent diffusion losses without causing pressure build-up in the tank. Additional control could be achieved with the use of a pressure relief valve or a smaller limited flow orifice. Note that an insulated tank could maintain the same emission control with a lower pressure valve than a tank that was not insulated.

3.3.2.3 - Volume-Compensating Air Bag

Another concept for minimizing pressure in a sealed fuel tank is through the use of a volume-compensating air bag. The purpose of the bag is to fill up the vapor space in the fuel tank above the fuel itself. By minimizing the vapor space, less air is available to mix with the heated fuel and less fuel evaporates. As vapor is generated in the small vapor space, air is forced

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[r] UL558, paragraphs 26.1 through 26.4

out of the air bag, which is vented to atmosphere. Because the bag collapses as vapor is generated, the volume of the vapor space grows and no pressure is generated. Once the fuel tank cools as ambient temperature goes down, the resulting vacuum in the fuel tank will open the bag back up. Depending on the size of the bag, pressure in the tank could be minimized; therefore, the use of a volume-compenating air bag could allow a manufacturer to reduce the pressure limit on its relief valve.

3.3.2.4 - Collapsible Bladder Fuel Tank

Probably the most effective technology for reducing evaporative emissions from fuel tanks is through the use of a collapsible fuel bladder. In this concept, a non-permeable bladder would be installed in the fuel tank to hold the fuel. As fuel is drawn from the bladder, the vacuum created collapses the bladder. Therefore, there is no vapor space and no pressure build up. Because the bladder would be sealed, there would be no vapors vented to the atmosphere.

3.3.2.5 - Charcoal Canister

The primary evaporative emission control device used in automotive applications is a charcoal canister. With this technology, vapor generated in the tank is vented through a charcoal canister. The activated charcoal collects and stores the hydrocarbons. Once the engine is running, purge air is drawn through the canister and the hydrocarbons are burned in the engine. These charcoal canisters generally are about a liter in size and have the capacity to store three days of vapor over the test procedure conditions.

For industrial applications, engines are typically used frequently which would limit the size of canister needed; however, introducing an evaporative canister is a complex undertaking, requiring extensive efforts to integrate evaporative and exhaust emission-control strategies. Large SI engine manufacturers also often sell loose engines to equipment manufacturers, who would also need to integrate the new technology into equipment designs.

3.3.2.6 - Floating Fuel and Vapor Separator

Another concept used in some stationary engine applications is a floating fuel and vapor separator. Generally small, impermeable plastic balls are floated in the fuel tank. The purpose of these balls is to provide a barrier between the surface of the fuel and the vapor space. However, this strategy does not appear to be viable for industrial fuel tanks. Because of the motion of the equipment, the fuel sloshes and the barrier would be continuously broken. Even small movements in the fuel could cause the balls to rotate and transfer fuel to the vapor space.

3.3.2.7 - Permeation Barriers

Another source of evaporative emissions is permeation through the walls of plastic fuel tanks and rubber hoses.

3.3.2.7.1 Fuel Tanks

Blow molding is widely used for the manufacture of small fuel tanks of recreational vehicles. Typically, blow molding is performed by creating a hollow tube, known as a parison, by pushing high-density polyethylene (HDPE) through an extruder with a screw. The parison is then pinched in a mold and inflated with an inert gas. In highway applications, non-permeable plastic fuel tanks are produced by blow molding a layer of ethylene vinyl alcohol (EVOH) or nylon between two layers of polyethylene. This process is called coextrusion and requires at least five layers: the barrier layer, adhesive layers on either side of the barrier layer, and HDPE as the outside layers which make up most of the thickness of the fuel tank walls. However, multi-layer construction requires two additional extruder screws which significantly increases the cost of the blow molding process.

Multi-layer fuel tanks can also be formed using injection molding. In this method, a low viscosity polymer is forced into a thin mold to create each side of the fuel tank. The two sides are then welded together. In typical fuel tank construction, the sides are welded together by using a hot plate for localized melting and then pressing the sides together. The sides may also be connected using vibration or sonic welding. To add a barrier layer, a thin sheet of the barrier material is placed inside the mold prior to injection of the poleythylene. The polyethylene, which generally has a much lower melting point than the barrier material, bonds with the barrier material to create a shell with an inner liner. As an alternative, an additional extruder can be added to inject the barrier layer prior to injecting the HDPE; however, this substantially increases the cost of the process.

A less expensive alternative to coextrusion is to blend a low permeable resin in with the HDPE and extrude it with a single screw. The trade name typically used for this permeation control strategy is Selar®. The low permeability resin, typically EVOH or nylon, creates non-continuous platelets in the HDPE fuel tank which reduce permeation by creating long, tortuous pathways that the hydrocarbon molecules must navigate to pass through the fuel tank walls. Although the barrier is not continuous, this strategy can still achieve greater than a 90 percent reduction in permeation of gasoline. EVOH has much higher permeation resistance to alcohol than nylon; therefore, it would be the preferred material to use for meeting our standard which is based on testing with a 10 percent ethanol fuel.

Another type of low permeation technology for fuel tanks would be to treat the surfaces of a plastic fuel tanks with a barrier layer. Two ways of achieving this are known as fluorination and sulfonation. The fluorination process causes a chemical reaction where exposed hydrogen atoms are replaced by larger fluorine atoms which a barrier on surface of the fuel tank. In this process, fuel tanks are generally processed post production by stacking them in a steel container. The container is then be voided of air and flooded with fluorine gas. By pulling a vacuum in the container, the fluorine gas is forced into every crevice in the fuel tanks. As a result of this process, both the inside and outside surfaces of the fuel tank would be treated. As an alternative, fuel tanks can be fluorinated on-line by exposing the inside surface of the fuel tank to fluorine during the blow molding process. However, this method may not prove as effective as off-line fluorination which treats the inside and outside surfaces.

Sulfonation is another surface treatment technology where sulfur trioxide is used to create the barrier by reacting with the exposed polyethylene to form sulfonic acid groups on the surface. Current practices for sulfonation are to place fuel tanks on a small assembly line and expose the inner surfaces to sulfur trioxide, then rinse with a neutralizing agent. However, can also be performed off-line. Either of these processes can be used to reduce gasoline permeation by more than 95 percent.

3.3.2.7.2 Fuel Hoses

Fuel hoses produced for use in recreational vehicles are generally extruded nitrile rubber with a cover for abrasion resistance. Lower permeability fuel hoses produced today for other applications are generally constructed in one of two ways: either with a low permeability layer or by using a low permeability rubber blend. By using hose with a low permeation thermoplastic layer, permeation emissions can be reduced by more than 95 percent. Because the thermoplastic layer is very thin, on the order of 0.1 to 0.2 mm, the rubber hose retains its flexibility. Two thermoplastics which have excellent permeation resistance, even with an alcohol-blend fuel, are ethylene-tetrafluoro-ethylene (ETFE) and tetra-fluoro-ethylene, hexa-fluoro-propylene, and vinyledene fluoride (THV).

In automotive applications, multilayer plastic tubing, made of fluoropolymers is generally used. An added benefit of these low permeability lines is that some fluoropolymers can be made to conduct electricity and therefore can prevent the buildup of static charges. Although this technology can achieve more than an order of magnitude lower permeation than barrier hoses, it is relatively inflexible and may need to be molded in specific shapes for each recreational vehicle design. Manufacturers have commented that they would need flexible hose to fit their many designs, resist vibration, and to simplify the hose connections and fittings.

An alternative approach to reducing the permeability of marine hoses would be to apply a surface treatment such as fluorination or sulfonation. This process would be performed in a manner similar to discussed above for fuel tanks.

3.4 CI Recreational Marine Engines

In this section, we discuss how emissions can be reduced from compression-ignition (CI) recreational marine engines. We believe recreational marine diesel engines can use the same technology for reducing emissions that will be used to meet the standards for commercial marine diesel engines.[7] Because of the similarities between recreational and commercial diesel engines, this chapter builds off the technological analysis in the Regulatory Impact Analysis for the commercial diesel marine engine rule.[8] This section discusses emissions formation, baseline technology, control strategies for CI recreational marine engines.

3.4.1 Background on Emissions Formation from Diesel Engines

Most, if not all, of compression-ignition recreational marine engines use diesel fuel. For this reason, we focus on recreational marine diesel engines in this section. In a diesel engine, the liquid fuel is injected into the combustion chamber after the air has been heated by compression (direct injection), or the fuel is injected into a prechamber, where combustion initiates before spreading to the rest of the combustion chamber (indirect injection). The fuel is injected in the form of a mist of fine droplets or vapor that mix with the air. Power output is controlled by regulating the amount of fuel injected into the combustion chamber, without throttling (limiting) the amount of air entering the engine. The compressed air heats the injected fuel droplets, causing the fuel to evaporate and mix with the available oxygen. At several sites where the fuel mixes with the oxygen, the fuel auto-ignites and the multiple flame fronts spread through the combustion chamber.

NOx and PM are the emission components of most concern from diesel engines. Incomplete evaporation and burning of the fine fuel droplets or vapor result in emissions of the very small particles of PM. Small amounts of lubricating oil that escape into the combustion chamber can also contribute to PM. Although the fuel-air ratio in a diesel cylinder is very lean, the air and fuel are not a homogeneous charge as in a gasoline engine. As the fuel is injected, the combustion takes place at the flame-front where the fuel-air ratio is near stoichiometry (chemically correct for combustion). At localized areas, or in cases where light-ends have vaporized and burned, molecules of carbon remain when temperatures and pressures in the cylinder become too low to sustain combustion as the piston reaches bottom dead center. Therefore, these heavy products of incomplete combustion are exhausted as PM.

NOx formation requires high temperatures and excess oxygen which are found in a diesel engine. Therefore, the diesel combustion process can cause the nitrogen in the air to combine with available oxygen to form NOx. High peak temperatures can be seen in typical unregulated diesel engine designs. This is because the fuel is injected early to help lead to more complete combustion, therefore, higher fuel efficiency. If fuel is injected too early, significantly more fuel will mix with air prior to combustion. Once combustion begins, the premixed fuel will burn at once leading to a very high temperature spike. This high temperature spike, in turn, leads to a high rate of NOx formation. Once combustion begins, diffusion burning occurs while the fuel is being injected which leads to a more constant, lower temperature, combustion process.

Because of the presence of excess oxygen, hydrocarbons evaporating in the combustion chamber tend to be completely burned and HC and CO are not emitted at high levels. Evaporative emissions from diesel engines are insignificant due to the low evaporation rate of diesel fuel.

Controlling both NOx and PM emissions requires different, sometimes opposing strategies. The key to controlling NOx emissions is reducing peak combustion temperatures since NOx forms at high temperatures. In contrast, the key to controlling PM is higher temperatures in the combustion chamber or faster burning. This reduces PM by decreasing the formation of particulates and by oxidizing those particulates that have formed. To control both NOx and PM, manufacturers need to combine approaches using many different design variables to achieve optimum performance. These design variables are discussed in more detail below.

3.4.2 Marinization Process

Like commercial marine engines, recreational marine engines are not generally built from the ground up as marine engines. Instead, they are often marinized land-based engines. The main difference between recreational and commercial marine engines is the application for which they are designed. Commercial engines are designed for high hours of use. Recreational engines are generally designed for higher power, but less hours of use. The following is a brief discussion of the marinization process, as it is performed by either engine manufacturers or post-manufacture marinizers (PMM).

3.4.2.1 Process common to all marine diesel engines

The most obvious changes made to a land-based engine as part of the marinization process concern the engine's cooling system. Marine engines generally operate in closed compartments without much air flow for cooling. This restriction can lead to engine performance and safety problems. To address engine performance problems, these engines make use of the ambient water to draw the heat out of the engine coolant. To address safety problems, marine engines are designed to minimize hot surfaces. One method of ensuring this, used mostly on smaller marine engines, is to run cooling water through a jacket around the exhaust system and the turbocharger. Larger engines generally use a thick insulation around the exhaust pipes.

Hardware changes associated with these cooling system changes often include water jacketed turbochargers, water cooled exhaust manifolds, heat exchangers, sea water pumps with connections and filters, and marine gear oil coolers. In addition, because of the greater cooling involved, it is often necessary to change to a single-chamber turbocharger, to avoid the cracking that can result from a cool outer wall and a hot chamber divider.

Marinization may also involve replacing engine components with similar components that are made of materials that are more carefully adapted to the marine environment. Material changes include more use of chrome and brass including changes to electronic fittings to resist water induced corrosion. Zinc anodes are often used to prevent engine components, such as raw-water heat exchangers, from being damaged by electrolysis.

3.4.2.2 Process unique to recreational marine diesel engines

Other important design changes are related to engine performance. Especially for planing hull vessels used in recreational and light duty commercial marine applications, manufacturers strive to maximize the power-to-weight ratio of their marine engines, typically by increasing the power from a given cylinder displacement. The most significant tool to accomplish this is the fuel injection system: the most direct way to increase power is to inject more fuel. This can require changes to the camshaft, cylinder head, and the injection timing and pressure.

Design limits for increased fuel to the cylinder are smoke and durability. Modifications made to the cooling system also help enhance performance. By cooling the charge, more air can be forced into the cylinder. As a result, more fuel can be injected and burned efficiently due to the increase in available oxygen. In addition, changes are often made to the pistons, cylinder head components, and the lubrication system. For instance, aluminum piston skirts may be used to reduce the weight of the pistons. Cylinder head changes include changing valve timing to optimize engine breathing characteristics. Increased oil quantity and flow may be used to enhance the durability of the engine.

Depending on the stage of production and the types of changes made, the marinization process can have an impact on the base engine's emission characteristics. In other words, a land-based engine that meets a particular set of emission limits may no longer meet these limits after it is marinized. This can be the case, for example, if the fuel system is changed to enhance engine power or if the cooling system no longer achieves the same degree of engine cooling as that of the base engine. Because marine diesel engines are currently unregulated, engine manufacturers have been able to design their marine engines to maximize performance. Especially for recreational marine engines, manufacturers often obtain power/weight ratios much higher than for land-based applications.

Recreational engine manufacturers strive for higher power/weight ratios than are necessary for commercial marine engines. Because of this, recreational marine engines use technology we projected to be used by commercial marine engines to meet the Tier 2 emissions standards such as raw-water aftercooling and electronic control. However, this technology is used to gain more power rather than to reduce emissions. The challenge presented by the emission control program will be to achieve the emission limits while maintaining favorable performance characteristics.

3.4.3 General Description of Technology for Recreational Marine Diesel Engines

We believe that the standards can be met using technology that has been developed for and used on land-based nonroad and highway engines. The Regulatory Impact Analysis for the commercial marine final rule includes a lengthy description of emission control technology for diesel marine engines. Table 3.4-1 outlines this description. By combining the strategies shown below, manufacturers can optimize the emissions and performance of their engines. We anticipate that the same percent reductions achievable on commercial marine engines would be achievable on recreational marine engines using the same technology. The same technology is used in land-based applications to achieve even a higher magnitude of emission reduction. In addition, this technology works consistently across the engine map encompassed by the NTE zone. A more detailed analysis of the application of several of these technologies to recreational marine engines is discussed in Chapter 4. The costs associated with applying these systems are considered in Chapter 5.

Table 3.4-1: Emission Control Strategies for Marine Diesel Engines

Technology	Description	HC	CO	NOx	PM
Combustion optimization:	timing retard–reduce peak cylinder temperatures by shortening the premixed burning phase	↑	↑	↓↓	↑↑
	reduced crevice volume–such as raising the top piston ring	↓	↓	↔	↓
	geometry–match piston crown geometry to injector spray	↓	↓	↓	↓
	increased compression ratio–raises cylinder pressures	↓	↓	↑	↓
	increased swirl–control of air motion for better mixing	↓	↓	↑,↔	↓
Advanced fuel injection controls	increased injection pressure–better atomization of fuel	↓	↓	↑,↔	↓
	nozzle geometry–optimize spray pattern	↓	↓	↓	↓
	valve-closed orifice–minimize leakage after injection	↓	↔	↔	↓
	rate shaping–inject small amount of fuel early to begin combustion to reduce premixed burning	↔	↔	↓	↔
	common rail–high pressure rail to injectors, excellent control of fuel rate, pressure, and timing	↓	↓	↓	↓
Improving charge air characteristics	turbocharging–increases available oxygen in the cylinder but heats intake air	↓	↓	↑	↓
	jacket-water aftercooling–uses engine coolant to cool charged air which increases available oxygen in cylinder	↔	↔	↓	↔
	raw-water aftercooling–uses ambient water to cool charge air; more effective than jacket-water aftercooling; may result in additional maintenance such as changing anodes	↔	↔	↓↓	↔
Electronic control	better control of fuel system including rate, pressure, and timing especially under transients; can use feedback loop	↓	↓	↓	↓
Exhaust gas recirculation	hot EGR–recirculated exhaust gas reduces combustion temperatures by absorbing heat and slowing reaction rates	↑	↑	↓	↑
	cooled EGR–reduces volume of recirculated gases so to allow more oxygen in the cylinder	↔	↔	↓↓	↑,↔
	soot removal–soot in recirculated gases may cause durability problems at high EGR rates; gas filter or trap; oil filter	↔	↔	↔	↓
Exhaust aftertreatment devices (would require "dry" exhaust)	oxidation catalyst–oxidizes hydrocarbons and soluble organic fraction of PM; will be poisoned by high levels of sulfur	↓	↓	↔	↓
	particulate trap–collect PM; use catalyst to regenerate at high temperature	↓	↓	↔	↓
	selective catalytic reduction–uses a catalyst and a reducing	↔	↔	↓	↔

Water emulsification	water is mixed with fuel or injected into the cylinder; water has a high heat capacity and will lower in-cylinder temperatures	↔	↔	↓	↔

Chapter 3 References

1. Heywood, J., “Internal Combustion Engine Fundamentals,” McGraw-Hill, Inc., New York, 1988, pp.829-836, Docket A-2000-01, Document IV-A-110.

2. Heywood, pp.827-829, Docket A-2000-01, Document IV-A-110.

3. Saikalis, G., Byers, R., Nogi., T., “Study on Air Assist Fuel Injector Atomization and Effects on Exhaust Emission Reduction,” SAE Paper 930323, 1993, Docket A-2000-01, Document II-A-55.

4. Energy and Environmental Analysis, “Benefits and Cost of Potential Tier 2 Emission Reduction Technologies”, Final Report, November 1997, Docket A-2000-01, Document II-A-01.

5. Southwest Research Institute, “Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines,” prepared for California ARB, California EPA, and South Coast Air Quality Management District, (SwRI 8778), April 1999, Docket A-2000-01, Document II-A-08.

6. Heywood, pp. 836-839, Docket A-2000-01, Document IV-A-110.

7. “Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or Above 37 kW; Final Rule,” 64 FR 73318, December 29, 1999.

8. Final Regulatory Impact Analysis for “Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or Above 37 kW; Final Rule,” November 1999, Docket A-2000-01, Document II-A-78.

Chapter 4: Feasibility of Standards

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 emission standards are technically achievable accounting for all the above factors.

It is important to note that the term "greatest degree of emission reduction achievable" applies with respect to in-use emissions from each production engine at the end of engine's useful life, rather than what is achievable under more ideal laboratory conditions. This means that the standards that are being established in this rulemaking must account for production variability and for deterioration in emission performance that will occur in use as the engines age and wear over the applicable useful life periods. We have considered these factors in determining the lowest emissions that will be feasible in the time frame required. Thus, in some cases, the emission standards are somewhat higher than the lowest emissions observed during laboratory testing. In general, we expect that manufacturers will design their engines and vehicles to be at 10- 20 percent below the applicable emission standard when produced to account for both production variability and deterioration. Chapter 6 includes more information about our expectations regarding compliance margins and deterioration rates.

4.1 CI Recreational Marine

The emission standards for CI recreational marine engines are summarized in the Executive Summary. We believe that manufacturers will be able to meet these standards using technology similar to that required for the commercial marine engine standards. This section discusses technology currently used on CI recreational marine engines and anticipated technology to meet the standards. In addition, this section discusses the emission test procedures and Not-to-Exceed requirements.

4.1.1 Baseline Technology for CI Recreational Marine Engines

We developed estimates of the current mix of technology for CI recreational marine engines based on data from the 1999 Power Systems Research (PSR) database and from conversations with marine manufacturers. Based on this information, we estimate that 97 % of new marine engines are turbocharged, and 80% of these turbocharged engines use aftercooling. The majority of these engines are four-stroke, but about 14% of new engines are two-stroke. Electronic controls have only recently been introduced into the marketplace; however, we anticipate that their use will increase as customers realize the performance benefits associated with electronic controls and as the natural migration of technology from on-highway to nonroad to marine engine applications occurs.

Table 4.1-1 presents data[1,2,3,4,5,6] from 25 recreational marine diesel engines based on the ISO E5 duty cycle. This data shows to what extent emissions need to be reduced from today's CI recreational marine engines to meet the standards.[s] On average, we are requiring significant reductions in HC+NOx and PM. However, this data seems to show that the diesel engine designs will either have to be focused on NOx or PM due to the trade-off between calibrating to minimize these pollutants. The CO standard will act more as a cap, but will require control to be established.

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[s] For most of the engines in Table 4.1-1, the standards are of 7.2 g/kW-hr HC+NOx, 5 g/kW-hr CO, and 0.2 g/kW-hr PM

Table 4.1-1: Emissions Data from CI Recreational Marine Engines

Rated Power (kW)	Control Management	Aftercooling	Emissions Data (g/kW-hr)			
			HC	NOx	CO	PM
120	electronic	raw-water	0.09	5.8	0.9	–
132	mechanical	raw-water	0.07	4.2	0.2	–
142	mechanical	separate circuit	0.79	8.6	1.1	–
162	mechanical	raw-water	0.11	4.0	0.2	–
164	electronic	raw-water	0.28	5.1	1.6	–
170	mechanical	raw-water	0.36	8.1	0.6	0.20
186	mechanical	raw-water	0.30	10.2	1.2	0.12
209	mechanical	raw-water	0.42	10.8	2.3	0.22
230	electronic	raw-water	0.28	5.5	1.8	0.39
235	mechanical	raw-water	0.45	9.8	1.8	0.20
265	mechanical	jacket-water	0.58	10.8	1.4	–
276	mechanical	raw-water	0.60	10.7	1.9	0.24
287	electronic	raw-water	0.28	7.9	–	0.12
321	mechanical	raw-water	0.37	7.7	0.9	0.23
324	mechanical	jacket-water	0.30	7.9	2.9	0.95
336	electronic	jacket-water	0.18	11.0	0.5	0.10
336	electronic	jacket-water	0.09	11.9	–	0.16
447	electronic	raw-water	0.12	9.3	–	0.17
447	mechanical	jacket-water	0.60	12.0	1.5	0.18
474	electronic	raw-water	0.34	7.7	0.5	0.07
537	electronic	jacket-water	0.08	10.7	–	0.19
820	electronic	separate circuit	0.33	9.5	0.8	0.13
1040	electronic	jacket-water	0.09	9.3	–	0.21
1080	electronic	separate circuit	0.18	7.6	1.2	0.15
1340	electronic	separate circuit	0.27	7.2	0.9	0.15

4.1.2 Anticipated Technology for CI Recreational Marine Engines

Marine engines are generally derived from land-based nonroad, locomotive, and to some extent highway engines. In addition, recreational marine engines will be able to use technology developed for commercial marine engines. This allows recreational marine engines, which generally have lower sales volumes than other nonroad engines, to be produced more cost-efficiently. Because the marine designs are derived from land-based engines, we believe that many of the emission-control technologies which are likely to be applied to nonroad engines to meet their Tier 2 and 3 emission standards will be applicable to marine engines. We also believe that the technologies listed below will be sufficient for meeting both the new emission standards and the Not to Exceed requirements discussed later in this chapter for the full useful life of these engines.

We anticipate that timing retard will likely be used in most CI recreational marine applications, especially at cruising speeds, to gain NOx reductions. The negative impacts of timing retard on HC, PM, fuel consumption and power can be offset with improved fuel injection systems with higher fuel injection pressures, optimized nozzle geometry, and potentially through injection rate shaping. We do not expect marine engine manufacturers to convert from direct injection to indirect injection due to these standards.

Regardless of environmental regulations, we believe that recreational marine engine manufacturers will make more use of electronic engine management controls in the future to satisfy customer demands of increased power and fuel economy. Through the use of electronic controls, additional reductions in HC, CO, NOx, and PM can be achieved. Electronics may be used to optimize engine calibrations under a wider range of operation. Most of the significant research and development for the improved fuel injection and engine management systems should be accomplished for land-based nonroad diesel engines which are being designed to meet Tier 2 and Tier 3 standards. Common rail should prove to be a useful technology for meeting even lower emission levels in the future, especially for smaller engines. Thus, the challenge for this control program will be transferring land-based techniques to marine engines.

We project that all CI recreational marine engines will be turbocharged and most will be aftercooled to meet emission standards. Aftercooling strategies will likely be mostly jacket-water charge air cooling, and in some cases, we believe that separate cooling circuits for the aftercooling will be used. We do not expect a significant increase in the use of raw-water charge air cooling for marine engines as a result of this rule. We recognize that raw-water aftercooling systems are currently in use in many applications. Chapter 5 presents one possible scenario of how these technologies could be used on CI recreational marine engines to meet the standards.

By adopting standards that will not go into effect until 2006, we are providing engine manufacturers with substantial lead time for developing, testing, and implementing emission control technologies. This lead time and the coordination of standards with those for commercial marine engines allows for a comprehensive program to integrate the most effective emission control approaches into the manufacturers’ overall design goals related to performance, durability, reliability, and fuel consumption.

4.1.3 Emission Measurement Procedures for CI Recreational Marine Engines

In any program we design to achieve emissions reductions from internal combustion engines, the test procedures we use to measure emissions are as important as the standards we put into place. These test procedure issues include duty cycle for certification, in-use verification testing, emission sampling methods, and test fuels.

4.1.3.1 Certification Duty Cycles

In choosing duty cycles for certification, we turned to the International Standards Organization (ISO).[7] For CI recreational marine engines, we based our standards on the ISO E5 duty cycle. This duty cycle is intended for "diesel engines for craft less than 24m length (propeller law)."

We specify the E5 duty cycle for measuring emissions from CI recreational marine engines. This cycle is similar to the E3 duty cycle which is used for commercial marine in that both cycles have four steady-state test points on an assumed cubic propeller curve. However, the E5 includes an extra mode at idle and has an average weighted power of 34% compared to the 69% for the E3. This duty cycle is presented in Table 4.1-2.

Table 4.1-2: ISO E5 Marine Duty Cycle

Mode	% of Rated Speed	% of Power at Rated Speed	Weighting Factor
1	100	100	0.08
2	91	75	0.13
3	80	50	0.17
4	63	25	0.32
5	idle	0	0.30

4.1.3.2 Emission Control of Typical In-Use Operation

We are concerned that if a marine engine is designed for low emissions on average over a small number of discrete test points, it may not necessarily operate with low emissions in-use. This is due to a range of speed and load combinations that can occur on a boat which do not necessarily lie on the test duty cycles. For instance, the test modes for the E5 duty cycle lie on average propeller curves. However, a propulsion marine engine may never be fitted with an "average propeller." In addition, a given engine on a boat may operate at higher torques than average if the boat is heavily loaded. We are also aware that, before a boat comes to plane, the engine operates closer to its full torque map than to the propeller curve.

We are applying the "Not-to-Exceed" (NTE) limit concept to recreational marine engines in a way that is similar to commercial marine engines. This concept basically picks a zone of operation under which a marine engine must not exceed the standard by a fixed percentage and is discussed in more detail in the commercial marine FRM.[8] Of course, the shape of the zone must be adjusted to reflect recreational engine use.

Under this final rule, we have the authority to use test data from new or in-use engines to confirm emissions compliance throughout an engine's useful life.

4.1.3.2.1 Engine operation included for NTE

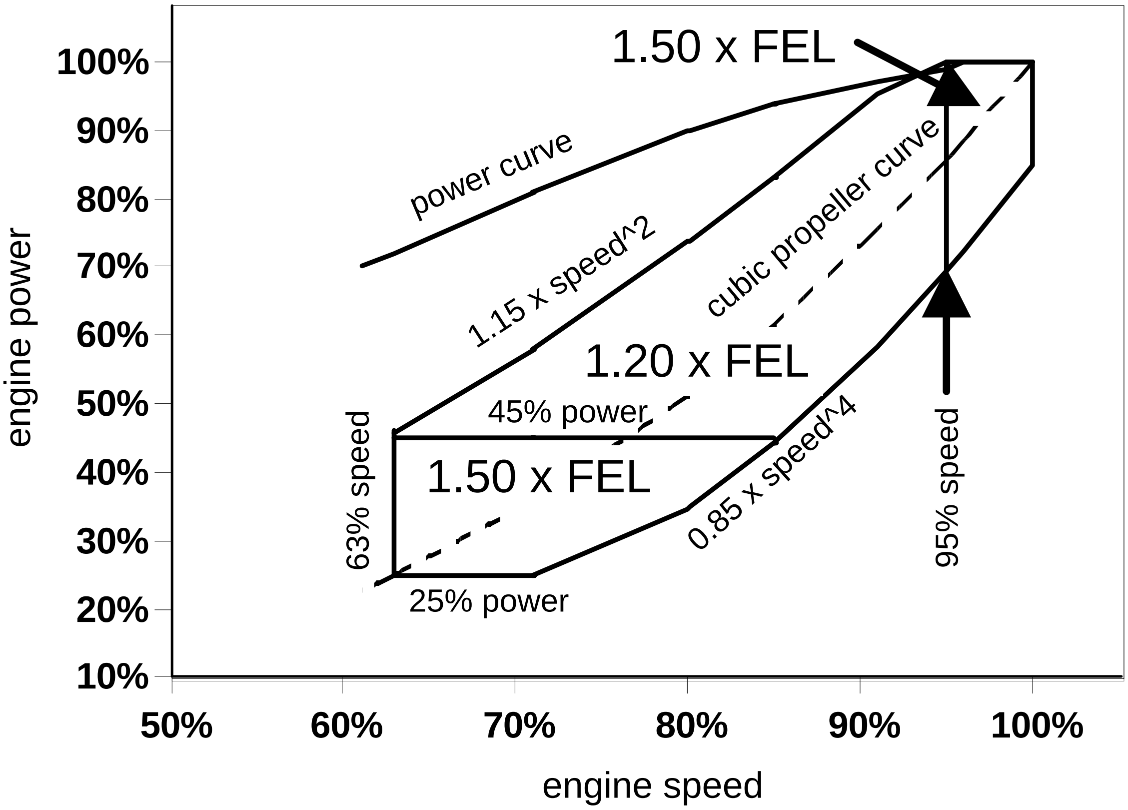
The shape of the NTE zones are based on our understanding of how recreational marine engines are used. Operation at low power is omitted from the NTE zone even though marine engines operate here in use. This omission is because, by definition, brake-specific emissions become very large at low power due to dividing by power values approaching zero.

We believe that the majority of marine engine operation is steady-state. We are therefore including only steady-state operation in the NTE requirements. Also, these are technology-forcing standards, so we expect engines to reduce emissions also under transient operation. If we find that the effectiveness of this program is compromised due to high emissions under transient operation, we will revisit this requirement in the future.

It should be noted that the emissions caps for operation in the NTE zone are based on the weighted emissions over the E5 duty cycle. Because idle emissions are part of these weighted values but not included in the NTE zone, it is likely that emissions in the NTE zone will be less than the weighted average. This alone reduces the stringency of a "not-to-exceed" approach for recreational when compared to commercial marine engines.

For compression-ignition engines, the NTE zone is defined by the maximum power curve, actual propeller curves, and speed and load limits. The E5 duty cycle itself is based on a cubic power curve through the peak power point. For the NTE zone, we define the upper boundary using a speed squared propeller curve passing through the 115% load point at rated speed and the lower boundary using on a speed to the fourth power curve passing through the 85% load point at rated speed. We believe these propeller curves represent the range of propeller curves seen in use.[9] To prevent imposing an unrealistic cap on a brake-specific basis, we are limiting this region to power at or above 25% of rated power and speeds at or above 63% of rated speed. These limits are consistent with mode 4 of the E5 duty cycle. Figure 4.1-1 presents the NTE zone for CI recreational marine engines.

Figure 4.1-1: NTE Zone for Recreational CI Marine Engines



We understand that an engine tested onboard a boat in use may not be operating as the manufacturer intended because the owner may not be using a propeller that is properly matched to the engine and boat. Also, the owner may have a boat that is overloaded and too heavy for the engine. The boundaries in Figure 4.1-1 are intended to contain typical operation of recreational diesel engines and exclude engines which are not used properly. Although the E5 uses a cubic power curve engines generally see some variation in use. These boundaries are consistent with operational data we collected.[10]

We are adopting emissions caps for the NTE zone that represent a multiplier times the weighted test result used for certification. Although ideally the engine should meet the certification level throughout the NTE zone, we understand that a cap of 1.00 times the standard is not reasonable, because there is inevitably some variation in emissions over the range of engine operation. This is consistent with the concept of a weighted modal emission test such as the steady-state tests included in this rule.

Consistent with the commercial requirements, we require that CI recreational marine engines must meet a cap of 1.50 times the certified level for HC+NOx, PM, and CO for the speed and power subzone below 45% of rated power and a cap of 1.20 times the certified levels at or above

45% of rated power. However, we are including an additional subzone, when compared with the commercial NTE zone, at speeds greater than 95% of rated. We are adopting a cap of 1.50 times the certified levels for this subzone. Our purpose for this additional subzone is to address the typical recreational design for higher rated power. This power is needed to ensure that the engine can bring the boat to plane.

We based the caps both on emissions data collected on the assumed propeller curve and on data collected from a recreational marine diesel engine over a wide range of steady-state operation. All of this data is cited earlier in this chapter. The data in Figures 4.1-2 through 4.1-4 show that, within the range of in-use testing points, HC+NOx and PM are generally well below the E5 weighted averages. This is likely due to the effects of emissions at idle. For all of these engines, modal CO results were below the standard. None of these engines are calibrated for emissions control.

Figure 4.1-2: Mode/E5 Average HC+NOx

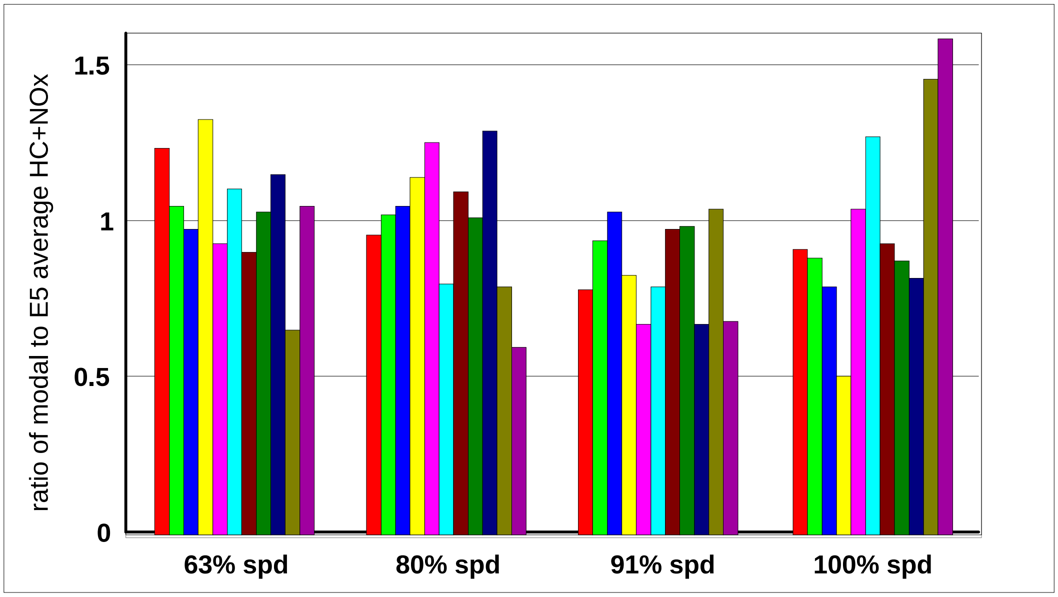


Figure 4.1-3: Mode/E5 Average PM

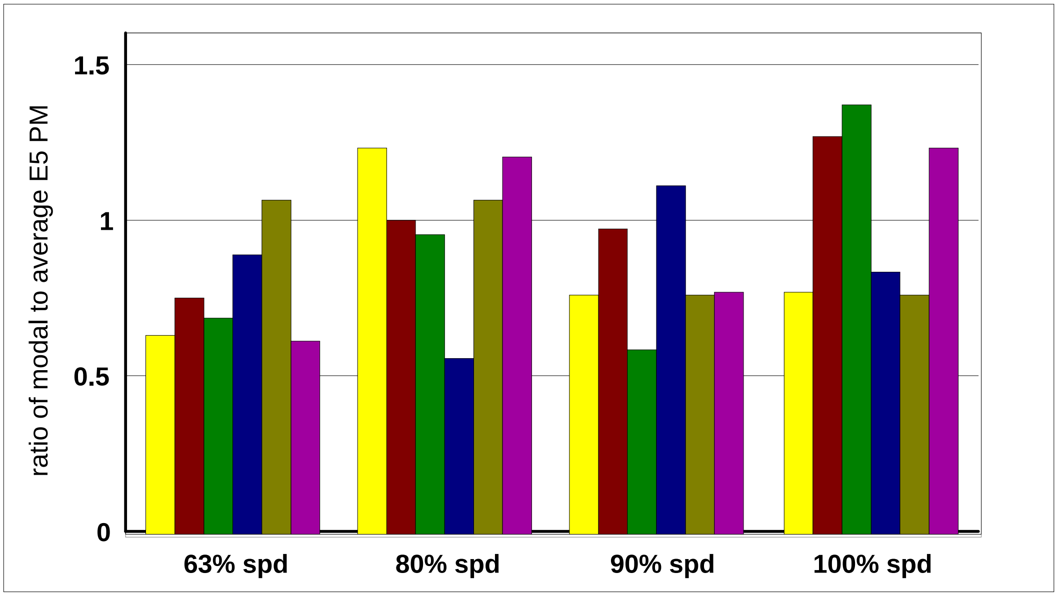
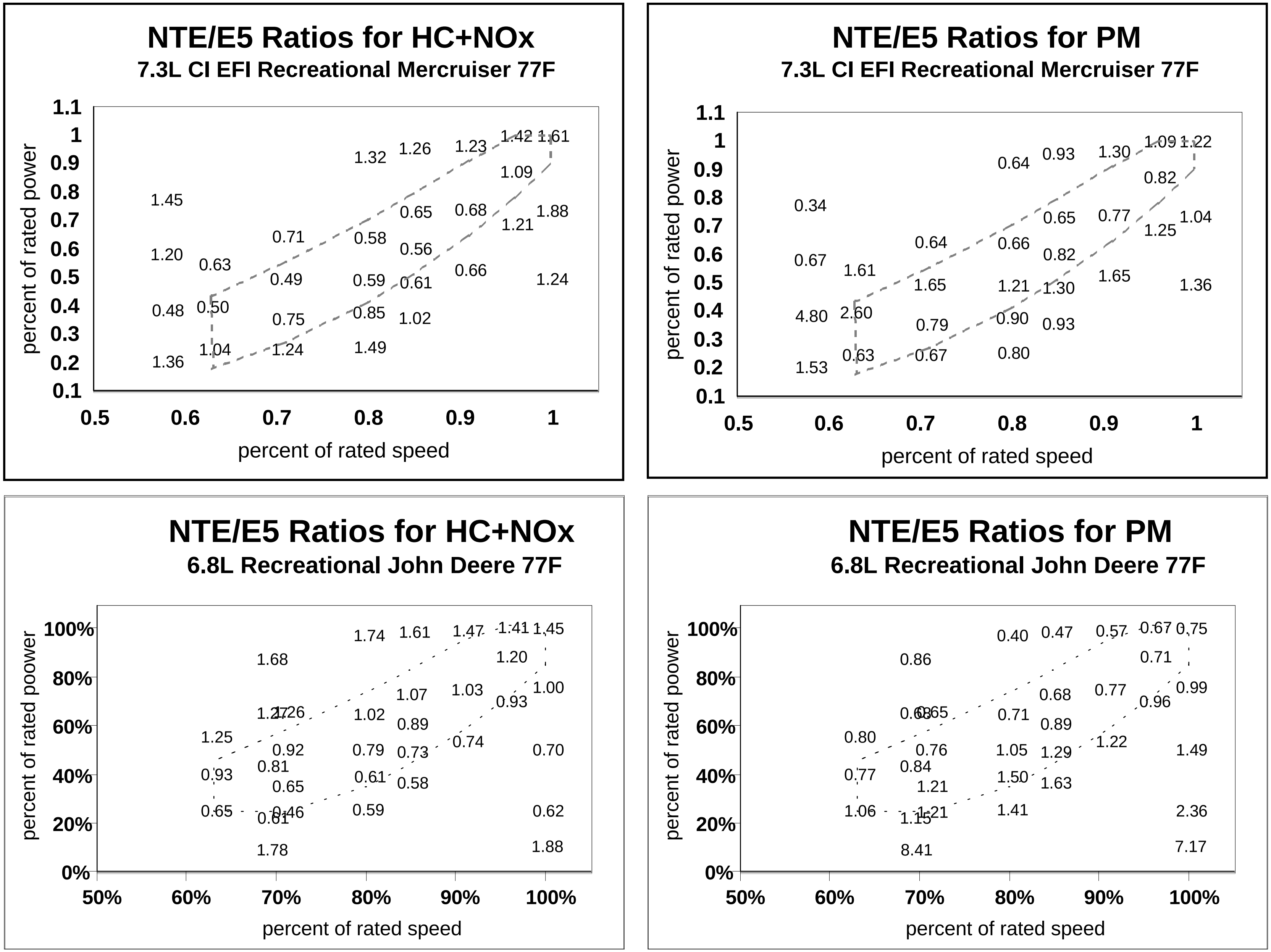


Figure 4.1-4: Ratio of Modal Emissions to E5 Cycle For Two Engines Tested Throughout NTE Zone



NTE/E5 Ratios for HC+NOx
7.3L CI EFI Recreational Mercruiser 77F

NTE/E5 Ratios for PM
7.3L CI EFI Recreational Mercruiser 77F

NTE/E5 Ratios for HC+NOx
6.8L Recreational John Deere 77F

NTE/E5 Ratios for PM
6.8L Recreational John Deere 77F

4.1.3.2.2 Ambient conditions during testing

Variations in ambient conditions can affect emissions from a marine engine. Such conditions include air temperature, humidity, and (especially for diesels) water temperature. We are applying the same ranges for these variables that apply to commercial marine engine. Within the ranges, no corrections can be made for emissions. Outside of the ranges, emissions can be corrected back to the nearest edge of the range. The ambient variable ranges are:

intake air temperature	13-35°C (55-95°F)
intake air humidity	7.1-10.7 g water/kg dry air (50-75 grains/lb. dry air)
ambient water temperature	5-27°C (41-80°F)

The air temperature and humidity ranges are consistent with those developed for NTE testing of highway heavy-duty diesel engines. The air temperature ranges were based on temperatures seen during ozone NAAQS exceedances.[11] For NTE testing in which the air temperature or humidity is outside of the range, emissions may be corrected back to the air temperature or humidity range. These corrections must be consistent with the equations in Title 40 of the Code of Federal Regulations (CFR), except that these equations correct to 25°C and 10.7 grams per kilogram of dry air, while corrections associated with the NTE testing shall be to the nearest outside edge of the specified ranges. For instance, if the temperature were higher than 35˚C, a temperature correction factor may be applied to the emissions results to determine what the emissions would be at 35˚C.

For marine engines using aftercooling, we believe the charge air temperature is essentially insensitive to ambient air temperature compared to the cooling effect of the aftercooler. SwRI tested this theory and found that when the ambient air temperature was increased from 21.9 to 32.2°C, the cooling water to the aftercooler of a diesel marine engine only had to be reduced by 0.5°C to maintain a constant charge air temperature.[12] According to the CFR correction factor, there is only a ±3% variation in NOx in the NTE humidity range.

Naturally aspirated engines should be more sensitive to intake air temperature because the temperature affects the density of the air into the engine. Therefore, high temperatures can limit the amount of air drawn into the cylinder. Our understanding is that many engines operate in and draw air from small engine compartments. This suggests that any naturally aspirated recreational engines used today are already designed to operate with high intake air temperatures. In any case, we do not believe that manufacturers will use naturally aspirated marine engines to meet the new standards.

Ambient water temperature also may affect emissions due to its impact on engine and charge air cooling. We based the water temperature range on temperatures that marine engines experience in the U.S. in use. Although marine engines experience water temperatures near freezing, we don't believe that additional emission control will be gained by lowering the minimum water temperature below 5°C. At this time, we aren't aware of an established correction factor for ambient water temperature. For this reason, NTE zone testing must be within the specified ambient water temperature range.

We don't think that the range of ambient water temperatures discussed above will have a significant effect on the stringency of the NTE requirements, even for aftercooled engines. Following the normal engine test practice recommended by SAE for aftercooled engines, the cooling water temperature would be set to 25±5°C.[13] This upper portion of the NTE temperature range is within the range suggested by SAE for engine testing. For lower temperatures, manufacturers can use a thermostat or other temperature regulating device to ensure that the charge air is not overcooled. In addition, the SAE practice presents data from four aftercooled diesel engines on the effects of cooling medium temperature on emissions. For every 5°C increase in temperature, HC decreases 1.8%, NOx increases 0.6%, and PM increases 0.1%.

We are aware that many marine engines are designed for operation in a given climate. For instance, recreational vessels operated in Seattle don't need to be designed for 27°C water temperatures. For situations such as this, manufacturers may petition for the appropriate temperature ranges associated with the NTE zone for a specific engine design. In addition, we understand there are times when emission control may need to be compromised for startability or safety. Manufacturers are not responsible for the NTE requirements under start-up conditions. In addition, manufacturers may petition to be exempt from emission control under specified extreme conditions such as engine overheating where emissions may increase under the engine-protection strategy.

4.1.3.3 Emissions Sampling

Aside from the duty cycle, the test procedures for marine engines are similar to those for land-based nonroad engines. However, there are a few other aspects of marine engine testing that need to be considered. Most recreational marine engines mix cooling water into the exhaust. This exhaust cooling is generally done to keep surface temperatures low for safety reasons and to tune the exhaust for performance and noise. Because the exhaust must be dry for dilute emission sampling, the cooling water must be routed away from the exhaust in a test engine.

Even though many marine engines exhaust their emissions directly into the water, we base our test procedures and associated standards on the emissions levels in the "dry" exhaust. Relatively little is known about water scrubbing of emissions. We must therefore consider all pollutants out of the engine to be a risk to public health. Additionally, we are not aware of a repeatable laboratory test procedure for measuring "wet" emissions. This sort of testing is nearly impossible from a vessel in-use. Finally, a large share of the emissions from this category come from large engines which emit their exhaust directly to the atmosphere.

The established method for sampling emissions is through the use of full dilution sampling. However, for larger engines the exhaust flows become so large that conventional dilute testing requires a very large and costly dilution tunnel. One option for these engines is to use a partial dilute sampling method in which only a portion of the exhaust is sampled. It is important that the partial sample be representative of the total exhaust flow. The total flow of exhaust can be determined by measuring fuel flow and balancing the carbon atoms in and out of the engine. For guidance on shipboard testing, the MARPOL NOx Technical Code specifies analytical instruments, test procedures, and data reduction techniques for performing test-bed and in-use emission measurements.[14] Partial dilution sampling methods can provide accurate steady-state measurements and show great promise for measuring transient emissions in the near future. We intend to pursue development of this method and put it in place prior to the date that the standards in this final rule become enforceable.

Pulling a marine engine from a boat and bringing it to a laboratory for testing could be burdensome. For this reason, we may perform in-use confirmatory testing onboard a boat. Our goal would be to perform the same sort of testing as for the laboratory. However, engines tested in a boat are not likely to operate exactly on the assumed propeller curve. For this reason, emissions measured within the NTE zone must meet the subzone caps based on the certified level during onboard testing. To facilitate onboard testing, manufacturers must provide a location with a threaded tap where a sampling probe may be inserted. This location must be upstream of where the water and exhaust mix at a location where the exhaust gases could be expected to be the most homogeneous.

There are several portable sampling systems on the market that, if used carefully, can give fairly accurate results for onboard testing. Engine speed can be monitored directly, but load may have to be determined indirectly. For engines operating at a constant speed, it should be relatively easy to set the engine to the points specified in the duty cycles.

4.1.3.4 Test Fuel Specifications

We are applying the recently finalized test fuel specifications for commercial marine engines to recreational marine diesel engines. These fuel specifications are similar to land-based nonroad fuel with a change in the sulfur content upper limit from 0.4 to 0.8 weight-percent (wt%). We believe this will simplify development and certification burdens for marine engines that are developed from land-based counterparts. This test fuel has a sulfur specification range of 0.03 to 0.80 wt%, which covers the range of sulfur levels observed for most in-use fuels. Manufacturers will be able to test using any fuel within this range for the purposes of certification. Thus, they will be able to harmonize their marine test fuel with U.S. highway (<0.05 wt%) and nonroad (0.03 to 0.40 wt%), and European testing (0.1 to 0.2 wt%).

The intent of these test fuel specifications is to ensure that engine manufacturers design their engines for the full range of typical fuels used by Category 1 marine engines in use. Because the technological feasibility of the new emission standards is based on fuel with up to 0.4 wt% sulfur, any testing done using fuel with a sulfur content above 0.4 wt% would be done with an allowance to adjust the measured PM emissions to the level corresponding with a test using fuel with 0.4 wt% sulfur. We do not expect the sulfur content to have a large impact on PM emissions because only about 2 percent of the sulfur in the fuel is converted to direct sulfate PM.[15]

The full range of test fuel specifications are presented in Table 4.1-3. Because testing conducted by us is limited to the test fuel specifications, it is important that the test fuel be representative of in-use fuels.

Table 4.1-3: Recreational Marine Diesel Test Fuel Specifications

Item	Procedure (ASTM)	Value (Type 2-D)
Initial Boiling Point, °C	D86-90	171-204
10% point, °C	D86-90	204-238
50% point, °C	D86-90	243-282
90% point, °C	D86-90	293-332
End Point, °C	D86-90	321-366
Cetane	D613-86	40-48
Gravity, API	D287-92	32-37
Total Sulfur, % mass	D129-21 or D2622-92	0.03-0.80
Aromatics, % volume	D1319-89 or D5186-91	10 minimum
Paraffins, Napthenes, Olefins	D1319-89	remainder
Flashpoint, °C	D93-90	54 minimum
Viscosity @ 38 °C, centistokes	D445-88	2.0-3.2

4.1.4 Impacts on Noise, Energy, and Safety

The Clean Air Act requires EPA to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for CI recreational marine engines.

One important source of noise in diesel combustion is the sound associated with the combustion event itself. When a premixed charge of fuel and air ignites, the very rapid combustion leads to a sharp increase in pressure, which is easily heard and recognized as the characteristic sound of a diesel engine. The conditions that lead to high noise levels also cause high levels of NOx formation. Fuel injection changes and other NOx control strategies therefore typically reduce engine noise, sometimes dramatically.

The impact of the new emission standards on energy is measured by the effect on fuel consumption from complying engines. Many of the marine engine manufacturers are expected to retard engine timing which increases fuel consumption somewhat. Most of the other technology changes anticipated in response to the new standards, however, have the potential to reduce fuel consumption as well as emissions. Redesigning combustion chambers, incorporating improved fuel injection systems, and introducing electronic controls provide the engine designer with powerful tools for improving fuel efficiency while simultaneously controlling emission formation. To the extent that manufacturers add aftercooling to non aftercooled engines and shift from jacket-water aftercooling to raw-water aftercooling, there will be a marked improvement in fuel-efficiency. Manufacturers of highway diesel engines have been able to steadily improve fuel efficiency even as new emission standards required significantly reduced emissions.

There are no known safety issues associated with the new emission standards. Marine engine manufacturers will likely use only proven technology that is currently used in other engines such as nonroad land-based diesel applications, locomotives, and diesel trucks.

4.2 Large Industrial SI Engines

This category of engines generally includes all nonrecreational land-based spark-ignition engines rated above 19 kW that are not installed in motor vehicles or stationary applications. In an earlier memorandum, we described the rationale for developing emission measurement procedures for transient and off-cycle engine operation.[16] Information from that memorandum is not repeated here, except to the extent that it supports decisions about the selecting the numerical emission standards.

The emission standards for Large SI engines are listed in the Executive Summary. The following paragraphs summarize the data and rationale supporting the standards.

4.2.1 2004 Standards

Engine manufacturers are currently developing technologies and calibrations to meet the 2004 standards that apply in California. We expect manufacturers to rely on electronically controlled, closed-loop fuel systems and three-way catalysts to meet those emission standards. As described below, emission data show that water-cooled engines can readily meet the California ARB standards (3 g/hp-hr NMHC+NOx; 37 g/hp-hr CO).

Manufacturers will have just over one year to prepare engines for nationwide sales starting in 2004. Implementing new standards with such a short lead time is only possible because manufacturers have been aware of their need to comply with the California ARB standards as well as our proposal to implement those standards nationwide. With no need to further modify engine designs, manufacturers should have time before 2004 to plan for increasing production volume for nationwide sale of engines that can meet the 2004 California ARB standards.

Adopting standards starting in 2004 allows us to align near-term requirements with those adopted by California ARB. This also provides early emission reductions and gives manufacturers the opportunity to amortize their costs over a broader sales volume before investing in the changes needed to address the long-term standards described below.

4.2.2 2007 Standards

The 2004 standards described above will reduce emissions from Large SI engines, but we believe these levels don’t fulfill the requirement to adopt standards achieving the “greatest degree of reduction achievable” from these engines in the long term. With additional time to optimize designs to better control emissions, manufacturers can optimize their designs to reduce emissions below the levels required by the 2004 standards. We are also adopting new procedures for measuring emissions starting in 2007, which will require further efforts to more carefully design and calibrate emission-control systems to achieve in-use emission reductions. The following discussion explains why we believe the 2007 emission standards are feasible.

The biggest uncertainty in adopting emission standards for Large SI engines was the degree to which emission-control systems deteriorate with age. While three-way catalysts and closed-loop fueling systems have been in place in highway applications for almost 20 years, we needed to collect information showing how these systems hold up under nonroad use. To address this, we participated in an investigative effort with Southwest Research Institute (SwRI), California ARB, and South Coast Air Quality Management District, as described in the memorandum referenced above.[17] The engines selected for testing had been retrofitted with emission-control systems in Spring 1997 after having already run for 5,000 and 12,000 hours. Both engines are in-line four-cylinder models operating on liquefied petroleum gas (LPG)—a 2-liter Mazda engine rated at 32 hp and a 3-liter GM engine rated at 45 hp. The retrofit consisted of a new, conventional three-way catalyst, electronic controls to work with the existing fuel system, and the associated sensors, wiring, and other hardware. The electronic controller allowed only a single adjustment for controlling air-fuel ratios across the range of speed-load combinations.

Laboratory testing consisted of measuring steady-state and transient emission levels, both before and after taking steps to optimize the system for low emissions. While the engines' emission-control systems originally focused on controlling CO emissions, the testing effort focused on simultaneously reducing HC, NOx, and CO emissions. This testing provides a good indication of the capability of these systems to control emissions over an engine's full useful life. The testing also shows the degree to which transient emissions are higher than steady-state emission levels for Large SI engine operation. Finally, the testing shows how emission levels vary for different engine operating modes. Emission testing included engine operation at a wide range of steady-state operating points and further engine operation over several different transient duty cycles. Much of the emissions variability at different speeds and loads can be attributed to the basic design of the controller, which has a single, global calibration setting. This data showing the variability of emissions is necessary to support the field-testing emission standards, as described further below.

4.2.2.1. Steady-state testing results

Testing results from the aged engines at SwRI showed very good emission control capability over the full useful life. Test results with emission control hardware on the aged engines lead to the conclusion that the systems operated with relatively stable emission levels over the several thousand hours. As shown in Table 4.2-1, the emission levels measured by SwRI are consistent with results from a wide variety of measurements on other engines. The data listed in the table includes only LPG-fueled engines. See Section 4.2.2.6 for a discussion of gasoline-fueled engines.

Table 4.2-1
Steady-State Emission Results from LPG-fueled Engines

Test engine	HC+NOx* g/hp-hr	CO g/hp-hr	Notes**
Mazda 2L[18]	0.51	3.25	4,000 hours, add-on retrofit
GM 3L	0.87	1.84	5,600 hours, add-on retrofit
Engine B	0.22	2.79	250 hours
GFI[19]	0.52 NMHC+NOx	2.23	5,000 hours
Toyota/ECS 2L[20]	1.14	0.78	zero-hour; ISO C1 duty cycle for nonroad diesel engines
GM/Impco 3L[21]	0.26	0.21	zero-hour

*Measurements are THC+NOx, unless otherwise noted.
**Emissions were measured on the ISO C2 duty cycle, unless otherwise noted.

This data set supports emission standards significantly more stringent than the 2004 standards. However, considering the need to focus on transient emission measurements, we believe it is not appropriate to adopt more stringent emission standards based on the steady-state duty cycles. Stringent emission standards based on certain discrete modes of operation may inappropriately constrain manufacturers from controlling emissions across the whole range of engine speeds and loads. We therefore intend to rely more heavily on the transient testing to determine the stringency of the emission-control program.

4.2.2.2 Transient testing results

The SwRI testing is the only known source of information for evaluating the transient emission levels from Large SI engines equipped with emission-control systems. Table 4.2-2 shows the results of this testing. The transient emission levels, though considerably lower than the 2004 standards, are higher than those measured on the steady-state duty cycles. A combination of factors contribute to this. First, these engines are unlikely to maintain precise control of air-fuel ratios during rapid changes in speed or load, resulting in decreased catalyst-conversion efficiency. Also, the transient duty cycle includes operation at engine speeds and loads that have higher steady-state emission levels than the seven modes constituting the C2 duty cycle. Both of these factors also cause uncontrolled emission levels to be higher, so the measured emission levels with the catalyst system still show a substantial reduction in emissions. Additional emission data measured during transient operation is shown in Section 4.2.2.7 for selecting the numerical values for the standards.

Table 4.2-2
Transient Test Results from SwRI Testing

Engine*	Duty Cycle	THC+NOx g/hp-hr	CO g/hp-hr
Mazda	Variable-speed, variable-load	1.1	9.9
	Constant-speed, variable-load	1.5	8.4
GM	Variable-speed, variable-load	1.2	7.0

*Based on the best calibration on the engine operating with an aged catalyst.

4.2.2.3 Off-cycle testing results

Engines operate in the field under both steady-state and transient operation. Although these emission levels are related to some degree, they are measured separately. This section therefore first considers steady-state operation.

Figures 4.2-1 through 4.2-6 show plots of emission levels from the test engines at several different steady-state operating modes. This includes the seven speed-load points in the ISO C2 duty cycle, with many additional test points spread across the engine map to show how emissions vary with engine operation. The plotted emission level shows the emissions at each normalized speed and normalized load point. The 100-percent load points at varying engine speeds form the engine's lug curve, which appears as a straight line because of the normalizing step.

Figure 4.2-1 shows the THC+NOx emissions from the Mazda engine when tested with an aged catalyst. While several points are higher than the 0.51 g/hp-hr level measured on the C2 duty cycle, the highest levels observed from the Mazda engine are around 2.3 g/hp-hr. The highest emissions are generally found at low engine speeds. Emission testing on the Mazda engine with a new catalyst showed very similar results on the C2 duty cycle, so testing was not done over the whole range of steady-state operating points shown in Figure 4.2-1.

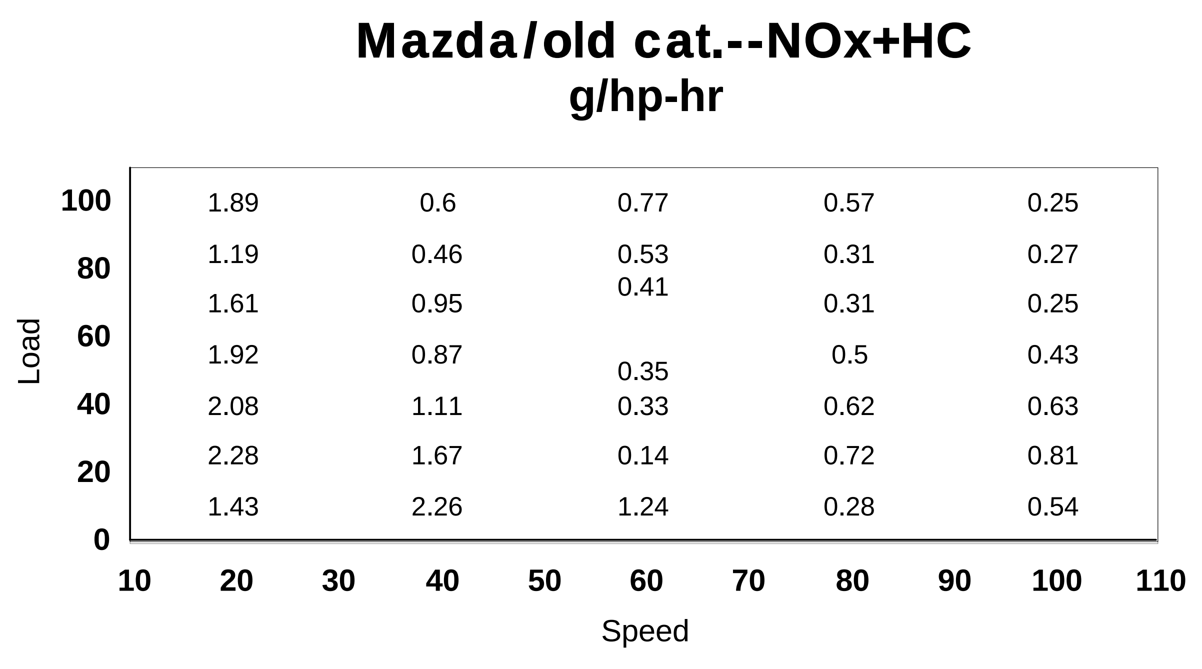
CO emissions from the same engine had a similar mix of very low emission points and several higher measurements. The CO levels along the engine's lug curve (100 percent load) range 12 to 22 g/hp-hr, well above the other points, most of which are under 4 g/hp-hr. The corner of the map with high-speed and low-load operation also has a high level of 9 g/hp-hr. These high-emission modes point to the need to address control of air-fuel ratios at these extremes of engine operation.

If CO emissions at these points were an inherent problem associated with these engines, we could take that into account in setting the standard. Figure 4.2-4 shows, however, that the GM engine with the same kind of aged emission-control system had emission levels at most of these points ranging from 0.7 to 4.7 g/hp-hr. The one remaining high point on the GM engine was

11.6 g/hp-hr at full load and low speed. A new high-emission point was 28 g/hp-hr at the lowest measured speed and load. Both of these points are much lower on the same engine with the new catalyst installed (see Figure 4.2-6). These data reinforce the conclusion that adequate development effort will enable manufacturers to achieve broad control of emissions across the engine map.

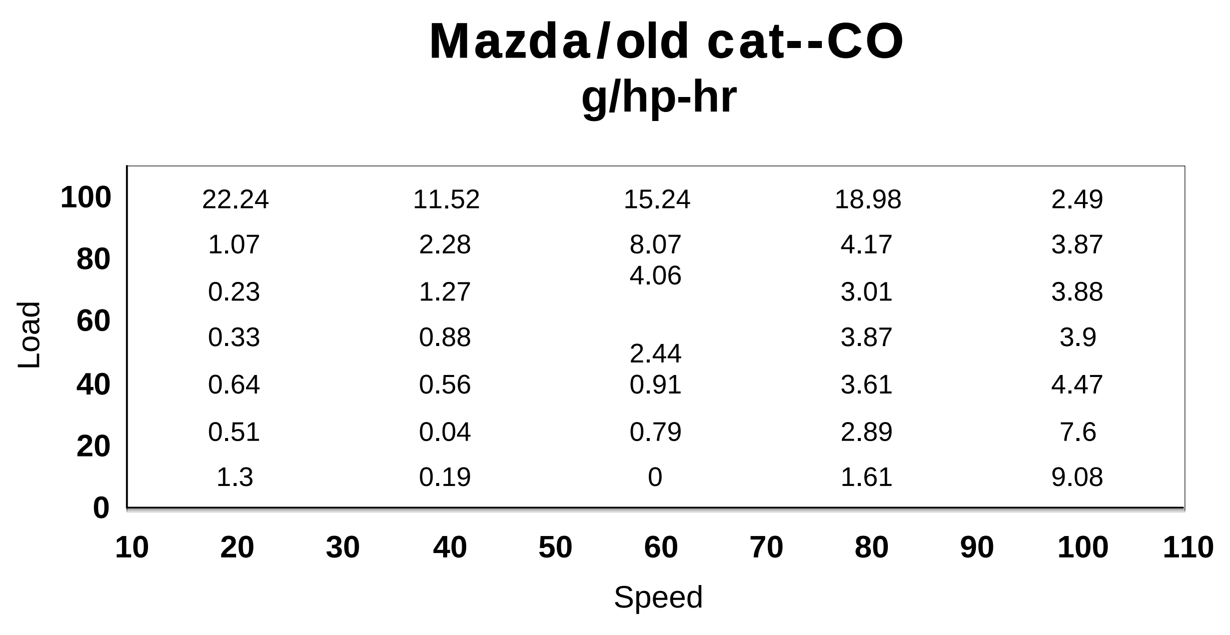
Figure 4.2-3 shows the THC+NOx emissions from the GM engine when tested with the aged catalyst. Emission trends across the engine map are similar to those from the Mazda engine, with somewhat higher low-speed emission levels between 2.3 and 4.4 g/hp-hr at various points. Operation on the new catalyst shows a significant shifting of high and low emission levels at low-speed operation, but the general observation is that the highest emission levels disappear, with 2.3 g/hp-hr being again the highest observed emission level over the engine map (see Figure 4.2-5).

Figure 4.2-1



C2 = 0.51 g/hp-hr

Figure 4.2-2



C2=3.25 g/hp-hr

Figure 4.2-3

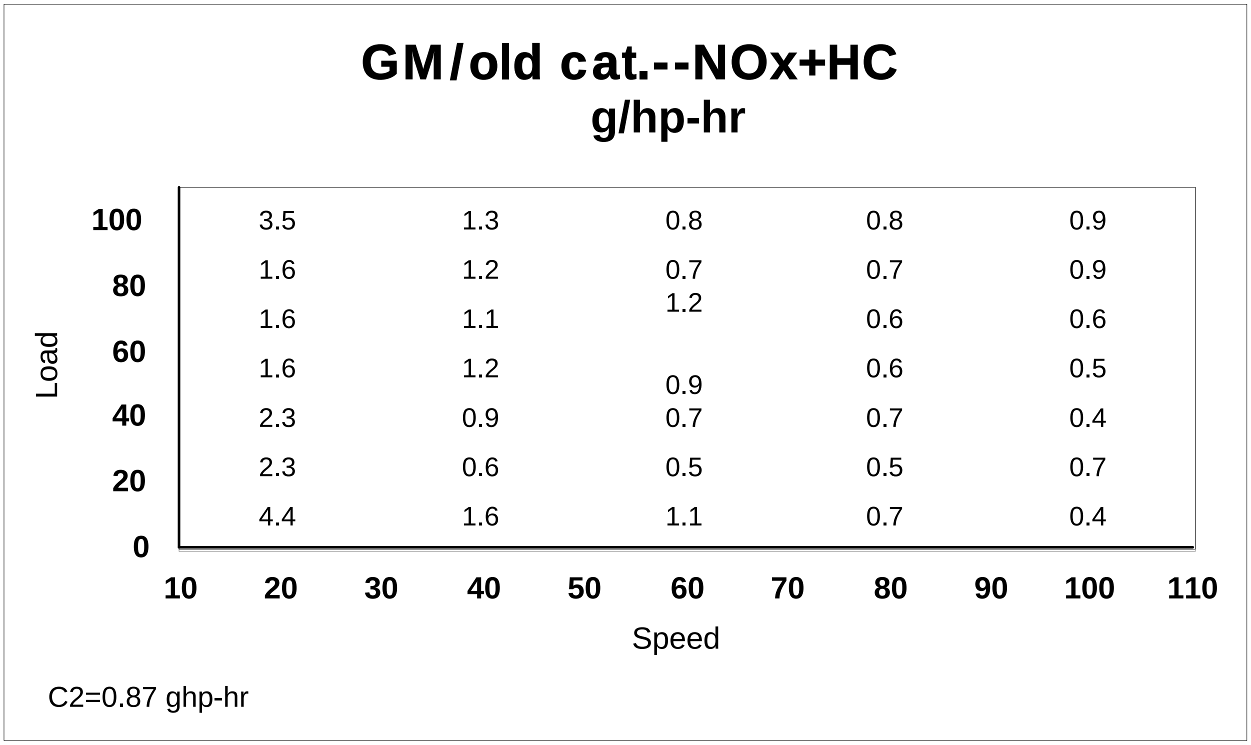


Figure 4.2-4

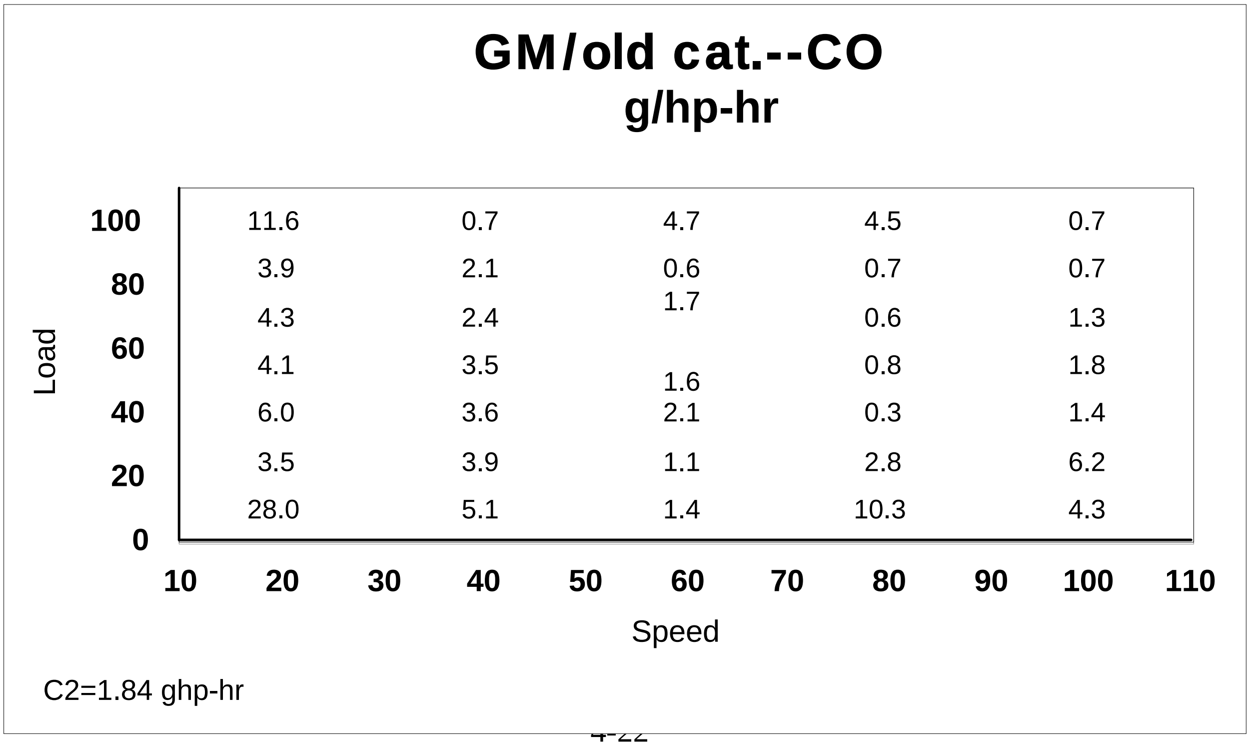


Figure 4.2-5

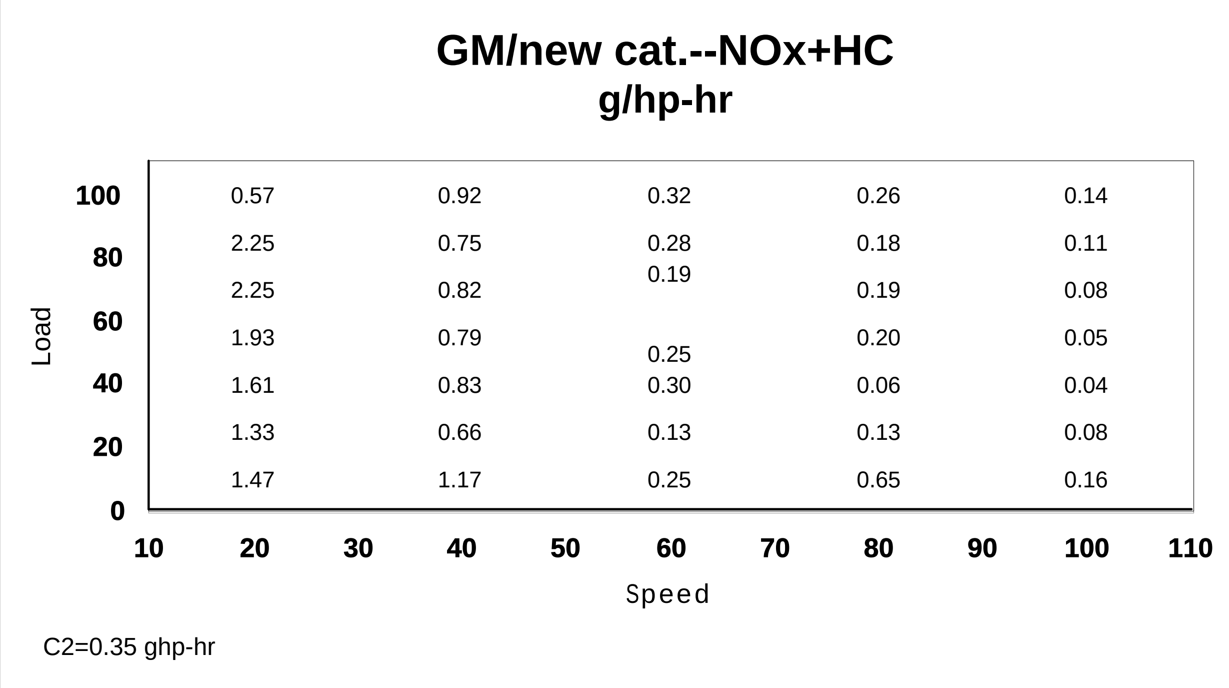
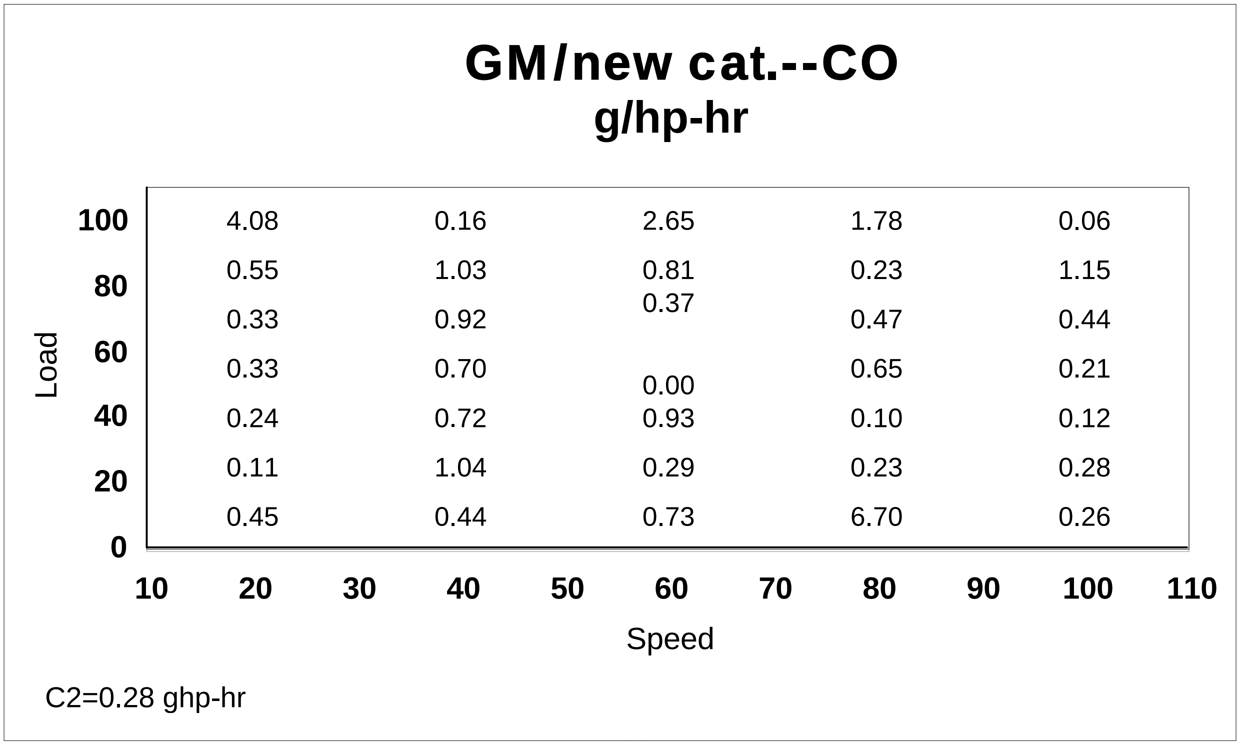


Figure 4.2-6



Field testing will typically also include transient emission measurement. Field-testing measurement may include any segment of normal operation with a two-minute minimum sampling period. This does not include engine starting, extended idling, or other cold-engine operation. Table 4.2-3 shows a wide variety of transient emission levels from the two test engines. While the engines were tested in the laboratory, the results show how emissions vary under normal operation when installed in nonroad equipment. These segments could be considered as valid field-testing measurements to show that an engine meets emission standards in the field when tested in nonroad equipment in which the engines are installed. Several segments included in the table were run with a hot start, which could significantly increase emission levels, depending on how long the engine runs in open loop after starting. This is especially important for CO emissions. Even with varied strategies for soaking and warming up engines, emission levels are generally between 1 and 2 g/hp-hr THC+NOx and between 4 and 13 g/hp-hr CO. Emission levels don't seem to vary dramatically between cycle segments, even where engine operation is significantly different.

Table 4.2-3
Transient Emission Measurements from SwRI Testing

Engine	Test Segment	THC+NOx g/hp-hr	CO, g/hp-hr	Notes
Mazda	"typical" forklift (5 min.)	2.0	5.7	hot start
	"high-transient" forklift (5 min.)	1.3	4.3	hot start
	highway certification test	1.2	4.6	hot start
	backhoe/loader cycle	1.3	9.1	20-minute soak before test
GM	"typical" forklift (5 min.)	1.3	9.5	hot start
	"high-transient" forklift (5 min.)	2.0	12.6	hot start
	highway certification test	1.0	4.4	3-minute warm-up; 2-minute soak
	backhoe/loader cycle	1.0	3.8	3-minute warm-up; 2-minute soak

4.2.2.4 Ambient conditions

While certification testing involves engine operation in a controlled environment, engines operate in conditions of widely varying temperature, pressure, and humidity. To take this into account, we are broadening the range of acceptable ambient conditions for field-testing measurements. Field-testing emission measurements must occur with ambient temperatures between 13° and 35° C (55° and 95° F), and with ambient pressures between 600 and 775 millimeters of mercury (which should cover almost all normal pressures from sea level to 7,000 feet above sea level). Tests will be considered valid regardless of humidity levels. This allows testing under a wider range of conditions in addition to helping ensure that engines are able to control emissions under the whole range of conditions under which they operate.

The SwRI test data published here are based on testing under laboratory conditions typical for the test location. Ambient temperatures ranged from 70 to 86° F. Barometric pressures were in a narrow range around 730 mm Hg. Humidity levels ranged from about 4 to 14 g of water per kg dry air, but all emission levels were corrected to a reference condition of 10.7 g/kg. Most testing occurred at humidity levels above 10.7, in which case actual NOx emission levels were up to 7 percent lower than reported by SwRI after correction.. In the driest conditions, measured NOx emission levels were up to 10 percent higher than reported. The field-testing standards take into account the possibility of a humidity effect of increasing NOx emissions. We are not aware of any reasons that varying ambient temperatures or pressures will have a significant effect on emission levels from spark-ignition engines.

4.2.2.5 Durability of Emission-Control Systems

SwRI tested engines that had already operated for the full useful life period with functioning emission-control systems. Before being retrofitted with catalysts and electronic fuel systems, these engines had already operated for 5,000 and 12,000 hours, respectively. The tested systems therefore provide very helpful information to show the capability of the anticipated emission-control technologies to function over a lifetime of normal in-use operation.

The testing effort required selection, testing, and re-calibration of installed emission-control systems that were not designed specifically to meet emission standards. These systems were therefore not necessarily designed for simultaneously controlling NOx, HC, and CO emissions, for lasting 5,000 hours or longer, or for performing effectively under all conditions and all types of operation that may occur. The testing effort therefore included a variety of judgments, and adjustments to evaluate the emission-control capability of the installed hardware. This effort highlighted several lessons that should help manufacturers design and produce durable systems.

Selecting engines from the field provided the first insights into the functionality of these systems. Tailpipe ppm measurements showed that several engines had catalysts that were inactive (or nearly inactive). These units were found to have loose catalyst material inside the housing, which led to a significant loss of the working volume of the catalyst and exhaust flow bypassing the catalyst material. Dimensional measurements showed that this resulted from a straightforward production error of improperly assembling the catalyst inside the shell.[22] This is not an inherent problem with catalyst production and is easily addressed with automated or more careful manual production processes. The catalyst from the GM engine selected for testing had also lost some of its structural integrity. Almost 20 percent of the working volume of the catalyst had disappeared. This catalyst was properly re-assembled with its reduced volume for further testing. This experience underscores the need for effective quality-control procedures in assembling catalysts.

Substituting a new catalyst on the aged system allowed emission measurements that help us estimate how much the catalysts degraded over time. This assessment is rather approximate, since we have no information about the zero-hour emissions performance of that exact catalyst. The new catalysts, which were produced about three years later under the same part numbers and nominal characteristics, generally performed in a way that was consistent with the aged catalysts. Not surprisingly, the catalyst with the reduced working volume showed a higher rate of deterioration than the intact catalyst. Both units, however, showed very stable control of NOx and HC emissions. CO deterioration rates were generally higher, but the degree of observed deterioration was very dependent on the particular duty cycle and calibration for a given set of emission measurements.

Measured emission levels from the aged catalysts shows what degree of conversion efficiency is possible for each pollutant after several thousand hours of operation. The emission data from the new catalysts suggest that manufacturers probably need to target low enough zero-hour CO emission levels to account for significant deterioration. The data also show that catalyst size is an important factor in addressing full-life emission control. The nominal sizes of the catalysts on the test engines were between 50 and 55 percent of total engine displacement. The cost analysis in Chapter 5 is based on initial compliance with a catalyst sized at 60 percent of total engine displacement. We expect manufacturers to reduce catalyst size as much as possible to reduce costs without risking the possibility of high in-use emissions.

Another important issue relates to degradation associated with fuel impurities, potential lack of maintenance, and wear of oxygen sensors. Fuel system components in LPG systems are prone to fuel deposits, primarily from condensation of heavy hydrocarbon constituents in the fuel. The vaporizer and mixer on the test engines showed a typical degree of fuel deposits from LPG operation. The vaporizer remained in the as-received condition for all emission measurements throughout the test program. Emission tests before and after cleaning the mixer give an indication of how much the deposits affect the ability of the closed-loop fueling system to keep the engine at stoichiometry. For the GM engine operating with the aged catalyst, the combined steps of cleaning the mixer and replacing the oxygen sensor improved overall catalyst efficiency on the C2 duty cycle from 55 to 61 percent for NOx. CO conversion efficiency improved only slightly. For the Mazda engine, the single step of cleaning the mixer slightly *decreased* average catalyst efficiency on the C2 duty cycle for NOx emissions; HC and CO conversion efficiency improved a small amount (see Table 4.2-4). Engines operating with new catalysts showed the same general patterns. These data show that closed-loop fueling systems can be relatively tolerant of problems related to fuel impurities.

Table 4.2-4
Average C2 Catalyst Conversion Efficiencies Before and After Maintenance

Engine	Pollutant	OLD CATALYST		NEW CATALYST	
		before maintenance	after maintenance	before maintenance	after maintenance
GM	NOx	54.7%	61.1%	45.6%	56.1%
	CO	96.3%	98.1%	99.3%	99.5%
	HC	93.8%	93.6%	93.6%	93.7%
Mazda	NOx	62.3%	61.5%	60.3%	60.1%
	CO	96.9%	98.9%	99.6%	99.6%
	HC	86.9%	93.2%	86.2%	94.3%

Manufacturers may nevertheless be concerned that some in-use operation can cause fuel deposits that exceed the fuel system's compensating ability to maintain correct air-fuel ratios. Two technologies are available to address this concern. First, the required diagnostic systems inform the operator if fuel-quality problems are severe enough to prevent the engine from operating at stoichiometry. A straightforward cleaning step would restore the fuel system to normal operation. Manufacturers may also be able to monitor mixer performance directly to detect problems with fuel deposits, rather than depending on air-fuel ratios as a secondary indicator. In any case, by informing the operator of the need for maintenance, the diagnostic system reduces the chance that the manufacturer will find high in-use emissions that result from fuel deposits.

The second technology to consider is designed to prevent fuel deposits from forming. A commercially available thermostat regulates fuel temperatures to avoid any high-temperature or low-temperature effects. In addition, some industry participants have made the general observation that some engine models are more susceptible to fuel deposits than others, suggesting that there may be other engine-design parameters that may help prevent these problems.

Maintaining the integrity of the exhaust system another basic but essential element of keeping control of air-fuel ratios. Any leaks in the exhaust pipe between the exhaust valves and the oxygen sensor would allow dilution air into the exhaust stream. The extra oxygen from the dilution air would cause the oxygen sensor to signal a need to run at a air-fuel ratio that is richer than optimal. If an exhaust leak occurs between the oxygen sensor and the catalyst, the engine will run at the correct air-fuel ratio, but the extra oxygen would affect catalyst conversion efficiencies. As evidenced by the test engines, manufacturers can select materials with sufficient quality to prevent exhaust leaks over the useful life of the engine.

4.2.2.7 Emission standards

4.2.2.7.1 Technology Basis

Three-way catalyst systems with electronic, closed-loop fuel systems have a great potential to reduce emissions from Large SI engines. We believe these technologies are capable of the greatest degree of emission reduction achievable from these engines in the projected time frame, considering the various statutory factors. In particular, we are not basing the emission standards on the emission-control capability from any of the following technologies.

- Spark timing
- Combustion-chamber redesign
- Gaseous fuel injection
- Exhaust gas recirculation

Incorporating these technologies with new engines could further reduce emissions; however, Large SI engine manufacturers typically produce 10,000 to 15,000 units annually, which limits the resources available for an extensive development program. Considering the limited development budgets for improving these engines, we believe it is more important to make a robust design with basic emission-control hardware than to achieve very low emission levels with complex hardware at a small number of steady-state test modes. Even without these additional technologies, we anticipate that manufacturers will be able to reduce emissions by about 90 percent from uncontrolled levels. Further optimizing an engine with a full set of emission-control hardware while meeting transient and field-testing emission standards is more of a burden than Large SI manufacturers can bear in the projected time frame. Manufacturers producing new engines may find it best to use some of these supplemental technologies to achieve the desired level of emission control and performance at an acceptable cost.

4.2.2.7.2 Duty-cycle emission standards

Given the control technology, as described above, there is a need to select emission standards that balance the tradeoff between NOx and CO emissions. Both NOx and CO vary with changing air-fuel ratios, but in an inverse relationship. This is especially important considering the degree to which these engines are used in enclosed areas.

Commenters representing states and environmental groups stressed the need to control HC+NOx emissions to address concerns for meeting ambient air quality standards for ozone. We are accordingly setting an HC+NOx emission standard of 2.0 g/hp-hr (2.7 g/kW-hr), which is somewhat more stringent than the proposed standard. We are adopting a slightly higher CO emission standard than proposed, which reflects the tradeoff between NOx and CO emissions. Further, we are adopting provisions that will encourage manufacturers to reduce HC+NOx even further by allowing higher CO levels where a manufacturer certifies to lower HC+NOx levels. Under this approach, customers desiring to protect workers or others in close proximity to the engines can choose engine models that offer the maximum control of CO emissions. Conversely, if individual exposure to CO emissions is less of a concern, manufacturers have a strong incentive to maximize control of HC+NOx emissions.

Table 4.2-5 shows the range of measured emission values from the engines tested with optimized emission controls. In general, the engines with higher CO values and lower HC+NOx values were calibrated with slightly richer air-fuel ratios, with all other engine parameters unchanged. The measured emission levels include a variety of duty cycles, but this doesn't seem to affect the observed trends. Also, Table 4.2-5 notes the length of time the engine was turned off before starting the transient duty cycle. All the data points shown are from measurements with the aged catalysts. Several measurements with the new catalyst showed that engines were able to achieve very low levels of both NOx and CO emissions.

Table 4.2-5
Range of Measured Emission Levels (g/hp-hr)

Engine*	HC	NOx	HC+NOx	CO	Cycle	soak, min.
GM	0.30	3.82	4.12	0.66	Backhoe-loader	4
GM	0.27	4.14	4.41	0.68	Backhoe-loader	2
GM	0.41	5.91	6.32	0.83	Backhoe-loader	20
GM	0.29	5.89	6.18	0.86	Large SI Composite	6
GM	0.27	4.42	4.69	0.87	Highway FTP	3
GM	0.28	5.33	5.61	0.89	Highway FTP	3
Mazda	0.34	0.88	1.22	4.61	Highway FTP	5
Mazda	0.58	0.15	0.73	6.66	Large SI Composite	5
Mazda	0.61	0.19	0.8	6.97	Large SI Composite	5
Mazda	0.66	0.14	0.8	7.5	Large SI Composite	5
Mazda	0.6	0.35	0.95	7.61	Large SI Composite	7
Mazda	0.51	0.7	1.21	7.76	Welder	4

*Both engines operated on LPG for all tests.

Figure 4.2-7 shows an attempt to apply a curve-fit to the data points. Using a log-log relationship as shown yielded an R-square value of 0.93, indicating a relatively good fit to the data. Table 4.2-6 and Figure 4.2-8 show the curve relating CO and HC+NOx emission levels using the mathematical relationship. This involves starting with a set of HC+NOx emission levels, then calculating the corresponding CO emission levels.[t] Finally, both CO and HC+NOx emission levels are increased by 10 percent to account for a compliance margin around the measured data points. These standards apply to all steady-state and transient duty-cycle testing for certification, production-line, and in-use testing.

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[t] While somewhat roundabout mathematically, solving for CO values from the logarithmic equation is most easily done by converting the curve-fit to an equation based on the natural log function. Using logarithm relationships yields the equivalent relationship (in metric units): $(\mathrm{HC+NOx}) \times \mathrm{CO}^{0.784} = 8.57$ or $\mathrm{CO} = (8.57 \div (\mathrm{HC+NOx}))^{1.276}$.

Figure 4.2-7

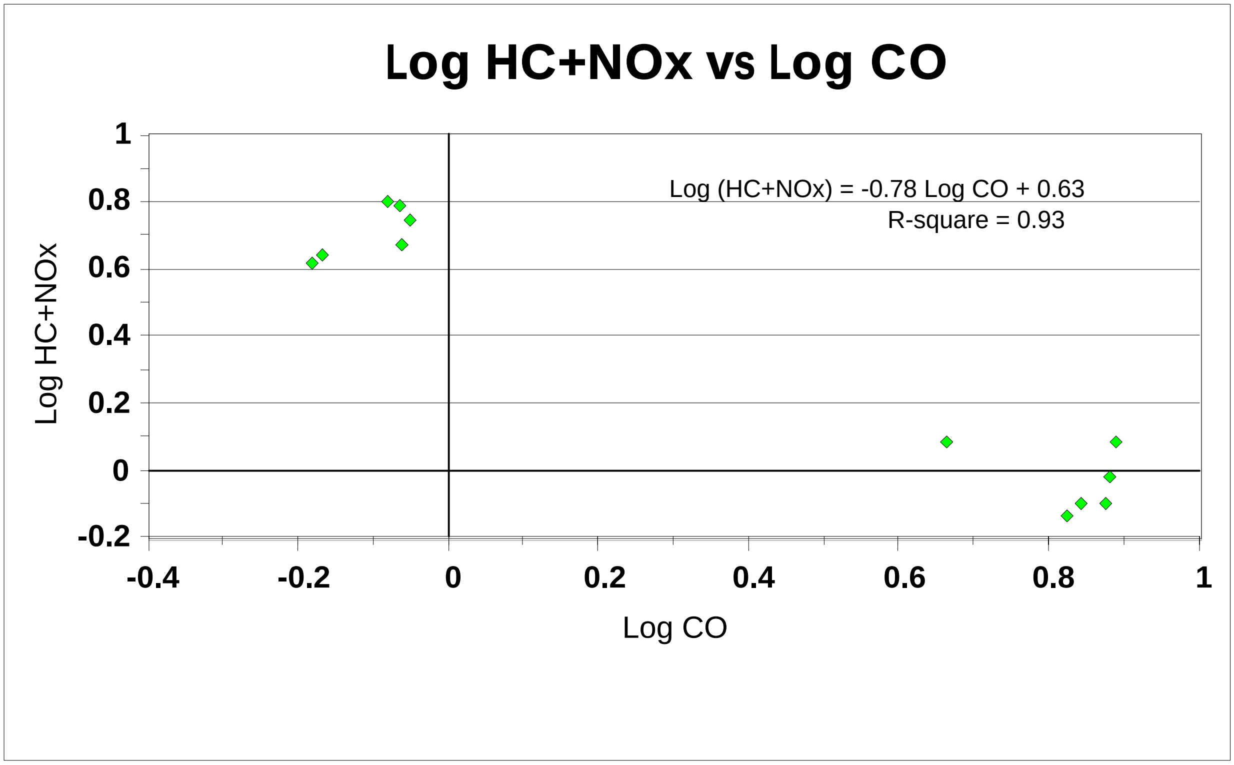
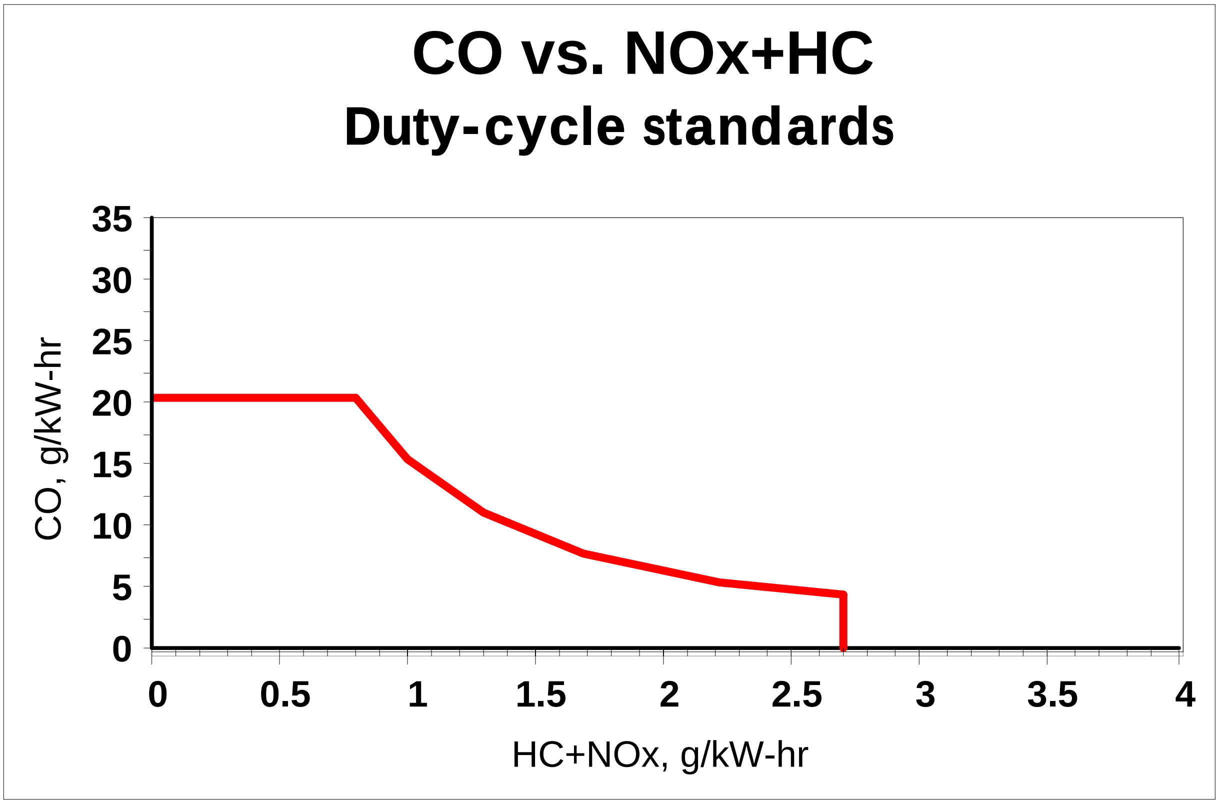


Table 4.2-6
Sample Standards Using the Optional Duty-cycle Standards(g/kW-hr)

HC+NOx	CO
2.70	4.4
2.20	5.6
1.70	7.9
1.30	11.1
1.00	15.5
0.80	20.6

Figure 4.2-8



We generally set standards by focusing on attaining ambient air quality in broad outdoor areas. The HC+NOx standard of 2.7 g/kW-hr is consistent with this focus and achieves significant reductions in ozone precursor emissions. Moreover, any of the emission levels shown in Table 4.2-6 provide large reductions in CO, NO, and NO_2 to address any concerns for individual exposures.

4.2.2.7.3 Engine protection

The table of standards above does not take into account the fact that some engines are unable to maintain sustained stoichiometric operation at high engine loads. Engines running rich at high load typically continue to have low HC+NOx emissions, but CO emissions increase substantially. However, operation over the transient duty cycle involves very little sustained high-load operation. Table 4.2-7 shows the total time during the 20-minute cycle with engine loads exceeding various thresholds. This alone shows that the standard for testing over the transient duty cycle needs little or no adjustment to account for rich operation under high-load conditions. Delaying rich operation would further ensure that emission-controls continue to function properly while still protecting against overheating. As a result, we don't believe that emission standards for the transient emission test should be adjusted to account for engine-protection strategies.

Table 4.2-7
Evaluation of High-Load Operation Over the Transient Duty Cycle

Torque threshold (percent of maximum at a given speed)	Total time over torque threshold (seconds)	Percent of 20-minute cycle	Average number of seconds during each minute
90%	16	1.3	0.8
85%	23	1.9	1.2
80%	41	3.4	2.0
75%	67	5.6	3.4

The steady-state duty cycles, however, have a fixed weighting to account for emission levels at high load operation. Also, delaying enrichment does not help with steady-state emissions, because emissions are measured only after engine operation and emission levels have stabilized. We are therefore setting a maximum CO level of 31 g/kW-hr during steady-state testing for engines needing protection strategies. This corresponds to the highest CO emission level we are allowing under field-testing standards, as noted in Table 1 and described further below. This less stringent standard would apply to all steady-state testing with the C2 or D2 duty cycles for certification, production-line, or in-use testing. The emission standards described in Table 1 would still apply to these engines when tested over the transient duty-cycle. We are also applying the field-testing standards equally to different engines, regardless of whether or not they are certifying to a less stringent CO emission standard for steady-state testing. This reflects our expectation that engines undergoing normal operation in the field will continue to meet emission standards.

Ford submitted test data with their gasoline engine showing that their emission levels comply with this less stringent CO standard for steady-state testing. For example, with a measured emission level of 23.9 g/kW-hr, they would have roughly a 20-percent compliance margin relative to a standard of 31 g/kW-hr. The proposed curve of candidate emission standards incorporated a 10-percent compliance margin, even though the measured emissions were from aged engines not designed to meet emission standards. Our emission modeling typically incorporates an assumed 20-percent compliance margin for spark-ignition engine emissions.

In addition, as described in the preamble to the final rule, we are adopting a combination of provisions to ensure that manufacturers will take steps to allow enrichment only under exceptional circumstances. This is necessary to ensure that engines in nonroad equipment don’t operate substantially under engine-protection regimes leading to compromised control of emissions.

4.2.2.7.4 Field-testing emission standards

Manufacturers may do testing under the in-use testing program using field-testing procedures. This has the potential to substantially reduce the cost of testing. Setting an emission standard for testing engines in the field requires that we take into account all the variability inherent in testing outside the laboratory. As discussed further below, this includes varying engine operation, and a wider range of ambient conditions, and the potential for less accurate or less precise emission measurements and calculations. Also, while the field-testing standards and procedures are designed for testing engines installed in equipment, engines can also be tested on a dynamometer to simulate what would happen in the field. In this case, extra precautionary steps would be necessary to ensure that the dynamometer testing could be characterized as "normal operation." Also, the less stringent field-testing standards would apply to any simulated field-testing on a dynamometer to take emission-measurement variability into account, as described below.

The SwRI test engines also show that Large SI engines are capable of controlling emissions under the wide range of operation covered by the field-testing provisions. A modest amount of additional development will be necessary to address isolated high-emission points uncovered by the testing. We believe that manufacturers will be able to reduce emissions as needed to meet the 2007 emission standards by spending time improving the precision of their engine calibrations, perhaps upgrading to more sophisticated control software to achieve this. Field testing may also include operation at a wider range of ambient conditions than for certification testing. Selecting emission standards for field testing that correspond with the duty-cycle standards requires consideration of the following factors:

- The data presented above show that emissions vary for different modes of engine operation. Manufacturers will need to spend time addressing high-emission points to ensure that engines are not overly sensitive to operation at certain speeds or loads. The data suggest that spark-ignition engines can be calibrated to improve control at the points with the highest emission rates.
- Established correction factors allow for adjustment to account for varying ambient conditions. Allowing adjustment of up to 10 percent adequately covers any potential increase in emissions resulting from extreme conditions.
- While emission measurements with field-testing equipment allow more flexibility in testing, they are not as precise or as accurate as in the laboratory; the regulations define specifications to limit the error in emission measurements. For most mass-flow and gas analyzer hardware, these tolerance remain quite small. Measurements and calculations for torque values introduce a greater potential for error in determining brake-specific emission levels. The tolerance for onboard torque readings allows for a 15-percent error in understating torque values, which would translate into a 15-percent error in overstating brake-specific emissions.

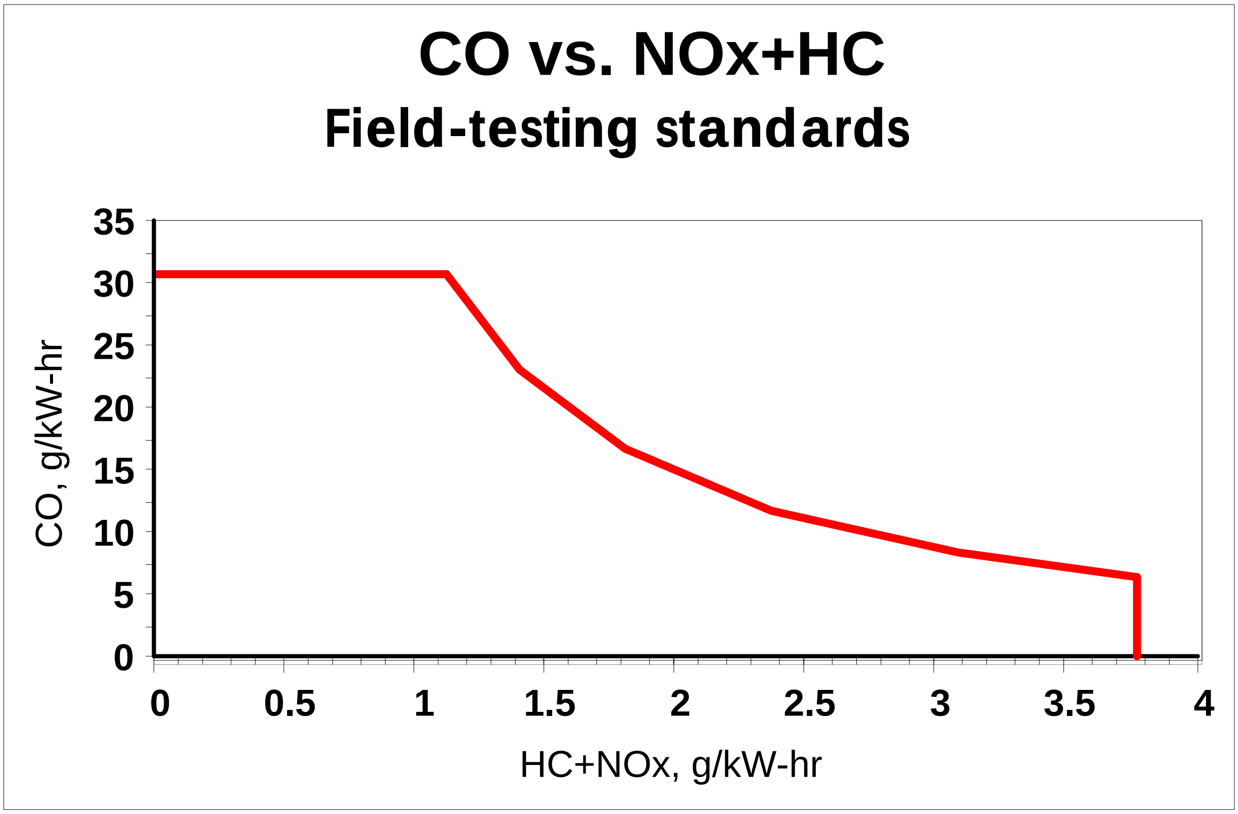
Taking all these factors into account, we believe it is appropriate to allow for a 40-percent increase in HC+NOx emissions relative to the SwRI measured values to account for the factors listed above. CO emissions are generally somewhat more sensitive to varying engine operation, so a 50-percent adjustment is appropriate for CO. The approach for field-testing standard follows the format described for duty-cycle testing. This results in an HC+NOx standard of 3.8 g/kW-hr (2.8 g/hp-hr), with scaled values for the CO standard, as shown in Table 4.2-8 and Figure 4.2-9.

These same numerical field-testing standards apply to natural gas engines. Much like for certification, we are excluding methane measurements from natural gas engines. Since there are currently no portable devices to measure methane (and therefore nonmethane hydrocarbons), the 3.8 g/kW-hr field-testing standard and the values in Table 4.2-8 apply only to NOx emissions for natural gas engines.

Table 4.2-8
Sample Standards Using the
Optional Field-testing Standards(g/kW-hr)

HC+NOx	CO
3.80	6.5
3.10	8.5
2.40	11.7
1.80	16.8
1.40	23.1
1.10	31.0

Figure 4.2-9



4.2.2.7.5 Evaporative emissions

Several manufacturers are currently producing products with pressurized fuel tanks to comply with Underwriters Laboratories specifications. Most fuel tanks in industrial applications are made of a thick-gauge sheet metal or structural steel, so increasing fuel pressures within the anticipated limits poses no risk of bursting or collapsing tanks. For those few applications that use plastic fuel tanks, equipment manufacturers already use or could easily use blow-molded tanks that are also able to withstand substantial pressure buildup. If an exceptional application relies on a fuel tank that must keep internal pressures near ambient levels, a volume-compensating bag would allow for adequate suppression of fuel vapors with minimal pressure buildup.[u]

Testing with pressurized fuel tanks shows emission data related to sealing fuel tanks. The tests included several pressures ranging from 0.5 to 2.25 psi. The 2.25 psi valve was an off-the-shelf automotive fuel cap with a nominal 2 psi pressure relief valve and 0.5 psi vacuum relief valve. For the other pressure settings, we used another automotive cap modified to allow

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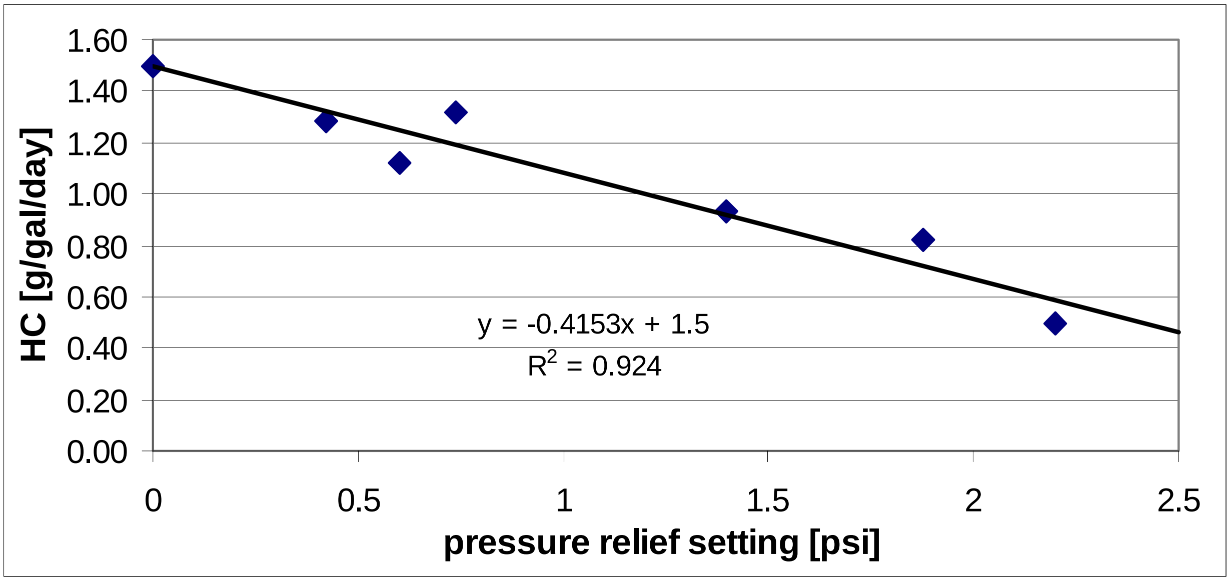
[u] "New Evaporative Control System for Gasoline Tanks," EPA Memorandum from Charles Moulis to Glenn Passavant, March 1, 2001, Docket A-2000-01, document II-B-16.

adjustments to the spring tension in the pressure relief valve. We performed these tests on an aluminum fuel tank to remove the variable of permeation. As shown in Figure 4.2-10, there was a fairly linear relationship between the pressure setting of the valve and the emissions measured over the proposed test procedure, which we would expect based on the theoretical relationships. At 3.5 psi, this relationship extropolates to a value of 0.2 g/gallon/day.

Figure 4.2-10: Effect of Pressure Cap on Diurnal Emissions



4.2.2.7.6 Conclusion

Manufacturers have been developing emission-control technologies to meet the 2004 emission standards since October 1998, when California ARB adopted the same standards. We expect that manufacturers will add three-way catalysts to their engines and use electronic closed-loop fueling systems. These technologies have been available for industrial engines for many years.

The SwRI testing program was based on aged engines and involved no effort to fine-tune air-fuel ratios or emission levels across the engine map. We expect that manufacturers will be able to control emission levels more broadly across the range of engine speeds and loads by improving control of air-fuel ratios at different operating modes. These improvements will reduce both steady-state and transient emission levels. The 2007 emission standards are based directly on the data presented above. The test results therefore show that these Large SI engines are capable of meeting the 2007 emission standards for both steady-state and transient duty cycles. Similarly, the data presented above show how off-cycle emissions vary for engines that have been designed for effective control of air-fuel ratios across the range of normal operation. Here too, the test engines generally had emission levels consistent with the 2007 field-testing standards, with certain limited exceptions as noted above.

The SwRI testing program involved about eight weeks of development effort to characterize and modify two engines to for optimized emissions on the steady-state and transient duty cycles, and for all kinds of off-cycle operation. Both of the test engines had logged several thousand hours of operation using off-the-shelf technologies that have been available for nonroad engines for many years. Several hardware and software adjustments were made to maintain optimal air-fuel ratios for effective control of all pollutants under all operating modes. Some further development effort will be necessary to address the few isolated modes with high emission levels, as described earlier in this section. Manufacturers may save development time by upgrading to the modestly more expensive controller with independent air-fuel control capability in different speed-load zones. This would achieve the same result, but would potentially reduce the cost of meeting the standards by reducing engineering time. We believe that the several years until 2007 allow enough lead time for manufacturers to carry out this development effort for all their engines.

We expect the SwRI testing program to provide extensive, basic information on optimizing the subject engines for low emissions, so manufacturers will need significantly less time and testing resources to modify additional engine models. For example, the SwRI testing shows how emissions change over varying speeds and loads; as a result, future testing can focus on far fewer test points to characterize a calibration. The test results also show how manufacturers will need to balance calibrations for controlling emissions of different pollutants across the range of engine speeds and loads.

The emission standards for Large SI engines are significantly more stringent than those we are adopting for recreational vehicles and those we have already adopted for lawn and garden engines. We believe this is appropriate, for several reasons. First, the similarity to automotive engines makes it possible to use basic automotive technology that has already been adapted to industrial use. Second the cost of Large SI equipment is typically much higher than the recreational or other light-duty products, so there is more capability for manufacturers to pass along cost increases in the marketplace. Third, the Large SI emission standards correspond with a substantial fuel savings, which offset the cost of regulation and provide a great value to the many commercial customers.

4.2.3 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Electronically controlled fuel systems are able to improve management the combustion event, and catalysts can be incorporated into existing equipment designs without compromising the muffling capabilities in the exhaust.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates. We project fuel consumption improvements that will reduce total nationwide fuel consumption by about 300 million gallons annually once the program is fully phased in. While a small number of engines already have these technologies, it seems that the industrial engine marketplace has generally not valued fuel economy highly enough to create sufficient demand for these technologies.

We believe the technology discussed here will have no negative impacts on safety. Electronic fuel injection is almost universally used in cars and trucks in the United States with very reliable performance. In addition, we expect cases of CO poisoning from these engines to decrease as a result of the reduced emission levels.

4.3 Snowmobile Engines

The following paragraphs summarize the data and rationale supporting the emission standards for snowmobiles, which are listed in the Executive Summary.

4.3.1 Baseline Technology and Emissions

Snowmobiles are equipped with relatively small high-performance two-stroke two and three cylinder engines that are either air- or liquid-cooled. The main emphasis of engine design is on performance, durability, and cost. Because these engines are currently unregulated, they have no emission controls. The fuel system used on these engines are almost exclusively carburetors, although a small number have electronic fuel injection. Two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary 2-stroke engines with a pump that sends two-cycle oil from a separate oil reserve to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. In fact, because performance and durability are such important qualities for snowmobile engines, they all operate with a “rich” air and fuel mixture. That is, they operate with excess fuel, which enhances performance and allows engine cooling which promotes longer lasting engine life. However, rich operation results in high levels of HC, CO, and PM emissions. Also, two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust resulting in high levels of raw HC.

We developed average baseline emission rates for snowmobiles based on the results of emissions testing of 23 snowmobiles.[23] Current average snowmobile emissions rates are 397 g/kW-hr (296 g/hp-hr) CO and 149 g/kW-hr (111 g/hp-hr) HC.

4.3.2 Potentially Available Snowmobile Technologies

A variety of technologies are currently available or in stages of development to be available for use on 2-stroke snowmobiles. These include engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, pulse air, and semi-direct and direct fuel injection. In addition to these 2-stroke technologies, it is also feasible to convert from using 2-stroke engines to 4-stroke engines. Each of these is discussed in the following sections.

4.3.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish, and tumble improve the combustion of the intake charge. Various snowmobile manufacturers have told us that they believe these modifications have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these changes[v].

4.3.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in snowmobile engines. First, strategies to improve fuel atomization promote more complete combustion of the fuel/air mixture. Additionally, production tolerances can be improved for more consistent fuel metering. Both of these allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ratio can be leaned out somewhat. Snowmobile engines are currently calibrated with rich air/fuel ratios for durability reasons. Manufacturers have stated that based on their experience, leaner calibrations can reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration[w]. Small improvements in fuel economy can also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) also reduce snowmobile engine durability, though many possible engine improvements could regain any lost durability that occurs with leaner calibrations. These include changes to the cylinder head, pistons, ports and pipes to reduce knock. In addition, critical engine components can be made more robust to improve durability.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines can also be employed, possibly with more accuracy, with fuel injection. At least one major snowmobile manufacturer currently employs electronic fuel injection on several of its snowmobile models.

4.3.2.3 Pulse Air

Pulse air injection into the exhaust stream mixes oxygen with the high temperature HC and CO in the exhaust. The added oxygen allows the further combustion of these exhaust constituents between the combustion chamber and tailpipe exhaust. Our testing of pulse air on four-stroke ATV engines indicated that reductions of 30-70% for HC and 30-80% for CO are possible. We believe similar reductions could be expected for engines used in snowmobile applications. We expect some modest reductions in two-stroke applications as well.

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[v] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

[w] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

4.3.2.4 Direct and Semi-direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that emissions from two-stroke engines are high is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft (PWC) engines. Bombardier has developed a semi-direct injection engine for snowmobiles that will be available in several different models for the 2003 model year. Manufacturers have indicated to us that two-stroke engines equipped with direct fuel injection systems could reduce HC emissions by 70 to 75 percent and reduce CO emissions by 50 to 70 percent. Certification results for 2002 model year PWC support the manufacturers projections, as shown in Table 4.3-1. This table shows the paired certification data from some PWC engines in both uncontrolled and direct injection configurations. The percent difference in FEL column refers to the HC + NOx FEL. This is a pretty good surrogate for HC since most of the HC + NOx level is made up of HC, as can be seen from the table.

Table 4.3-1
Certification Levels of Direct Injection vs. Uncontrolled Engines

Mfr	% difference in FEL	size (liter)	power (kW)	FEL (HC + NOx)	HC cert level	CO cert level	Technology
Kawasaki	67%	1.071	95.6	46.0	38.4	103.1	Direct injection, electronic control
		1.071	88.3	140.0	136.76	241.8	Carburetor
Polaris	72%	0.78	Not Reported	47.1	33.2	135.2	Direct injection
		0.70	Not Reported	165	158.8	217.0	Carburetor
Bombardier	73%	0.9514	88.9	36.8	24.5	100.1	Direct injection, electronic control
		0.9513	89.5	137.8	136.7	330.6	Carburetor
Polaris	65%	1.16	85.26	46.3	37.46	100.4	Direct injection
		1.16	93.25	134.0	130.8	359.3	Carburetor

Substantial improvements in fuel economy could also be expected with these technologies. We believe these technologies hold promise for application to snowmobiles. All four of the major snowmobile manufacturers have indicated that they consider direct fuel injection as a viable technology for controlling emissions and are currently either analyzing various direct injection systems or are in the process of developing their own system.

Manufacturers must address a variety of technical design issues for adapting the technology to snowmobile operation, such as operating in colder ambient temperatures and at variable altitude. Manufacturers have also stated that the direct injection systems used in many of their PWC cannot simply be placed into their snowmobiles because of inherent differences in snowmobile and PWC engines. Primarily the fact that PWC engines operate at considerably lower engine speeds than snowmobile engines. PWC engines typically operate at maximum engine speeds of 6,000 rpm, compared to engine speeds of almost double that for snowmobiles. This poses a problem because some of the current direct injection designs can't properly operate at such high engine speeds. While these are all legitimate concerns, we believe that this technology can be adapted without significant problems. Bombardier's use of direct fuel injection in several snowmobile models in the 2003 model year demonstrates that these issues have been resolved enough for Bombardier to be comfortable selling snowmobiles with such engines. However, direct fuel injection is a complex technology and there are several different types of approaches to designing these systems and not all manufacturers have the same access to the various systems. Therefore, it appears important to provide manufacturers with sufficient lead time to resolve all of the potential issues with direct injection so that it can be widely available for all snowmobile models, instead of a few niches models for a select manufacturer or two. That is why we believe it is appropriate to give manufacturers until 2012. This will give manufacturers sufficient time to incorporate these development efforts into their overall research plan and apply these technologies to a substantial percentage of their snowmobiles.

4.3.2.5 Four-Stroke Engines

In addition to the two-stroke technologies just discussed, the use of four-stroke engines in snowmobiles is feasible. Four-stroke engines have been used in numerous recreational vehicle applications for years. Four-stroke engines have also been used in limited numbers over the years in snowmobiles. In 1999, Arctic Cat released a four-stroke touring sled. Polaris followed two years later with their four-stroke touring sled in 2001. Table 4.3-2 provides emission results from a 2001 Arctic Cat four-stroke touring sled and a 2001 Polaris Frontier (four-stroke), both owned and tested by the National Park Service (NPS) at Southwest Research Institute. Table 4.3-3 presents certification data from four 2002 PWC's equipped with four-stroke engines. The engines in these PWC are higher output engines than the Arctic Cat and Polaris snowmobile four-stroke engines and have emission results very similar to that which a high-output four-stroke snowmobile engine could expect to emit.

Table 4.3-2
Four-Stroke Snowmobile Emissions

Manufacturer	Model	Engine Displacement	HC (g/kW-hr)	CO (g/kW-hr)	NOx (g/kW-hr)
Arctic Cat	4-Stroke Touring	660 cc	6.2	79.9	15.0
Polaris	Frontier	784 cc	3.2	79.1	7.0

Table 4.3-3
Four-Stroke PWC Certification Emission results

Manufacturer	Model	Engine Displacement	HC (g/kW-hr)	CO (g/kW-hr)	NOx (g/kW-hr)
Honda	Aqua Trax F-12	1,244 cc	11.2	266.0	3.8
Honda	Aqua Trax F-12X	1,244 cc	10.7	235.3	4.6
Bombardier	GTX 4-TEC	1,504 cc	9.6	161.7	5.0
Yamaha	FX140	998 cc	16.6	255.1	5.9

Much has changed in the time since we published our proposed standards. In October 2001, when we published our proposed standards for snowmobiles, there was only one manufacturer that had introduced a four-stroke snowmobile (the Polaris Frontier was released soon after). Today, all four of the major snowmobile manufacturers have developed a four-stroke engine for snowmobiles. In fact, the 2003 model year will see four-stroke engines in several models from all four manufacturers. The models will range from touring sleds to sport, mountain, and high-performance models. Since four-stroke engines do not rely on scavenging of the exhaust gases with the incoming air/fuel mixture, they have inherently lower HC emissions compared to two-strokes (up to 90 percent lower). Four-stroke engines can also have reductions in CO emissions, depending on the power output of the engines and the engine calibration. A smaller four-stroke engine calibrated to operate at or near stoichiometry could reduce CO emissions significantly. This is demonstrated above in Table 4.3-2, since both of these snowmobiles use four-stroke engines equipped with closed-loop control EFI systems which try to maintain the air and fuel mixture at or near stoichiometry. A larger four-stroke engine calibrated for maximum power could generate CO emission levels closer to a comparably powered two-stroke engine. Table 4.3-3 above, demonstrates this. Although the engines in this table are from PWCs, they are high-output four-stroke engines producing horsepower in excess of 100 hp, that are very similar to what could be expected to be used in a high-performance snowmobile. The CO emissions from the four PWC engines are considerably higher than the CO levels from the two lower powered four-stroke snowmobiles. Four-stroke engines have a lower power density compared to two-stroke engines. Two-stroke engines have a power stroke every other stroke compared to a power stroke every fourth stroke for a four-stroke engine. Thus, a comparably powered four-stroke engine requires almost a third more engine displacement, to equal the power of a two-stroke engine. The impact this has on snowmobile applications is that a four-stroke engine is already heavier than a two-stroke engine because of the valve-train system. In order to have comparable power output with a two-stroke, a four-stroke engine needs to have a larger displacement. This is achieved through an increase in the cylinder bore and/or stroke or by adding more cylinders, which all have the potential effect of adding even more weight. Thus, for a four-stroke to be competitive with a two-stroke engine, manufacturers need to find a way to reduce weight in the engine and elsewhere in the snowmobile. This could entail the use of lighter materials in the engine and chassis or reducing the size of the fuel tank to take advantage of the superior fuel efficiency of the four-stroke engine while maintaining the same cruising time/range.

Another way to increase the output from a four-stroke engine is to use a turbocharger or supercharger. Both of these devices act as air compressors, providing increased air density in the engines's combustion chambers, which allows more efficient burning of air and fuel and results in higher horsepower output. A turbocharger uses exhaust gases to compress air, while a supercharger is mechanically driven using a belt between the supercharger and typically the camshaft. Honda is currently selling a turbocharged version of their four-stroke personal watercraft. A turbocharger or supercharger could provide an increase in power without having to increase the engine displacement. Regardless of the strategy used, it is apparent that four-stroke engines will have a larger role in snowmobile applications than originally thought.

However, it is important to provide sufficient lead time for the development and implementation of some four-stroke engines in snowmobiles, similar to the concern with direct fuel injection. For example, in the case of the Yamaha four-stroke snowmobile, a considerable amount of effort and resources went into designing a new snowmobile from the ground up specifically to accommodate the size, weight and power characteristics of a four-stroke engine. A completely new chassis was designed which allowed the somewhat heavier engine to be placed lower and further back than is typical for two-stroke snowmobiles. This was necessary to maintain the kind of handling characteristics required of a high performance snowmobile. While a stock four-stroke engine can be placed into an existing snowmobile model and made to work acceptably, as can be seen in the Polaris and Arctic Cat four-stroke offerings, such designs are only practical for lower powered touring snowmobiles. Since the vast majority of the snowmobile market is in higher performance sleds, we believe that the conversion of all snowmobiles to four-strokes would require that many current snowmobile chassis be replaced with new models designed from the ground up. This could be a substantial undertaking for the snowmobile industry given the number of models it offers and niche markets it currently serves. That is why we believe the delay of our proposed Phase 2 standards by two years will give manufacturers time to incorporate these development efforts into their overall research plan as they apply these technologies to their snowmobiles.

4.3.3 Test and Measurement Issues

4.3.3.1 Test procedure

We are generally adopting the snowmobile test procedure developed by Southwest Research Institute in cooperation with the International Snowmobile Manufacturers Association for all snowmobile emissions testing.[24] This test procedure consists of two main parts; the duty cycle that the snowmobile engine operates over during testing and other testing protocols involving the measurement of emissions (sampling and analytical equipment, specification of test fuel, atmospheric conditions for testing, etc.). While the snowmobile duty cycle was developed specifically to reflect snowmobile operation, many of the testing protocols are well established in other EPA emissions programs and have been simply adapted where appropriate for snowmobiles.

The snowmobile duty cycle was developed by instrumenting several snowmobiles and operating them in the field in a variety of typical riding styles, including aggressive (trail), moderate (trail), double (trail with operator and one passenger), freestyle (off-trail), and lake driving. A statistical analysis of the collected data produced the five mode steady-state test cycle shown in Table 4.3-4. The snowmobiles used to generate this data were not derived from members of the general public found openly operating in these riding styles, but were snowmobiles operated by contractor personnel in staged set-ups of these riding styles. This duty cycle was used to generate the baseline emissions levels for snowmobiles, and we believe it is the most appropriate cycle for demonstrating reductions in snowmobile emissions at this time.

Table 4.3-4
Snowmobile Engine Test Cycle

Mode	1	2	3	4	5
Normalized Speed	1	0.85	0.75	0.65	Idle
Normalized Torque	1	0.51	0.33	0.19	0
Relative Weighting (%)	12	27	25	31	5

The other testing protocols are largely derived from our regulations for marine outboard and personal watercraft engines.[25] The testing equipment and procedures from that regulation are largely appropriate for snowmobiles. However, unlike snowmobiles, outboard and personal watercraft engines tend to operate in fairly warm ambient temperatures. Thus, some provision needs to be made in the snowmobile test procedure to account for the colder ambient temperatures typical of snowmobile operation. Since snowmobile carburetors are jetted for specific ambient temperatures and pressures, we could take one of two general approaches. The first is to require testing at ambient temperatures typical of snowmobile operation, with appropriate jetting. A variation of this option is to simply require that the engine inlet air temperature be representative of typical snowmobile operation, without requiring that the entire test cell be at that temperature. The second is to allow testing at higher temperatures than typically experienced during snowmobile operation, with jetting appropriate to the warmer ambient temperatures.

Manufacturers shared confidential emission data with us that indicated that there was no difference between testing snowmobiles with cold inlet air and testing at higher temperatures with carburetor jetting adjusted for the warmer temperature. We also did some limited testing which substantiates the manufacturer's claim. Some manufacturers argued that even though there was no difference between the test methods, we should still require testing with cold inlet air because it would be more representative. Other manufacturers felt that the increased cost of cold inlet air testing made this approach undesirable. We decided that since there was ample evidence that two approaches would produce similar results with the technologies we expect to be used and that it did not make sense to require manufacturers to incur the cost of cold inlet air testing if it wouldn't provide any additional benefit. Therefore, we are allowing manufacturers to test at warmer (i.e., typical test cell temperature 68°F-86°F) with carburetor jetting set to the appropriate temperature.

4.3.3.2 HC is a Good Proxy for Fine PM Emissions

We believe the best way to regulate fine PM emissions from current snowmobile engines is to set standards based on HC emissions. Unlike other recreational vehicles, the current fleet of snowmobiles consists almost exclusively of two-stroke engines. Two-stroke engines inject lubricating oil into the air intake system where it is combusted with the air and fuel mixture in the combustion chamber. This is done to provide lubrication to the piston and crankshaft, since the crankcase is used as part of the fuel delivery system and cannot be used as a sump for oil storage as in four-stroke engines. As a result, in addition to products of incomplete combustion, two-stroke engines also emit a mixture of uncombusted fuel and lubricant oil. HC-related emissions from snowmobiles increase PM concentrations in two ways. Snowmobile engines emit HCs directly as particles (e.g., droplets of lubricant oil). Snowmobile engines also emit HC gases, as well as raw unburned HCs from the fuel which either condense in cold temperatures to particles or react chemically to transform into particles as they move in the atmosphere. As discussed above, fine particles can cause a variety of adverse health and welfare effects, including visibility impairment.

We believe HC measurements will serve as a reasonable surrogate for fine PM measurement for snowmobiles for several reasons. First, emissions of PM and HC from these engines are related. Test data show that over 70 percent of the average volatile organic fraction of PM from a typical 2-stroke snowmobile engine is organic hydrocarbons, largely from lubricating oil components.[x] The HC measurements (which use a 191 Celsius/375.8 degree

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[x] Memo to Docket, Mike Samulski. "Hydrocarbon Measurements as an Indicator for Particulate Matter Emissions in Snowmobiles," September 6, 2002, Docket A-2000-01; Document IV-B.

Carroll, JN, JJ White, IA Khalek, NY Kado. Characterization of Snowmobile Particulate Emissions. Society of Automotive Engineers Technical Paper Series. Particle Size Distribution in the Exhaust of Diesel and Gasoline. SP-1552, 2000-01-2003. June 19-22, 2000.

Fahrenheit heated FID) would capture the volatile component which in ambient temperatures would be particles (as droplets).

Second, many of the technologies that will be employed to reduce HC emissions are expected to reduce PM (e.g., 4-stroke engines, pulse air, and direct fuel injection techniques). The organic emissions are a mixture of fuel and oil, and reductions in the organic emissions will likely yield both HC and PM reductions. For example, the HC emission factor for a typical 2-stroke snowmobile is 111 g/hp-hr. The HC emission factor for a direct fuel injection engine is 21.8, and for a 4-stroke is 7.8 g/hp-hr, representing a 80 percent and 99 percent reduction, respectively. Similarly, the PM emission factor for a typical 2-stroke snowmobile is 2.7 g/hp-hr. The corresponding PM emission factor for a direct fuel injection engine is 0.57, and for a 4-stroke is 0.15 g/hp-hr, representing a 75 percent and 93 percent reduction, respectively. HC measurements would capture the reduction from both the gas and particle (at ambient temperature) phases.

Thus, manufacturers will generally reduce PM emissions as a result of reducing HC emissions, making separate PM standards less necessary. Moreover, PM standards would only cover the PM directly emitted at the tailpipe. It would not measure the gaseous or semi-volatile organic emissions which would condense or be converted into PM in the atmosphere. By contrast HC measurements would include the gaseous HC which could condense or be converted into PM in the atmosphere. Thus, the HC measurement would be a more comprehensive measurement. HC standards actually will reduce secondary PM emissions that would not necessarily be reduced by PM standards.

Finally, from an implementation point of view, PM is not routinely measured in snowmobiles, and there is no currently established protocol for measuring PM and substantial technical issues to overcome to create a new method. Establishing additional PM test procedures would entail additional costs for manufacturers. HC measurements are more routinely performed on these types of engines, and these measurements serve as a more reliable basis for setting a numeric standard. Thus, we believe that regulation of HC is the best way to reduce PM emissions from current snowmobile engines.

We included a NOx standard for snowmobiles as part of the long-term program. NOx emissions from current snowmobiles are very small, especially compared to HC. This standard will essentially cap NOx emissions from these engines to prevent backsliding in advanced technology engines. We are not promulgating standards that would require substantial reductions in NOx because we believe that non-aftertreatment based standards which force substantial NOx reductions could put upward pressure on HC emissions and would not necessarily lead to reductions in ambient PM. Given the overwhelming level of HC, CO and PM compared to NOx, and the secondary PM expected to result from high HC levels, it would be premature and possibly counterproductive to promulgate NOx standards that require significant NOx reductions from snowmobiles at this time. We have therefore decided to structure our long term HC+NOx standard for 2012 and later model year snowmobiles to require only a cap on NOx emissions from the advanced technology engines which will be the dominant technology in the new snowmobiles certified at that time.

4.3.4 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Four-stroke engines can have considerably lower sound levels than two-stroke engines. Electronically controlled fuel systems are able to improve management of the combustion event which can help lower noise levels.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for two-stroke engines as well as for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke snowmobile is 12 miles per gallon (mpg). Average mileage for a four-stroke snowmobile is 18 mpg and up to 20 mpg for a two-stroke with direct injection. We project that these fuel consumption benefits will reduce total nationwide fuel consumption by more than 50 million gallons annually once the program is fully phased in.

We believe the technology discussed here will have no negative impacts on safety. Electronic fuel injection is almost universally used in cars, trucks and highway motorcycles in the United States with very reliable performance. While the manufacturers have expressed some concern about heavier weight and cold-starting for four stroke engines we believe these are not significant concerns. There are already four-stroke models in production today and obviously they are not being introduced into commerce with known safety concerns. A two-stroke snowmobile has a fuel tank of about 12 gallons. A four-stroke could have a fuel tank of 8 gallons and maintain the same driving time/range. This would lead to a weight reaction of 25 pounds to help offset concerns about increased weight of four-stroke snowmobiles. If cold starting of four strokes is an issue, it can be resolved with the assistance of an electronic starter or a dry sump oil system that stores oil in a separate tank rather than in the crankcase, thus eliminating the concern over high viscous oil adding excessive resistance to the starting process.

4.3.5 Conclusions

4.3.5.1 Phase 1 Standards

For the Phase 1 standards which start in the 2006 model year, we are allowing a phase-in schedule that requires 50 percent of a manufacturers snowmobile fleet to meet the standards in the 2006 model year and 100 percent to meet the standards in the 2007 model year. Snowmobile manufacturers will have three main emission control technologies for meeting these standards: modified two-stroke technologies (combination of engine modifications and fuel system improvements), direct fuel injection, and four-stroke engine technology. We expect that the Phase 1 emission standards will be met through a combination or mixture of these three emission control strategies. All three of these strategies have been proven to be feasible and are already available on some sleds today. Four-stroke engines and direct fuel injection technology have already been demonstrated to be capable of achieving emission reductions well in excess of our standards. Significant reductions are also achievable using modified two-stroke technologies.

For the 2006 model year, we expect manufacturers to rely most heavily on modifications to existing two-stroke engines with a small amount (e.g., 10 percent) of direct injection two-stroke engines and four-stroke engines (e.g., another 10 percent). In the context of an averaging program, the use of direct injection technology and four-stroke engines will not only be necessary to meet the standards, but may also allow some manufacturers to leave a small percentage of engines unchanged, most specifically, inexpensive entry-level sleds that manufacturers have argued are very cost sensitive. Such an approach may be necessary given the lead time and the fairly large number of engine models to be modified and certified. Table 4.3-5 provided below presents a potential technology mix scenario for the Phase 1 standards. The average reduction level at the bottom of the table represents average reductions for a manufacturer’s entire fleet which already incorporates compliance margin and useful life consideration, since each engine family FEL will have a unique compliance margin. The percent reduction presented in the table is based on HC and CO. Obviously, a manufacturer could change the technology mix based on cost and performance considerations.

Table 4.3-5
Potential Snowmobile Technology Mix for Phase 1 Standards

Technology	Percent Usage	Percent Reduction HC	Percent Reduction CO	Fleet % Reduction HC	Fleet % Reduction CO
Minimal Control Engines*	20%	0%	0%	0%	0%
Carburetor/EFI Recalibration + Engine Modifications	60%	30%	30%	18%	18%
Direct Injection	10%	75%	70%	7.5%	7%
Four-Stroke	10%	90%	50%	9%	5%
Average Reduction				35%	30%

* Some minimal control may be required to account for deterioration and to ensure certification FELs are met in production.

4.3.5.2 Phase 2 Standards

We are also finalizing Phase 2 standards in the 2010 model year that will serve as transitional standards to our more stringent Phase 3 standards. As for the Phase 1 standards, we believe manufactures will rely on a mixture of technologies, with the focus on modified two-stroke technologies, perhaps including pulse air injection, direct fuel injection, and four-stroke engines. We expect that to meet the 2010 standards, manufacturers will employ more of the advanced technologies such as direct injection and four-stroke engines and less of the modified two-stroke technologies. We anticipate manufacturers will have numerous technology mix scenarios that they will consider. Table 4.3-6 provided below presents a potential technology mix scenario for the Phase 2 standards. Obviously, a manufacturer could change the technology mix based on cost and performance considerations. As for the Phase 1 standards, the use of advanced technologies such as direct injection and four-stroke engines, in the context of our averaging program, may allow some manufacturers to have a small percentage of engines with minimal change. As discussed above in sections 4.3.2.4 and 4.3.2.5, we believe the biggest task manufacturers will face in meeting our standards will be the converting of their large current fleet of snowmobiles equipped with unregulated two-stroke engines to snowmobiles equipped with advanced clean technologies, such as direct injection and four-stroke engines.

Table 4.3-6
Potential Snowmobile Technology Mix for 2010 Standards

Technology	Percent Usage	Percent Reduction HC	Percent Reduction CO	Fleet % Reduction HC	Fleet % Reduction CO
Minimal Control Engines*	20%	0%	0%	0%	0%
Carburetor/EFI Recalibration + Engine Modifications + Pulse Air Injection	30%	35%	35%	10.5%	10.5%
Direct Injection	35%	75%	70%	26%	24.5%
Four-Stroke	15%	90%	50%	13.5%	7.5%
Average Reduction				50%	43%

* Some minimal control may be required to account for deterioration and to ensure certification FELs are met in production.

4.3.5.3 Phase 3 Standards

We are finalizing Phase 3 standards in the 2012 model year that we believe will require a significant percentage of snowmobile models to be equipped with advanced technologies. As with our Phase 1 and Phase 2 standards, we believe manufactures will rely on a mixture of technologies, with the focus on direct fuel injection and four-stroke engines. While we expect that to meet the 2012 standards manufacturers will employ considerably more of the advanced technologies such as direct injection and four-stroke engines, they may still use a relatively small amount of the modified two-stroke technologies. To provide manufacturers with additional flexibility, we are allowing the Phase 3 standards to be met by using the following equation:

$$100 = \left(1 - \frac{(HC + NOx)_{STD} - 15}{150}\right) \times 100 + \left(1 - \frac{CO_{STD}}{400}\right) \times 100$$

Under this equation, the sum of reductions in HC+NOx and CO must equal or exceed 100 percent on a corporate average basis. Corporate average HC levels cannot exceed 75 g/kW-hr as in the Phase 2 requirement. We believe this will allow manufacturers to use a broader variety of technology mixes than our proposed Phase 2 standards. Tables 4.3-7 and 4.3-8 provided below present a couple of potential technology mix scenarios for the Phase 3 standards.   For the Phase 3 standards, we are including a HC+NOx requirement. This was done because, as the tables below will show, the number of four-stroke snowmobiles is anticipated to significantly increase compared to the number used to meet our Phase 1 and Phase 2 standards. Four-stroke engines emit significantly higher levels of NOx emissions than two-stroke engines. In order to make sure that NOx emissions do not become a problem as a result of the increase in the number of four-stroke snowmobiles, we decided to establish a NOx standard as well.   The NOx standard is set at a level that makes it more of a cap, 15 g/kW-hr. This level should be inherently achievable for the majority of four-stroke engines. However, should a manufacturer attempt to design a four-stroke snowmobile that operates with a very lean air and fuel mixture to get even further HC reductions, this standard will prevent backsliding. NOx emissions from two-stroke engines are inherently well below the 15 g/kW-hr level.

We do not believe that incorporating the 15 g/kW-hr NOx standard as part of the HC+NOx standard will provide any incentive to increase HC significantly.   NOx emissions from four-stroke engines are sufficiently close to 15 g/kW-hr that there will be little ability to increase HC even marginally. For two-stroke engines, while the 15 g/kW-hr level for NOx is well above typical two-stroke NOx emissions, it is still well below two-stroke HC emissions and does not provide enough of a margin to avoid use of advanced technologies on most engines. At most, it may provide a slight compliance cushion for these engines.

Table 4.3-7
Potential Snowmobile Technology Mix for Phase 3 Standards

Technology	Percent Usage	Percent Reduction HC	Percent Reduction CO	Fleet % Reduction HC	Fleet % Reduction CO
Carburetor/EFI Recalibration + Engine Modifications + Pulse Air Injection	20-30%	23-35%	23-35%	7-11.5%	7-11.5%
Direct Injection	50%	75%	70%	37.5%	35%
Four-Stroke	20%	90%	50%	18%	10%
Average Reduction				63%	52%

Table 4.3-8
Potential Snowmobile Technology Mix for Phase 3 Standards

Technology	Percent Usage	Percent Reduction HC	Percent Reduction CO	Fleet % Reduction HC	Fleet % Reduction CO
Carburetor/EFI Recalibration + Engine Modifications + Pulse Air Injection	0-20%	0-35%	0-35%	0-7%	0-7%
Direct Injection	10%	75%	70%	7.5%	7%
Four-Stroke	70%	90%	50%	63%	35%
Average Reduction				71%	42%

Clearly the technologies necessary to meet our 2012 standards are feasible, and in many cases the technologies are already being used on various snowmobile applications. As these technologies have been shown to provide emission reductions at or beyond the reductions needed to meet the standards, the standards are clearly feasible given the appropriate lead time even when considering production variability and emissions deterioration. The challenge manufacturers will face will be deciding which technologies to use for different applications and how consumers will respond to those technologies. In our testing efforts we attempted to order one of the new 2003 Yamaha RX-1 high performance four-stroke snowmobiles, but were surprised to find out that local dealers said there would be a six month wait to get one due to the high demand. We verified with Yamaha that they indeed have commitments for virtually every one of the new RX-1 models they are making and it’s not a limited run, but rather a full scale production build. Therefore, if the Yamaha case is any indication, we believe there are a number of viable technologies available to meet our 2010 standards and the public is not only going to accept them, but embrace them.

Tables 4.3-7 and 4.3-8 are meant to show some possible technology mix scenarios that manufacturers may choose to comply with the Phase 3 standards in 2012. Implicit in these tables is the possibility that, under the averaging program, there may still be some largely unmodified two-stroke engines sold under the Phase 3 program. There are several reasons why a manufacturer might choose to continue to sell a small number of baseline technology snowmobiles under the Phase 3 program. First, it may prove significantly more expensive to reduce the emissions of a particular engine family relative to a manufacturer's other product offerings, and the manufacturer may simply choose to apply additional technology to some of its other models rather than put the extra effort and expense into reducing emissions from every one of its models. Second, a particular engine family may not respond as well to technology changes as other engine families, and the manufacturer may choose to apply additional technology to some of its other offerings rather than spending the resources to overcome the technological hurdles associated with a particular engine family. This could be because the technologies may affect the performance of the particular snowmobile model, including increased weight and startability concerns, and thus need further refinement for implementation. Finally, a manufacturer may intend to discontinue a particular engine family in the near future and may choose to focus its efforts on its other product offerings rather than spend the resources to reduce emissions from an engine family that is scheduled to be discontinued.

While it is possible that there may be some baseline technology snowmobiles in the product mix under the Phase 3 program, we expect that sales of such snowmobiles will be minimal for the following reasons. First, as Tables 4.3-7 and 4.3-8 show, we expect that compliance with the Phase 3 standards will require that at least 70 percent of snowmobile production employ some form of advanced technology such as direct injection two-stroke technology, or four-stroke engines. There may be some uncertainty amongst manufacturers as to whether they will be able to sell enough snowmobiles with advanced technology to allow for including baseline technology snowmobiles in their product mix. Manufacturers will likely choose to apply some level of emissions control to every snowmobile they sell in order to assure compliance with the Phase 3 standards on average. Similarly, there is no assurance that the advanced technologies will reduce emissions as well as expected on all engine families in the time frame provided, and we expect that manufacturers will also choose to apply some level of technology to every snowmobile in order to provide a compliance margin in case some technologies or particular applications of technologies do not perform as expected.

4.4 All-Terrain Vehicles/Engines

The following paragraphs summarize the data and rationale supporting the emission standards for ATVs, which are listed in the Executive Summary.

4.4.1 Baseline Technology and Emissions

ATVs have been in popular use for over 25 years. Some of the earliest and most popular ATVs were three-wheeled off-highway motorcycles with large balloon tires. Due to safety concerns, the three-wheeled ATVs were phased-out in the mid-1980s and replaced by the current and more popular vehicle known as “quad runners” or simply “quads.” Quads resemble the earlier three-wheeled ATVs except the single front wheel was replaced with two wheels that are controlled by a steering system. The ATV steering system uses motorcycle handlebars, but otherwise looks and operates like an automotive design. The operator sits on and rides the quad much like a motorcycle. The engines used in quads tend to be very similar to those used in off-highway motorcycles - relatively small single cylinder two- or four-stroke engines that are either air- or liquid-cooled. Recently, some manufacturers have introduced ATVs equipped with larger four-stroke two-cylinder V-twin engines. Quads are typically divided into two types: utility and sport. The utility quads are designed for recreational use but have the ability to perform many utility functions such as plowing snow, tilling gardens, and mowing lawns to name a few. They are typically heavier and equipped with relatively large four-stroke engines and automatic transmissions with reverse gear. Sport quads are smaller and designed primarily for recreational purposes. They are equipped with two- or four-stroke engines and manual transmissions.

Although ATVs are not currently regulated federally, they are regulated in California. The California ATV standards are based on the FTP cycle just like highway motorcycles, however, California allows manufacturers to optionally certify to a steady-state engine cycle (SAE J1088) and meet the California non-handheld small SI utility engine standards. Manufacturers have felt that these standards are unattainable with two-stroke engine technology. Therefore, all of the ATVs certified in California are equipped with four-stroke engines. California ultimately allowed manufacturers to sell uncertified engines as long as those ATVs and motorcycles equipped with uncertified engines were operated exclusively on restricted public lands and at specified times of the year. This allowed manufacturers to continue to produce and sell two-stroke ATVs in California. Thus, the main emphasis of ATV engine design federally, and for two-stroke powered ATVs in California, is on performance, durability, and cost. Although some manufacturers offer some of their California models nationwide, most ATVs sold federally have no emission controls.

ATVs predominantly use four-stroke engines (e.g., 80 percent of all sales are four-stroke). The smaller percentage of two-stroke engines are found primarily in the small engine displacement “youth” models. Of the seven major ATV manufacturers, only two make two-stroke ATVs for adults. These models are either inexpensive entry models or high-performance sport models. The fuel system used on ATVs, whether two- or four-stroke, are almost exclusively carburetors, although at least one manufacturer has introduced a four-stroke ATV with electronic fuel injection. Although ATVs are mostly four-stroke equipped, they still can have relatively high levels of HC and extremely high levels of CO, because many of them operate with a “rich” air and fuel mixture, which enhances performance and allows engine cooling, which promotes longer lasting engine life. This is also true for two-stroke equipped ATVs. Rich operation results in high levels of HC, CO, and PM emissions. In addition, two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary 2-stroke engines with a pump that sends two-cycle oil from a separate oil reservoir to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. Because two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust, lubricating oil particles are also released into the atmosphere, becoming HC particles or particulate matter (PM). The scavenging losses also result in high levels of raw HC. This is in contrast to four-stroke engines that use the crankcase as an oil sump and a pump to distribute oil throughout the engine, resulting in virtually no PM..

We tested 11 four-stroke and three two-stroke ATVs over the FTP. Tables 4.4-1 and 4.4-2 shows that the HC emission rate for the four-stroke ATVs is significantly lower than for the two-stroke ATVs, whereas the NOx emissions from the two-strokes were considerably lower than from the four-strokes. The CO emissions were also lower for the two-stroke ATVs. The four-stroke ATVs that we tested that had high levels of CO also happened to be 50-state certified vehicles, meaning they are California vehicles sold nationwide. Because there are California standards for HC+NOx, manufacturers have tended to calibrate the ATVs fuel system to run even richer than normal to meet the NOx standard. Since the CO standard in California is relatively high, these ATVs can run rich and still meet the CO standards. Another observation that can be made from the test results is that of the 11 four-stroke models tested, the four ATVs with the lowest emissions were sport models. The other seven models were all utility models. The four sport models, the Yamaha Warrior and Raptor, the Honda 300EX, and Polaris Trail Boss had an average HC+NOx level of 1.35 g/km, below our 1.5 g/km standard, and an average CO level of 28.5 g/km, only slightly above our standard of 25 g/km. In fact, the Warrior and Raptor already meet our standards with considerable headroom. The average HC+NOx and CO emissions levels for the seven utility models were 2.20 g/km and 33.7 g/km, respectively. This may indicate that when testing over the highway motorcycle test procedure, utility ATVs may be at a disadvantage compared to the sport models because of their lower power-to-weight ratio and use of continuously variable transmissions. Even when tested over the less strenuous Class I highway motorcycle test cycle, the utility ATVs appeared to be operating at higher loads than the sport models. Although we didn’t examine all of the ATVs, the Warrior operated at a slightly leaner air and fuel mixture than the Polaris Sportsman. This could be model or manufacturer specific, but if this is at all indicative of how sport and utility ATVs fuel systems are calibrated, the fact that utility ATVs already operate very rich could be exacerbated when operated over the FTP, resulting in the higher HC and CO levels that we observed.

Table 4.4-1
Four-Stroke ATV Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Kawasaki	Bayou	1989	280 cc	1.17	14.09	0.640
Honda	300EX	1997	298 cc	1.14	34.60	0.155
Polaris	Trail Boss	1998	324 cc	1.56	43.41	0.195
Yamaha	Warrior	1998	349 cc	0.98	19.44	0.190
Polaris	Sportsman	2001	499 cc	2.68	56.50	0.295
Arctic Cat	375 Automatic	2001	375 cc	1.70	49.70	0.190
Yamaha	Big Bear	2001	400 cc	2.30	41.41	0.170
Honda	Rancher	2001	400 cc	1.74	33.98	0.150
Bombardier	4X4 AWD	2001	500 cc	1.62	20.70	0.740
Polaris	Sportsman	2001	499 cc	1.56	19.21	0.420
Yamaha	Raptor	2001	660 cc	0.97	16.56	0.210
Average				1.58	31.78	0.305

Table 4.4-2
Two-Stroke ATV Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Suzuki	LT80	1998	79 cc	7.66	24.23	0.047
Polaris	Scrambler	2001	89 cc	38.12	25.08	0.057
Polaris	Trailblazer	2000	250 cc	18.91	44.71	0.040
Average				21.56	31.34	0.048

4.4.2 Potentially Available ATV Technologies

A variety of technologies are currently available or in stages of development to be available for use on two-stroke ATVs, such as engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, and semi-direct and direct fuel injection. However, it is our belief that manufacturers will choose to convert their two-stroke engines to four-stroke applications, because of the cost and complexity of the above mentioned technologies necessary to make a two-stroke engine meet our standards. We believe that to meet our ATV standards, manufacturers will use four-stroke engines. Depending on the size, performance and calibration of the engine, they will also need to make improvements to the fuel system, consisting of improved carburetor tolerances and a leaner air and fuel mixture, and in some cases the use of pulse air injection.

4.4.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke and four-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications for two-stroke engines that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish and tumble would serve to improve the combustion of the intake charge for both two- and four-stroke engines. Manufacturers have indicated that they believe these modifications for two-stroke engines have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these things, but would be insufficient alone to meet our standards[y].

4.4.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in ATV engines. First, strategies to improve fuel atomization would promote more complete combustion of the fuel/air mixture. Additionally, production tolerances could be improved for more consistent fuel metering. Both of these things would allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ratio could be leaned out some. ATV engines are currently calibrated with rich air/fuel ratios for durability and performance reasons. According to manufacturers, based on their experience, leaner calibrations could serve to reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration[z]. Small improvements in fuel economy could also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) could create concerns about ATV engine durability. There are many engine improvements that could be made to regain any lost durability that occurs with leaner calibration. These include changes to the cylinder head, pistons, pipes and ports for two-stroke and valves for four-stroke, to reduce knock. In addition, critical engine components could be made more robust with improvements such as better metallurgy to improve durability.

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[y] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

[z] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines could also be employed, possibly with more accuracy, with the use of fuel injection. At least one ATV manufacturer currently employs electronic fuel injection on one of its ATV models.

4.4.2.3 Direct and Semi-Direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that two-stroke engines have such high levels of HC emissions is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft engines and some are showing upwards of 70 percent reductions in emissions. Direct injection is also being used by some motorcycle manufacturers (e.g., Aprilla) on small mopeds, scooters, and motorcycles to meet emission standards for two-strokes in Europe and Asia. A new start-up company called Rev! Motorcycles plans to manufacturer high-performance recreational and competition off-highway motorcycles with direct fuel injection two-stroke engines in the next year or so (for more, see Section 4.7.2.3). They have not indicated whether they will manufacturer any ATVs. Substantial improvements in fuel economy could also be expected with these technologies. However, there are some issues with ATV operation (larger displacement engines that experience more transient operation than watercraft and small mopeds) that make the application of the direct injection technologies somewhat more challenging for ATVs than for personal watercraft and small displacement scooters. The biggest obstacle for this technology is that the many of the two-stroke equipped ATVs are youth models which emphasize low price. Direct injection is relatively expensive and may not be considered to be cost effective for these engines.

4.4.2.4 Four-Stroke Engines

Four-stroke engines produce significantly lower levels of HC emissions than two-stroke engines. This is primarily due to the fact that two-stroke engines experience high scavenging losses that allow up to a third of the unburned air and fuel mixture to escape into the atmosphere during the combustion process. Since four-stroke engines have a valve-train system and introduce the air and fuel mixture into the combustion chamber when the exhaust valve is closed or almost closed, there is very little scavenging of unburned fuel. Thus, four-stroke engines have superior HC control to conventional two-stroke engines. Four-stroke engines have comparable CO performance to two-stroke engines. CO emissions result from incomplete combustion due to an excess of fuel in the air and fuel mixture. Thus, CO emissions are a function of air and fuel mixture. Current unregulated four-stroke and two-stroke engines both operate with a rich air and fuel mixture, resulting in high levels of CO emissions. Therefore, four-stroke engines do not have inherently low CO emission levels. Four-stroke engines also generate higher NOx emission levels than two-stroke engines. This is because NOx emissions are a function of temperature. Higher combustion temperatures generate higher NOx emission levels. Four-stroke engines have more complete combustion than conventional two-stroke engines, which results in higher combustion temperatures and higher NOx emission levels. Thus, four-stroke engines are an excellent choice for significantly reducing HC emissions. However, to reduce CO emissions, a four-stroke engine may need some fuel system calibration changes, engine modifications, or the use of secondary air or a catalyst. To reduce NOx emissions from a four-stroke engine would require fuel system calibration changes, engine modifications, exhaust gas recirculation (EGR), or a catalyst.

Since 80 percent of all ATVs sold each year are four-stroke, there is no question about the feasibility of using four-stroke engine technology for ATVs. Conversion from two-stroke to four-stroke engine technology also results in improvements to fuel consumption and engine durability. These benefits could be especially valuable to consumers who purchase utility ATVs.

The ATV models that are currently equipped with two-stroke engines tend to be small-displacement youth models, entry-level adult ATVs and high-performance adult sport ATVs. While most youth ATVs are equipped with two-stroke engines, there are several manufactures who offer four-stroke models. Youth ATVs are regulated by the Consumer Product Safety Commission (CPSC). Although the regulations are voluntary, manufacturers take them very seriously, and one of the their requirements is that youth ATV speeds be governed. For “Y6" ATVs (i.e., age 6 and up) the maximum speed is 15 miles per hour (mph) and for “Y12" ATVs (i.e., age 12 and up), the maximum speed is 30 mph. By Consent Decree these are limited to 50 cc and 90 cc, respectively. Some manufacturers have argued that because of these constraints, they need to use light-weight two-stroke engines, which have higher power-to-weight ratios than four-stroke engines, in order to have sufficient power to operate the ATV. However, as mentioned earlier, some manufacturers already use four-stroke engines in these applications without any problem. The power required to meet the maximum speed limits for these little ATVs is low enough that a four-stroke engine is more than adequate. The real issue appears to be cost. Manufacturers argue that youth ATVs are price sensitive and that minor increases in cost would be undesirable. Four-stroke engines are more expensive than similarly powered two-stroke engines. This appears to be the issue with entry-level adult ATVs as well. Those manufacturers that offer two-stroke entry-level ATVs also offer similar entry-level machines with four-stroke engines. The argument is that consumers of their product like having the ability to choose between engine types. In addition, manufacturers have expressed concern that these smaller engines have lower cylinder surface to volume area ratios than larger displacement engines, thus increasing the difficulty of in-cylinder control of HC emissions. That is one of the reasons that we 1) are allowing engines under 99 cc to stay in the relatively less stringent utility engine program and 2) that we permit averaging across the entire spectrum of ATV vehicles/engines if they certify to the FTP-based standards.

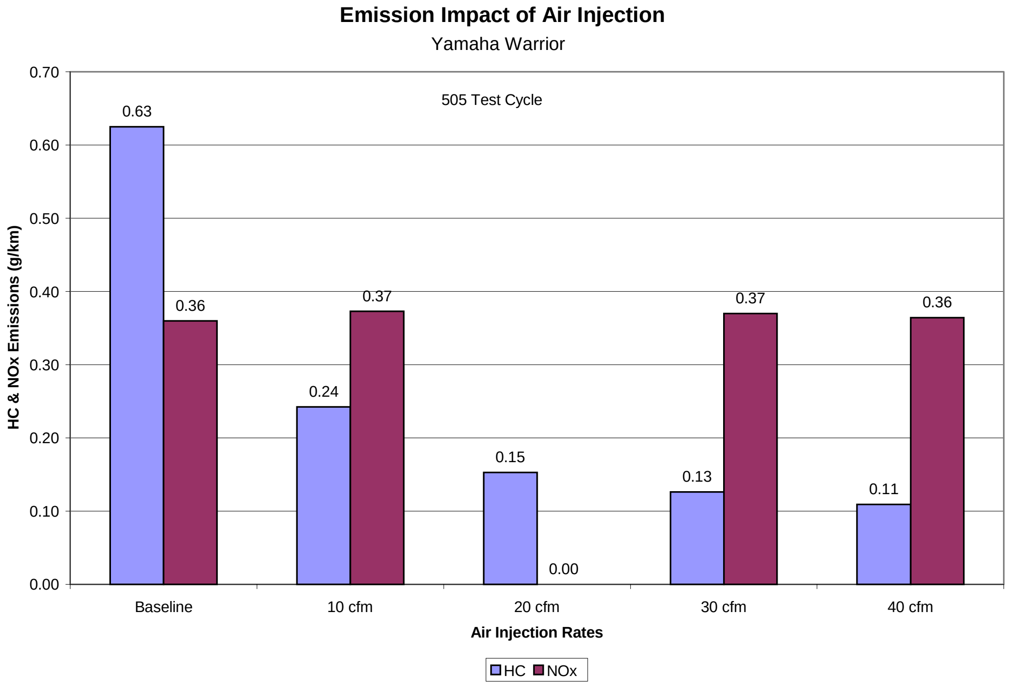
Adult sport ATVs equipped with two-stroke engines were at one time considered the only ATVs that were capable of providing true high-performance. However, advancements in four-stroke engine technology for ATVs and off-highway motorcycles have now made it possible for larger displacement high-powered four-stroke engines to equal, and in some cases surpass, the performance of the high-powered two-stroke engines. Again, the argument for two-stroke engines appears to be a matter of choice for consumers. However, since only two manufacturers produce two-stroke adult ATVs, we believe that the relatively low sales volumes for these models will make it cost prohibitive to reduce two-stroke emissions to the levels necessary to meet our standards. Nonetheless, the credit exchange program (ABT) we are including for ATV s creates the possibility for manufacturers to retain some lower emission two-stroke ATVs and offset their higher emissions with reductions from 4-stroke models.

4.4.2.5 Air Injection

Secondary pulse air injection involves the introduction of fresh air into the exhaust pipe immediately after the exhaust gases exit the engine. The extra air causes further combustion to occur as the gases pass through the exhaust pipe, thereby oxidizing more of the HC and CO that escape the combustion chamber. This type of system is relatively inexpensive and uncomplicated because it does not require an air pump; air is drawn into the exhaust through a one-way reed valve due to the pulses of negative pressure inside the exhaust pipe. Secondary pulse-air injection is one of the most effective non-catalytic, emissions control technologies; compared to engines without the system, reductions of 30-70% for HC and 30-80% for CO are possible with pulse-air injection.

This technology is fairly common on highway motorcycles and is used on some off-highway motorcycle models in California to meet the California off-highway motorcycle and ATV emission standards. We believe that secondary air injection will not be necessary to meet our standards for all models, but will be a viable control technology for some machines. We tested three different four-stroke ATVs with secondary air. A 1998 Yamaha Warrior sport model, a 2001 Polaris Sportsman High Output (H.O.) utility model, and a 2001 Polaris Sportsman utility model. Initially we didn't have access to a pulse air system so we used shop air introduced into the exhaust manifold at various flow rates to simulate air injection. To save time and money, we performed our tests over the hot 505 section of the Class I Motorcycle cycle. This is a warmed-up version of the first bag or 505 seconds of the FTP test cycle. The initial tests with shop air indicated that air injected into the exhaust stream could reduce HC emissions from 5-percent to 60-percent depending on the vehicle and the amount of air injected. For example, the Warrior was very responsive to air injection. We tested at flow rates of 10, 20, 30, and 40 cubic feet per minute (cfm). HC emissions were reduced from 25-percent to 60-percent depending on the flow rate. Figure 4.4-1 illustrates these reductions. We also experimented with the air and fuel mixture and found that if we leaned the mixture slightly, the air injection had an even greater effect, reducing HC emissions by 83-percent from the uncontrolled baseline level with 40 cfm of air. Our next task was to determine how the various flow rates we tested compared to the capabilities of a pulse air system. A pulse air system uses a system of check valves which uses the normal pressure pulsations in the intake manifold to draw in air from outside and inject into the exhaust manifold. A reed valve is used in the exhaust manifold to prevent reverse airflow of exhaust gases through the system. A valve called the "air injection" valve reacts to high intake manifold vacuum and will cut-off the supply of air during engine decelerations, thereby preventing after burn in the exhaust system.

Figure 4.4-1



Since generic pulse air systems can’t be simply purchased from the store or dealership, we had to modify an existing pulse air system to work on our test ATVs. We purchased a pulse air system for a 1995 BMW 100R. Because this is a multi-cylindered engine, we had to make some modifications to get it to work with a single-cylinder ATV engine. We were able to successfully install the pulse air system onto the Warrior and performed several hot 505 test runs to see how the pulse air system compared with the various flow rates of shop air. For our shop air tests, we injected a constant flow rate over the entire 505 seconds of the test. Because a pulse air system relies on drawing air into the exhaust system during negative pressure pulses in the cylinder, increasing the engine speed increases the magnitude of the positive pressure pulses resulting in increased back-pressure which can make a pulse air system ineffective. Our biggest concern was that a pulse air system might not have the same overall flow capacity as our shop air experiments since the pulse air system is only capable of drawing air into the exhaust manifold during lower speeds where increased exhaust back-pressure is decreased. Due to timing constraints, we only tested the Warrior with the pulse air system in conjunction with the enleaned carburetor setting. The carburetor was enleaned by raising the jet needle one clip notch. When we raised the clip two notches, the engine ran too lean and performance and driveability were affected. With pulse air and the slightly lean calibration, the Warrior had emissions comparable to the 20-30 cfm shop air results. Figure 4.4-2 shows the results between shop air and the pulse air results. When the Warrior was tested over the full FTP with pulse air and the slightly lean calibration, HC and CO emissions were reduced from baseline levels, while NOx increased. HC was reduced by 73-percent, CO was reduced by 83-percent and NOx was increased by 47-percent. The NOx emission increase is most likely due to the leaner air and fuel mixture. The HC+NOx level was reduced by 54-percent from the baseline level as shown in Table 4.4-3.

Figure 4.4-2

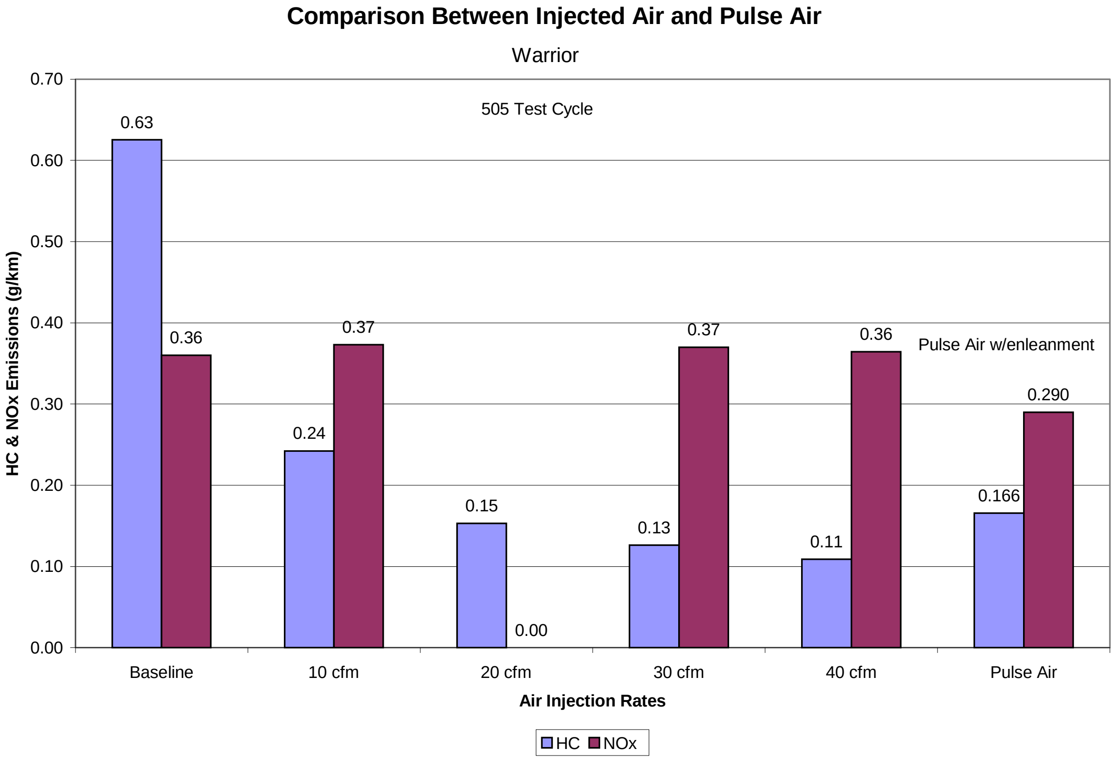


Table 4.4-3
Yamaha Warrior Emissions with and without Pulse Air Injection

Test Configuration	HC	CO	NOx	HC+NOx
Baseline	0.98	19.44	0.19	1.17
Pulse Air w/enleanment	0.26	3.33	0.28	0.54

The two Polaris Sportsman models proved to be more problematic than the Warrior. As discussed above, the utility ATVs all had higher baseline emissions levels than the sport models. The Polaris Sportsman High Output (H.O.) had the highest baseline emissions of any of the ATVs we tested. HC+NOx emissions were 3.0 g/km, almost 100-percent higher than our standard of 1.5 g/km, while CO was 56.5 g/km, 125-percent higher than the standard of 25 g/km. The regular Sportsman was cleaner than the H.O. model with a HC+NOx level of 1.98 g/km and a CO level of 19.2 g/km. As a result of these higher baseline emissions, the two Sportsman models were at a disadvantage compared to the relatively clean Warrior. When supplying shop air to the two Sportsman models we saw varied results. The higher emitting H.O. model responded to air injection. However, the emissions were still so high that we stopped any further testing and focused on catalyst use for this model. The regular Sportsman model was less receptive to air injection. In fact the same levels of flow that resulted in sharp reductions for the Warrior had only minimal effects for this vehicle. Further investigation indicated that the air and fuel mixture was too rich for the injected air to have any significant effect. We tried to lean-out the air and fuel mixture by raising the jet needle clip to the top of the needle, similar to what we did for the Warrior, but there was no response. We had to use a different, leaner main jet, in order to successfully lean-out the air and fuel mixture. With the air and fuel mixture leaner, we ran several tests with shop air and found that the Sportsman was more receptive to air injection, so we decided to install the BMW pulse air system that we modified for the Yamaha Warrior to the Sportsman. We ran a full FTP with the pulse air system and the leaner main jet installed and found that emissions were reduced considerably. HC and CO were reduced by 71-percent and 68-percent, respectively. NOx emissions increased by 45-percent. Limited time prevented us from further investigating ways to reduce the air and fuel mixture. However, as Table 4.4-4 shows, the Sportsman was able to meet the standard using this approach.

Table 4.4-4
Polaris Sportsman Emissions with and without Pulse Air Injection

Test Configuration	HC	CO	NOx	HC+NOx
Baseline	1.56	19.21	0.42	1.98
Pulse Air w/enleanment	0.49	6.12	0.60	1.09

4.4.2.6 Catalyst Technology

For our proposal, we proposed Phase 2 standards of 1.0 g/km HC+NOx. To achieve a standard of 1.0 g/km, manufacturers will actually have to design their emission control system to meet an emission level lower than the standard to account for deterioration and provide an acceptable certification emission margin. Manufactures typically aim for a certification emissions margin of 20 percent. Our NONROAD emission model uses a deterioration factor of 1.17 for four-stroke ATV engines. Taking these factors into consideration would result in a potential emission level design goal of approximately 0.7 g/km. To meet this level of HC+NOx control, we projected in our proposal that it might be necessary for some ATV models to use a catalyst. To establish the feasibility of using a catalyst on an ATV, we tested the Polaris Sportsman High Output (HO) ATV equipped with several different catalysts. The Sportsman is a large utility ATV equipped with a 500 cc (HO) four-stroke engine and is one of the larger ATV models currently offered in the market. We chose this model to demonstrate catalyst viability because, as mentioned above, it had the highest baseline emissions of any of the ATVs we tested, and it is a California certified vehicle that is sold nationwide. We tested the Polaris with three different catalysts. Two of the catalysts were three-way catalysts with metal substrates and cell densities of 200 cells/in^2 . One of the catalyst's had a Pt/Rh washcoat, while the other used a Pd-only washcoat. The third catalyst was an oxidation catalyst with a ceramic substrate and a cell density of 400 cells/in^2. Table 4.4-5 shows that emissions were significantly reduced when the various catalysts were installed on the Sportsman. However, even though there was a significant reduction in emissions, the ATV was still unable to meet the proposed 1.0 g/km HC+NOx standard, let alone the design target of approximately 0.7 g/km.

Table 4.4-5
Polaris Sportsman 500 Emissions with Various Catalysts

Catalyst	HC	CO	NOx	HC+NOx
Baseline	2.68	56.5	0.3	2.98
TWC (Pd-only)	1.27	35.27	0.05	1.32
TWC (Pt/Rh)	1.29	32.6	0.04	1.33
Oxidation	1.38	28.87	0.02	1.4

The three catalysts that we used had volumes ranging from 400 to 500 cc. Most highway motorcycles typically use catalysts with a catalyst-to-engine volume ratio of one half. In other words, they typically use a catalyst that has a volume approximately half of the engine's displacement. For our catalyst cost estimation in the proposal, we argued that this would be a good assumption for ATVs as well. We estimated that for ATVs, the catalyst size necessary to meet our proposed HC+NOx standard of 1.0 g/km would be equal to half of the engine displacement. We projected an average catalyst volume of 200 cc. The catalysts that we tested were roughly double the size of catalysts we projected would be necessary to meet our standards. We chose to use these catalysts not because of their size, but because of their availability. All three catalysts are used in production highway motorcycle applications and were provided to us by catalyst manufacturers. The highway motorcycles that these catalyst are from have an engine displacement of approximately 900 cc. The implication of this is that even with catalysts twice as large as we projected would be necessary to meet our 1.0 g/km standard, the emission reductions for this ATV were still about 33-percent short of the standard.

Due to rulemaking schedule constraints, we had limited time to perform the testing and analyses that we felt were necessary to support the proposed standards. One of the consequences of this timing was that were unable to test the Sportsman with the various catalysts with pulse air injection and a leaner air and fuel mixture. It is quite possible, that had we been able to perform those tests we would have found that the emissions from the Sportsman could be brought down to levels below the proposed Phase 2 standards. However, with our limited success with air injection and enleaning of the air and fuel mixture with the two Sportsman models, it is also possible that these additional strategies would not have helped quickly. We are confident that the use of a catalyst has the potential to significantly reduce emissions for many ATV applications, but at this time we can not confidently claim they will work for all applications without further investigation.

4.4.3 Test Cycle/Procedure

For ATVs, we specify the current highway motorcycle test procedure for measuring emissions. The highway motorcycle test procedure is the same test procedure as used for light-duty vehicles (i.e., passenger cars and trucks) and is referred to as the Federal Test Procedure (FTP). The FTP for a particular class of engine or equipment is actually the aggregate of all of the emissions tests that the engine or equipment must meet to be certified. However, the term FTP has also been used traditionally to refer to the exhaust emission test based on the Urban Dynamometer Driving Schedule (UDDS), also referred to as the LA4 (Los Angeles Driving Cycle #4). The UDDS is a chassis dynamometer driving cycle that consists of numerous "hills" which represent a driving event. Each hill includes accelerations, steady-state operation, and decelerations. There is an idle between each hill. The FTP consists of a cold start UDDS, a 10 minute soak, and a hot start. The emissions from these three separate events are collected into three unique bags. Each bag represents one of the events. Bag 1 represents cold transient operation, bag 2 represents cold stabilized operation, and bag 3 represents hot transient operation.

Highway motorcycles are divided into three classes based on engine displacement, with Class I (50 to 169 cc) being the smallest and Class III (280 cc and over) being the largest. The highway motorcycle regulations allow Class I motorcycles to be tested on a less severe UDDS cycle than the Class II and III motorcycles. This is accomplished by reducing the acceleration and deceleration rates on some the more aggressive "hills" and by reducing the top speed from 56 miles per hour to 35 mile per hour. California requires ATVs to be tested over the Class I motorcycle cycle. Our testing has shown that some utility ATVs are at a disadvantage when tested over the Class II and III cycles because utility ATVs use continuously variable transmissions (CVT), similar to snowmobiles. These transmissions tend to be geared towards lower speed operation for ATVs with high torque generation at lower engine speeds. This is so they can perform a broad variety of utilitarian tasks, such as plowing snow, hauling loads, cutting grass and other high load activities. As a result, when operated over the Class II or III motorcycle test cycle, these vehicles operate under a much higher load than would be typically expected in real-world operating conditions. Operating under higher loads means the engine runs at a richer air and fuel mixture and generates higher levels of emissions. We received comments from manufacturers stating that if keep the FTP as the main ATV test cycle, that we should only require the Class I cycle, similar to California. As a result of these comments and our own experience testing various ATVs over the FTP, we have decided to require Class I motorcycle test cycle rather than using all three cycles depending on the engine displacement as proposed.

Some manufacturers have noted that they do not currently have chassis-based test facilities capable of testing ATVs. Manufacturers have noted that requiring chassis-based testing for ATVs would require them to invest in additional testing facilities which can handle ATVs, since ATVs do not fit on the same chassis dynamometer roller(s) as motorcycles used in chassis testing. Some manufacturers also have stated that low pressure tires on ATVs would not stand up to the rigors of a chassis dynamometer test. California provides manufacturers with the option of certifying ATVs using the engine-based, utility engine test procedure (SAE J1088), and most manufacturers use this option for certifying their ATVs. Manufacturers have facilities to chassis test motorcycles and therefore California does not provide an engine testing certification option for off-highway motorcycles.

We have tested numerous ATVs over the FTP and have found that several methods can be used to test ATVs on chassis dynamometers. The most practical method for testing an ATV on a motorcycle dynamometer is to disconnect one of the drive wheels and test with only one drive wheel in contact with the dynamometer. For chassis dynamometers set-up to test light-duty vehicles, wheel spacers or a wide axle can be utilized to make sure the drive wheels fit the width of the dynamometer. We have found that the low pressure tires have withstood dynamometer testing without any problems.

We acknowledge that a chassis dynamometer could be costly to purchase and difficult to put in place in the short run, especially for some smaller manufacturers. ATV manufacturers may therefore certify using the J1088 engine test cycle per the California off-highway motorcycle and ATV program for the model years 2006 through 2008. After 2008, this option expires and the FTP becomes the required test cycle. If manufacturers can develop an alternate transient test cycle (engine or chassis) that shows correlation with the FTP or demonstrates representativeness of actual ATV operation greater than the FTP, then, through rulemaking, we would consider allowing the option of an alternative test cycle in place of the FTP.

4.4.4 Small Displacement Engines

For small displacement ATVs of 70 cc or less, we proposed that they would have the permanent option to certify to the proposed FTP-based ATV standards or meet the Phase 1 Small SI emission standards for non-handheld Class 1 engines. These standards are 16.1 g/kW-hr HC+NOx and 610 g/kW-hr CO. Manufacturers argued that ATVs with engine displacements between 70 cc and 99 cc also should be allowed to certify to the Small SI standards, since the differences between a 70 cc and 99 cc engine is very small and the ATVs equipped with 99 cc engines face the same obstacles with the FTP test cycle as the 70 cc and below ATVs. They also argued that the Phase 1 Small SI standards are too stringent for these engines and recommended that EPA adopt the Phase 2 standards for Class 1B engines of 40 g/kW-hr for HC+NOx and 610 g/kW-hr for CO.

We recognize that the vast majority of engine families, including 4-stroke engines, below 100 cc are not certified to the California standards, which is an indication to us that the standards proposed may not be feasible for most engines in this size range given the lead time provided. However, manufacturers did not provide supporting data and we do not have data to confirm that the level recommended by the manufacturers would result in an appropriate level of control. We examined the 2002 model year certification data for non-handheld Small SI engines certified to the Phase 2 Class I-A and I-B engine standards (engines below 100 cc)and found that the five engine families certified to these standards had average emissions for HC+NOx of about 25 g/kW-hr (see Table 4.4-6). All of these engine families had CO emissions below 500 g/kW-hr and well below the 610 g/kW-hr level recommended by manufacturers.

Table 4.4-6
2002 Certification Data for Non-Handheld Small SI Phase 2 Class I-A and I-B Engines

Manufacturer	Engine Family	Displacement	HC+NOx (g/kW-hr)	CO (g/kW-hr)
Honda	2HNXS.0224AK	22.2	31.6	329.8
MTD Southwest	2MTDS.0264Y2	26.2	14.7	483.2
Honda	2HNXS.0314AK	31.1	41.0	391.4
Honda	2HNXS.0574AK	49.4	25.4	372.1
Honda	2HNXS.0991AK	98.5	13.4	445.3
Average			25.2	404.4

We believe these levels are more representative of the levels that can be achieved with the lead time provided through the use of 4-stroke engines than the standards recommended by the manufacturers. Since we are offering averaging with the HC+NOx standard, a standard based on the average of 25.0 g/kW-hr for the five engine families is appropriate for ATVs with an engine displacement under 99 cc. Since we are not offering an averaging program for CO emissions, it is apparent from the above data that a standard of 400 g/kW-hr would be very difficult for these smaller ATV engines to achieve. Therefore, based on the above data, we believe that a standard of 500 g/kW-hr can be achieved with engines under 99 cc. We believe these standards can be meet through the use of the various technologies described above.

4.4.5 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Virtually all ATVs are equipped sound suppression systems or mufflers. The four-stroke engines used in ATVs are considerably more quiet than two-stroke engines. Electronically controlled fuel systems are able to improve management of the combustion event which can further help lower noise levels.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke ATV is 20-25 mpg, while the average four-stroke ATV gets 30-50 mpg.

We believe the technology discussed here would have no negative impacts on safety. Four-stroke engine technology has been utilized on ATVs for numerous years without any incident. Secondary air and catalysts have been utilized in highway motorcycles and lawn and garden equipment without any safety concerns.

4.4.6 Conclusion

We expect that the ATV emission standards will largely be met through the conversion of two-stroke engines to four-stroke engines and with some minor carburetor calibration modifications and air-fuel ratio enleanment, combined with some use of pulse air injection for the four-stroke engines which now dominate this market. Our test data indicates that ATVs can have a wide variety of emissions performance. Some models are very clean and will require a relatively minor improvement to meet our standards. Other ATVs, especially larger heavier utility models, will require substantially more work. Our development testing indicates that control strategies such as carburetor enleanment and pulse air injection can significantly reduce emissions. In particular, these strategies are a path to allow most ATV models to meet a HC+NOx standard of 1.5 g/km with due consideration to useful life requirements and compliance margins most manufacturers adopt for various reasons. The other main control strategy that we examined was the use of catalysts. While it is well known that catalysts can significantly reduce exhaust emissions, the results that we had in our testing program fell short of complete success. For numerous reasons, including lack of time and hardware, we were unsuccessful at getting all of our test ATVs to meet our proposed HC+NOx standard of 1.0 g/km. We believe further investigation is warranted. However, due to scheduling concerns, we did not have the time to complete this investigation. As a result, we have decided to postpone the setting of phase 2 standards at this time. We plan to continue to investigate the emission reduction capabilities of ATVs and may establish a second phase of standards in the future.

We are confident that control strategies such as the use of a four-stroke engine with carburetor enleanment and pulse air injection can easily meet our HC+NOx emission standard of 1.5 g/km even with a 20-percent headroom to accommodate production variability and deterioration by the 2006 model year. That is why we are, for now, establishing a single set of standards for ATVs of 1.5 g/km HC+NOx and 25 g/km CO. These technologies have been utilized in a number of different applications, such as highway motorcycles, personal watercraft, lawn and garden equipment, and small scooters. These technologies also have potential benefits beyond emission reductions (e.g., improved fuel economy, reliability and performance, and reduced noise).

4.5 Off-Highway Motorcycles

The following paragraphs summarize the data and rationale supporting the emission standards for off-highway motorcycles, which are listed in the Executive Summary.

4.5.1 Baseline Technology and Emissions

Off-highway motorcycles are similar in appearance to highway motorcycles, but there are several important distinctions between the two types of machines. Off-highway motorcycles are not street-legal and are primarily operated on public and private lands over trails and open land. Off-highway motorcycles tend to be much smaller, lighter and more maneuverable than their larger highway counterparts. They are equipped with relatively small-displacement single-cylinder two- or four-stroke engines ranging from 50 to 650 cubic centimeters (cc). The exhaust systems for off-highway motorcycles are distinctively routed high on the frame to prevent damage from brush, rocks, and water. Off-highway motorcycles are designed to be operated over varying surfaces, such as dirt, sand, and mud, and are equipped with knobby tires which provide better traction in off-road conditions. Unlike highway motorcycles, off-highway motorcycles have fenders mounted far from the wheels and closer to the rider to keep dirt and mud from spraying the rider and clogging between the fender and tire. Off-highway motorcycles are also equipped with a more advanced suspension system than those for highway motorcycles. This allows the operator to ride over obstacles and make jumps safely. This advanced suspension system tends to make off-highway motorcycles much taller than highway motorcycles, in some cases up to a foot taller.

Thirty percent of off-highway motorcycle sales are generally considered to be competition motorcycles. The vast majority of competition off-highway motorcycles are two-strokes. The CAA requires us to exempt from our regulations vehicles used for competition purposes. The off-highway motorcycles that remain once competition bikes are excluded are recreational trail bikes and small-displacement youth bikes. The majority of recreational trail bikes are equipped with four-stroke engines. Youth off-highway motorcycles are almost evenly divided between four-stroke and two-stroke engines.

The fuel system used on off-highway motorcycles, whether two- or four-stroke, are almost exclusively carburetors, although at least one manufacturer has introduced a four-stroke off-highway motorcycle with electronic fuel injection. Although many off-highway motorcycles are four-stroke equipped, they still can have relatively high levels of HC and extremely high levels of CO, because many of them operate with a “rich” air and fuel mixture, which enhances performance and allows engine cooling which promotes longer engine life. This is also true for two-stroke equipped off-highway motorcycles. Rich operation results in high levels of HC, CO, and PM emissions. In addition, two-stroke engines lubricate the piston and crankshaft by mixing oil with the air and fuel mixture. This is accomplished by most contemporary two-stroke engines with a pump that sends two-cycle oil from a separate oil reservoir to the carburetor where it is mixed with the air and fuel mixture. Some less expensive two-stroke engines require that the oil be mixed with the gasoline in the fuel tank. Because two-stroke engines tend to have high scavenging losses, where up to a third of the unburned air and fuel mixture goes out of the exhaust, lubricating oil particles are also released into the atmosphere, becoming HC particles or particulate matter (PM). The scavenging losses also result in high levels of raw HC. This is in contrast to four-stroke engines that use the crankcase as an oil sump and a pump to distribute oil throughout the engine, resulting in virtually no PM.

We tested six high-performance two-stroke motorcycles and four high-performance four-stroke motorcycles over the FTP. Tables 4.5-1 and 4.5-2 shows that the HC emissions for the four-stroke bikes is significantly lower than for the two-stroke bikes, whereas the NOx emissions from the two-strokes were a bit lower. The CO levels were also considerably lower for the four-stroke bikes.

Table 4.5-1
Four-Stroke Off-Highway Motorcycles Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
Yamaha	WR250F	2001	249 cc	1.46	26.74	0.110
Yamaha	WR400F	1999	398 cc	1.07	20.95	0.155
KTM	400EXC	2001	398 cc	1.17	28.61	0.050
Husaberg	FE501	2001	498 cc	1.30	25.81	0..163
Average				1.25	25.52	0.109

Table 4.5-2
Two-Stroke Off-Highway Motorcycles Emissions (g/km)

Make	Model	Model Year	Eng. Displ.	HC	CO	NOx
KTM	125SX	2001	124 cc	33.77	31.00	0.008
KTM	125SX	2001	124 cc	61.41	32.43	0.011
KTM	200EXC	2001	198 cc	53.09	39.89	0.025
KTM	250SX	2001	249 cc	62.89	49.29	0.011
KTM	250EXC	2001	249 cc	59.13	40.54	0.016
KTM	300EXC	2001	398 cc	47.39	45.29	0.012
Average				52.95	39.74	0.060

4.5.2 Potentially Available Off-Highway Motorcycle Technologies

A variety of technologies are currently available or in stages of development to be available for use on two-stroke off-highway motorcycles, such as engine modifications, improvements to carburetion (improved fuel control and atomization, as well as improved production tolerances), enleanment strategies for both carbureted and fuel injected engines, and semi-direct and direct fuel injection. However, it is our belief that manufacturers will, in most cases, choose to convert their two-stroke engines to four-stroke applications, because of the cost and complexity of the above mentioned technologies necessary to make a two-stroke engine meet our standards. For our standards, we believe that a four-stroke engine with minor improvements to carburetion and enleanment strategies will be all that is required. Each of these is discussed in the following sections.

4.5.2.1 Engine Modifications

There are a variety of engine modifications that could reduce emissions from two-stroke and four-stroke engines. The modifications generally either increase trapping efficiency (i.e., reduce fuel short-circuiting) or improve combustion efficiency. Those modifications for two-stroke engines that increase trapping efficiency include optimizing the intake, scavenge and exhaust port shape and size, and port placement, as well as optimizing port exhaust tuning and bore/stroke ratios. Optimized combustion charge swirl, squish and tumble would serve to improve the combustion of the intake charge for both two- and four-stroke engines. Manufacturers have indicated that these modifications for two-stroke engines have the potential to reduce emissions by up to 40 percent, depending on how well the unmodified engine is optimized for these things, but would be insufficient alone to meet our standards[aa].

4.5.2.2 Carburetion Improvements

There are several things that can be done to improve carburetion in off-highway motorcycle engines. First, strategies to improve fuel atomization would promote more complete combustion of the fuel/air mixture. Additionally, production tolerances could be improved for more consistent fuel metering. Both of these things would allow for more accurate control of the air/fuel ratio. In conjunction with these improvements in carburetion, the air/fuel ratio could be leaned out some. Off-highway motorcycle engines are currently calibrated with rich air/fuel ratios for durability and performance reasons. According to manufacturers, leaner calibrations would serve to reduce CO and HC emissions by up to 20 percent, depending on how lean the unmodified engine is prior to recalibration[bb]. Small improvements in fuel economy could also be expected with recalibration.

The calibration changes just discussed (as well as some of the engine modifications previously discussed) could create concerns about off-highway motorcycle engine durability. There are many engine improvements that could be made to regain any lost durability that occurs with leaner calibration. These include changes to the cylinder head, pistons, pipes and ports for two-stroke and valves for four-stroke, to reduce knock. In addition, critical engine components could be made more robust with improvements such as better metallurgy to improve durability.

Carburetion improvements alone will not allow manufacturers to meet our standards,

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[aa] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

[bb] See “Memo to Docket on Technical Discussions with Recreational Vehicle Manufacturers,” from Linc Wehrly. Docket A-2000-01, IV-B-43.

especially for two-stroke engines. Carburetion improvements with four-stroke engines may be necessary.

The same calibration changes to the air/fuel ratio just discussed for carbureted engines could also be employed, possibly with more accuracy, with the use of fuel injection. At least one off-highway motorcycle manufacturer currently employs electronic fuel injection on one of its models.

4.5.2.3 Direct and Semi-Direct Fuel Injection

In addition to rich air/fuel ratios, one of the main reasons that two-stroke engines have such high levels of HC emissions is scavenging losses, as described above. One way to reduce or eliminate such losses is to inject the fuel into the cylinder after the exhaust port has closed. This can be done by injecting the fuel into the cylinder through the transfer port (semi-direct injection) or directly into the cylinder (direct injection). Both of these approaches are currently being used successfully in two-stroke personal watercraft engines and some are showing upwards of 70 percent reductions in emissions. Direct injection is also being used by some motorcycle manufacturers (e.g., Aprilla) on small mopeds, scooters, and motorcycles to meet emission standards for two-strokes in Europe and Asia. As discussed above, a small start-up company called Rev! Motorcycles is planning in the near future to manufacture two-stroke high-performance recreational and competition off-highway motorcycles utilizing direct fuel injection. Rev! claims they will be able to meet our optional HC+NOx standard of 4.0 g/km. They have provided limited data based on computer simulation of what they expect their technology to achieve.[26]

Substantial improvements in fuel economy could also be expected with direct injection. However, there are some issues with off-highway motorcycle operation (larger displacement engines that experience more transient operation than watercraft and small mopeds) that make the application of the direct injection technologies somewhat more challenging for motorcycles than for personal watercraft and small displacement scooters. The biggest obstacle for this technology is that the many of the two-stroke equipped off-highway motorcycles are youth models which emphasize low price. Rev! acknowledges that direct injection is expensive and their motorcycle will have a premium price, but they expressed confidence that the success of their system would attract customers and the cost of the system would eventually go down.

4.5.2.4 Four-Stroke Engines

Four-stroke engines produce significantly lower levels of HC emissions than two-stroke engines. This is primarily due to the fact that two-stroke engines experience high scavenging losses that allow up to a third of the unburned air and fuel mixture to escape into the atmosphere during the combustion process. Since four-stroke engines have a valve-train system and introduce the air and fuel mixture into the combustion chamber when the exhaust valve is closed or almost closed, there is very little scavenging of unburned fuel. Thus, four-stroke engines have superior HC control to conventional two-stroke engines. Four-stroke engines have comparable

CO performance to two-stroke engines. CO emissions result from incomplete combustion due to an excess of fuel in the air and fuel mixture. Thus, CO emissions are a function of air and fuel mixture. Current unregulated four-stroke and two-stroke engines both operate with a rich air and fuel mixture, resulting in high levels of CO emissions. Therefore, four-stroke engines do not have inherently low CO emission levels. Four-stroke engines also generate higher NOx emission levels than two-stroke engines. This is because NOx emissions are a function of temperature. Higher combustion temperatures generate higher NOx emission levels. Four-stroke engines have more complete combustion than conventional two-stroke engines, which results in higher combustion temperatures and higher NOx emission levels. Thus, four-stroke engines are an excellent choice for significantly reducing HC emissions. However, to reduce CO emissions, a four-stroke engine may need some fuel system calibration changes, engine modifications, or the use of secondary air or a catalyst. To reduce Nox emissions from a four-stroke engine would require fuel system calibration changes, engine modifications, exhaust gas recirculation (EGR), or a catalyst.

We expect that the conversion of off-highway motorcycle models utilizing two-stroke engines to four-stroke engines will be the main method of achieving our off-highway motorcycle standards. As with ATVs, the question of feasibility for four-stroke engines in off-highway motorcycles is moot, since more than half of the existing off-highway models are already four-stroke and, in some cases, have been for a long time. Honda has used four-stroke engines in all of their off-highway motorcycles (except for their competition motocross bikes) for over thirty years. In fact, over the last 5 to 10 years, the trend has been to slowly replace two-stroke models with four-stroke engines. Although the California emission standards have had some impact on this trend, it has been minor. Four-stroke engines are more durable, reliable, quieter and get far better fuel economy than two-stroke engines. But probably the single most important factor in the spread of the four-stroke engine has been major advances in weight reduction and performance.

Four-stroke engines typically weigh more than two-stroke engines because they need a valve-train system, consisting of intake and exhaust valves, camshafts, valve springs, valve timing chains and other components, as well as storing lubricating oil in the crankcase. Since a four-stroke engine produces a power-stroke once every four revolutions of the crankshaft, compared to a two-stroke which produces one once every two revolutions, a four-stroke engine of equal displacement to a two-stroke engine produces less power, on the average of 30 percent less. So in the past, off-highway motorcycles that used four-stroke engines tended to use very heavy, large displacement engines, but yet had average power and performance. However, recent breakthroughs in technologies have allowed manufacturers to design off-highway motorcycles that use lighter and stronger materials for the engine and the motorcycle frame. The advanced four-stroke technologies, such as multiple valves, used in some of the high-performance four-stroke highway motorcycles, have found their way onto off-highway motorcycles, resulting in vastly improved performance. The newer four-stroke bikes also tend to have an engine power band or range that is milder of more forgiving than a typical two-stroke bike. Two-stroke bikes tend to run poorly at idle and during low load situations. They also typically generate low levels of torque at low to medium speeds, whereas four-stroke bikes traditionally generate a great deal of low-end and mid-range torque. This is important to off-highway motorcycle riders because it is common when riding off-highway motorcycles on trails or other surfaces to come across obstacles that require slow speed maneuverability. A two-stroke engine that idles poorly and has poor low-end torque can easily stall during these maneuvers, whereas a four-stroke bike excels under these conditions. Current sales figures, as well as articles in off-highway motorcycle trade magazines, indicate that four-stroke off-highway motorcycles are more popular than ever.

4.5.2.5 Air Injection

Secondary pulse air injection involves the introduction of fresh air into the exhaust pipe immediately after the gases exit the engine. The extra air causes further combustion to occur as the gases pass through the exhaust pipe, thereby controlling more of the hydrocarbons that escape the combustion chamber. This type of system is relatively inexpensive and uncomplicated because it does not require an air pump; air is drawn into the exhaust through a one-way reed valve due to the pulses of negative pressure inside the exhaust pipe. Secondary pulse-air injection is one of the most effective non-catalytic, emissions control technologies; compared to engines without the system, reductions of 10-40% for HC are possible with pulse-air injection.

This technology is fairly common on highway motorcycles and is used on some off-highway motorcycle models in California to meet the California off-highway motorcycle and ATV emission standards. We believe that secondary air injection should not be necessary to meet our standards, however, some manufacturers may choose to use it on some four-stroke engine models.

4.5.2.6 Catalyst Technology

We do not believe catalysts will be necessary to meet our standards of 2.0 g/km HC+NOx and 25.0 g/km CO. We did not pursue standards that would require catalyst technology for off-highway motorcycles because we do not believe that potential safety and durability issues with catalysts for off-highway motorcycle applications have been adequately addressed. As discussed above in Section 4.4.2.6, to meet our proposed Phase 2 ATV standard of 1.0 g/km HC+NOx would require a design goal of 0.6 to 0.7 g/km HC+NOx to account for certification compliance margin and emission system deterioration. Although we did not perform any testing of off-highway motorcycles with catalysts, the results from our ATV testing gave us additional concern over the viability of catalysts with off-highway motorcycles. For the Polaris Sportsman (HO), a large 500 cc utility ATV model, we were unable to successfully reduce HC+NOx emissions below 1.3 g/km using a production three-way catalyst from a federally certified 900 cc highway motorcycle. The catalysts were larger in volume, precious metal loading, and physical size than we had initially projected would be necessary for ATVs. The physical size of these catalysts were well beyond what would be considered acceptable for off-highway motorcycle applications.

The highway motorcycle that the production catalysts were from weighs around 450 pounds. Typical four-stroke off-highway motorcycles weigh between 225 and 280 pounds. The exhaust system, and thus the catalyst, were routed low to the ground where the extra weight would be least noticeable. For a four-stroke off-highway motorcycle, the exhaust pipe is routed high on the frame to provide a better center of gravity and keep the exhaust pipe away from water, rocks, logs, and other items that could damage the pipe. Placing such a large catalyst in a four-stroke off-highway motorcycle would pose problems of extra weight and packaging, since it is difficult to find locations in the exhaust pipe to place a large catalyst so that it wouldn't interfere with the rider.

We have concerns about the safety and durability of catalysts in off-highway motorcycle applications. As discussed above, off-highway motorcycles operate in very harsh conditions. They experience extreme shock and jarring that can easily damage a catalyst. It is very common for off-highway motorcycles to come into contact with rocks, logs, stumps, and trees through the course of regular riding activities or accidentally in the form of a crash. The substrate of a catalyst can be very fragile, depending on the material used. We are unaware of any data on the durability of a catalyst under such harsh operating conditions. There currently are no off-highway motorcycle models equipped with a catalyst and we know of no studies performed on the long term durability of a catalyst in an off-highway motorcycle application.

Catalysts operate at very high temperatures which can be a concern for burning the rider or potentially starting a fire in the riding environment that they frequent, such as forests and grassy fields. While heat shields may possibly prevent the rider from burns, there is the problem of where to locate the catalyst so that the catalyst is not in the way of the rider adding concern over potential burns. Off-highway motorcycles are much taller than highway motorcycles. In fact, for some shorter riders they are unable to touch the ground with both feet when straddling their off-highway motorcycle. This can be an additional concern for potential catalyst burns and where to locate the catalyst. Because the motorcycle is so tall, the rider often has to lean to one side or another of the bike to keep their balance when the motorcycle is not moving. It is imperative that the catalyst not be located in a manner that would exacerbate the possibility of burning the rider or interfering with the riders balance when standing still on the motorcycle. There is also a question over the durability of heat shields in these harsh applications. Heat shields used for many highway vehicle applications are not designed for the extreme conditions that these vehicles operate in. Again, we are not aware of any data that demonstrates the effectiveness of catalyst heat shields for off-highway motorcycles.

4.5.3 Test Procedure

For off-highway motorcycles, we specify the current highway motorcycle test procedure for measuring emissions. The highway motorcycle test procedure is the same test procedure as that used for light-duty vehicles (i.e., passenger cars and trucks) and is referred to as the Federal Test Procedure (FTP). The FTP for a particular class of engine or equipment is actually the aggregate of all of the emissions tests that the engine or equipment must meet to be certified. However, the term FTP has also been used traditionally to refer to the exhaust emission test based on the Urban Dynamometer Driving Schedule (UDDS), also referred to as the LA4 (Los Angeles Driving Cycle #4). The UDDS is a chassis dynamometer driving cycle that consists of numerous "hills" which represent a driving event. Each hill includes accelerations, steady-state operation, and decelerations. There is an idle between each hill. The FTP consists of a cold start UDDS, a 10 minute soak, and a hot start. The emissions from these three separate events are collected into three unique bags. Each bag represents one of the events. Bag 1 represents cold transient operation, bag 2 represents cold stabilized operation, and bag 3 represents hot transient operation.

In the California program, highway motorcycles are divided into three classes based on engine displacement, with Class I (50 to 169 cc) being the smallest and Class III (280 cc and over) being the largest. The highway motorcycle regulations allow Class I motorcycles to be tested on a less severe UDDS cycle than the Class II and III motorcycles. This is accomplished by reducing the acceleration and deceleration rates on some the more aggressive "hills." We are applying this same class/cycle distinction for off-highway motorcycles. In other words, off-highway motorcycles with an engine displacement between 50 and 279 cc (Class I and II) must be tested over the Class I highway motorcycle FTP test cycle. Off-highway motorcycles with engine displacements greater than 280 cc would be tested over the Class III highway motorcycle FTP test cycle.

4.5.4 Impacts on Noise, Energy, and Safety

The Clean Air Act directs us to consider potential impacts on noise, energy, and safety when establishing the feasibility of emission standards for nonroad engines.

As automotive technology demonstrates, achieving low emissions from spark-ignition engines can correspond with greatly reduced noise levels. Virtually all recreational off-highway motorcycles are equipped with sound suppression systems or mufflers. The four-stroke engines used in off-highway motorcycles are considerably more quiet than the two-stroke engines used.

Adopting new technologies for controlling fuel metering and air-fuel mixing will lead to substantial improvements in fuel consumption rates for four-stroke engines. Four-stroke engines have far less fuel consumption than two-stroke engines. Average mileage for a baseline two-stroke off-highway motorcycle is 20-25 mpg, while the average four-stroke off-highway motorcycle gets 45-50 mpg.

We believe the technology discussed here would have no negative impacts on safety. Four-stroke engine technology has been utilized on off-highway motorcycles for numerous years without any incident. Secondary air and catalysts have been utilized in highway motorcycles and lawn and garden equipment without any safety concerns.

4.5.5 Conclusion

We expect that the off-highway motorcycle emission standards will largely be met through the conversion of two-stroke engines to four-stroke engines with some minor carburetor calibration modifications and air-fuel ratio enleanment for some four-strokes. Four-stroke engines are common in many off-highway motorcycles and have been used for many years. Certification data from California's off-highway program presented below in Table 4.5-3, as well as data from our own testing (see Table 4.5-1 above) suggest that four-stroke engines with some minor fuel system calibration modifications will be capable of meeting our emission standards even when considering production variability and deterioration. We believe the current sales volumes of two-stroke off-highway motorcycles, combined with the cost to modify two-stroke engines for significant emission reductions, will discourage the use of two-stroke engine technology.

Table 4.5-3
2001 Model Year California Off-highway Motorcycle Certification Data (g/km)

Manufacturer	Model*	Engine Disp.	HC	CO
Honda	XR650R	650 cc	1.0	11.7
Honda	XR400R	400 cc	0.5	6.2
Honda	XR200R	200 cc	0.7	6.8
Honda	XR100R	100 cc	0.8	4.9
Honda	XR80R	80 cc	0.6	6.3
Honda	XR70R	70 cc	0.8	8.2
Honda	XR50R	50 cc	1.0	8.6
Kawasaki	KLX300	300 cc	1.0	5.1
Yamaha	TT-R250	250 cc	0.7	10.9
Yamaha	TT-R225	225 cc	0.7	12.4
Yamaha	TT-R125	125 cc	0.8	5.1
Yamaha	TT-R90	90 cc	0.8	4.9

* All models are four-stroke

4.6 Permeation Control from Recreational Vehicles

The following paragraphs summarize the data and rationale supporting the permeation emission standards for recreational vehicles, which are listed in the Executive Summary.

4.6.1 Baseline Technology and Emissions

4.6.1.1 Fuel Tanks

Recreational vehicle fuel tanks are generally blow-molded or injection-molded using high density polyethylene (HDPE). Data on the permeation rates of fuel through the walls of polyethylene fuel tanks shows that recreational vehicle HDPE fuel tanks have very high permeation rates compared to those used in automotive applications. We tested four ATV fuel tanks in our lab for permeation. We also tested three portable marine fuel tanks and two portable gas cans which are of similar construction. This testing was performed at 29°C (85°F) with gasoline. Prior to testing, the fuel tanks had been stored with fuel in them for more than a month to stabilize the permeation rate. The permeation rates are presented in Table 4.6-1. The average for these ten fuel tanks is 1.32 grams per gallon per day.

Table 4.6-1: Permeation Rates for Plastic Fuel Tanks Tested by EPA at 29°C

Tank Capacity [gallons]	Permeation Loss [g/gal/day]	Tank Type
1.3	1.66	all terrain vehicle
1.3	2.90	all terrain vehicle
1.8	1.29	all terrain vehicle
2.1	2.28	all terrain vehicle
5.3	1.00	all terrain vehicle
6.0	0.61	portable marine
6.0	1.19	portable marine
6.0	0.78	portable marine
6.6	0.77	portable fuel container
6.6	0.75	portable fuel container

The California Air Resources Board (ARB) investigated permeation rates from portable fuel containers and lawn & garden equipment fuel tanks. Although this testing was not on recreational vehicle fuel tanks, the fuel tanks tested are of similar construction. The ARB data is compiled in several data reports on their web site and is included in our docket.[27,28,29,30,31] Table 4.6-2 presents a summary of this data which was collected using the ARB test procedures described in Section 4.6.3. Although the test temperature is cycled from 18 - 41°C rather than held at a constant temperature, the results would likely be similar if the data were collected at the average temperature of 29°C used in the EPA testing. The average for these 36 fuel tanks is 1.07 grams per gallon per day.

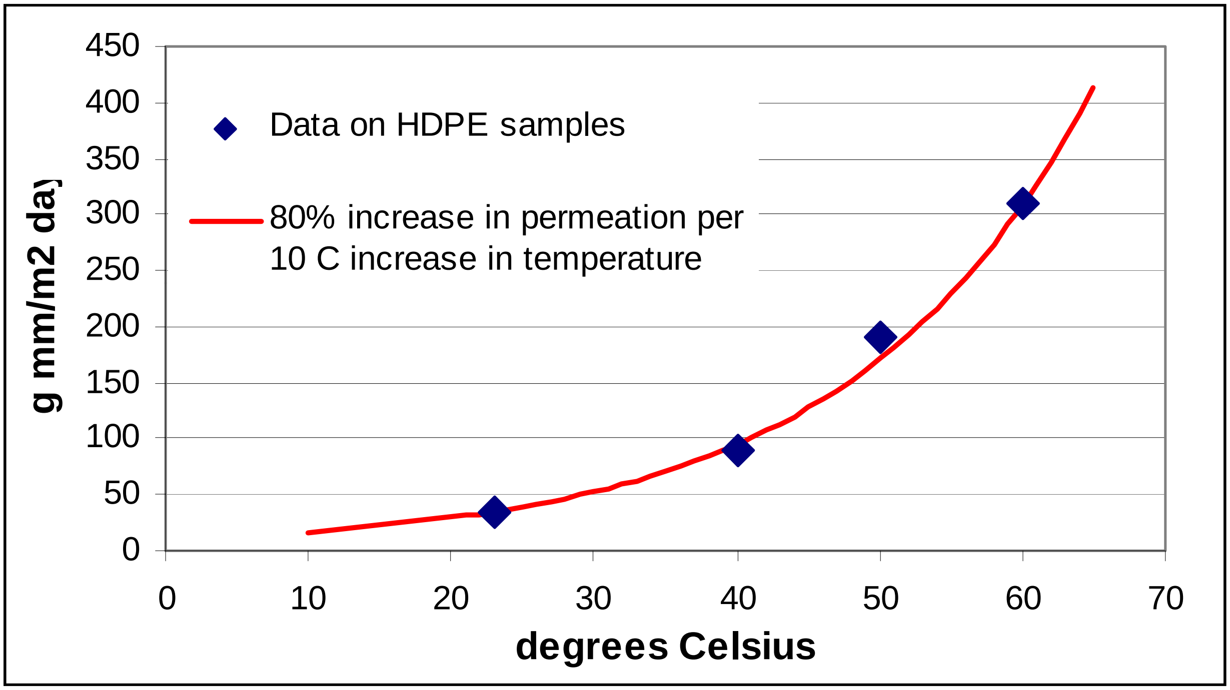
Table 4.6-2: Permeation Rates for Plastic Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Tank Capacity [gallons]	Permeation Loss [g/gal/day]	Tank Type
1.0	1.63	portable fuel container
1.0	1.63	portable fuel container
1.0	1.51	portable fuel container
1.0	0.80	portable fuel container
1.0	0.75	portable fuel container
1.0	0.75	portable fuel container
1.3	0.50	portable fuel container
1.3	0.49	portable fuel container
1.3	0.51	portable fuel container
1.3	0.52	portable fuel container
1.3	0.51	portable fuel container
1.3	0.51	portable fuel container
1.3	1.51	portable fuel container
1.3	1.52	portable fuel container
1.4	1.27	lawn & garden
1.7	0.67	lawn & garden
2.1	1.88	portable fuel container
2.1	1.95	portable fuel container
2.1	1.91	portable fuel container
2.1	1.78	portable fuel container
2.5	1.46	portable fuel container
2.5	1.09	portable fuel container
3.9	0.77	lawn & garden
3.9	0.88	lawn & garden
5.0	0.89	portable fuel container
5.0	0.62	portable fuel container
5.0	0.99	portable fuel container
5.0	0.55	lawn & garden
5.0	0.77	lawn & garden
5.0	0.64	lawn & garden
5.0	1.39	portable fuel container
5.0	1.46	portable fuel container
5.0	1.41	portable fuel container
5.0	1.47	portable fuel container
6.6	1.09	portable fuel container
7.5	0.35	lawn & garden

It is well known that the rate of permeation is a function of temperature. For most materials, permeability increases by about a factor of 2 for every 10°C increase in temperature.[32] Based on data collected on HDPE samples at four temperatures,[33,34] we estimate that the permeation of gasoline through HDPE increases by about 80 percent for every 10°C increase in temperature. This relationship is presented in Figure 4.6-1, and the numeric data can be found in

Section 4.6.2.3.

Figure 4.6-1: Effect of Temperature on HDPE Permeation



Based on the data from 46 fuel tanks in Tables 8.4-1 and 8.4-2, the average permeation rate at 29°C is 1.12 grams per gallon per day. However, the standard is based on units of grams per square meter per day at 28°C. Based on measurements of cut away fuel tanks of this size, we have found that the wall thickness ranges from 4 to 5 mm. Using an average wall thickness of 4.5 mm and a permeation rate for HDPE of 47 g mm/m^2/day at 28°C (Figure 4.6-1) we estimate that the baseline permeation rate is about 10.4 g/m^2/day. Data presented later in this chapter (see Section 4.2.8.3) shows that the permeation rate of fuel through HDPE is fairly insensitive to the amount of alcohol in the fuel.

4.6.1.2 Fuel Hoses

Fuel hoses produced for use in recreational vehicles are generally extruded nitrile rubber with a cover for abrasion resistance. These hoses are generally designed to meet the requirements under SAE J30[35] for an R7 classification. R7 hose has a maximum permeation rate of 550 g/m^2/day at 23°C on ASTM Fuel C (50% toluene, 50% iso-octane). On a fuel containing an alcohol blend, permeation would likely be higher from these fuel hoses. R7 hose is made primarily of nitrile rubber (NBR). Based on the data presented in Section 4.2.8.3, permeation through NBR is about 50 percent higher when tested on Fuel CE10 (10% ethanol) compared to testing on Fuel C.

4.6.2 Permeation Reduction Technologies

4.6.2.1 Fuel Tanks

As discussed in Chapter 3, there are several strategies that can be used to reduce permeation from plastic fuel tanks. This section presents data collected on five permeation control strategies: sulfonation, fluorination, non-continuous barrier platelets, coextruded continuous barrier, and alternative materials.

4.6.2.1.1 Sulfonation

We tested one sulfonated, 6 gallon, HDPE, portable marine fuel tank at 29°C (85°F) with gasoline. Prior to testing, the fuel tank had been stored with gasoline in it for more than 10 weeks to stabilize the permeation rate. We measured a permeation rate of 0.08 g/gallon/day which represents more than a 90 percent reduction from baseline.

The California Air Resources Board (ARB) collected test data on permeation rates from sulfonated portable fuel containers using California certification fuel.[36] The results show that sulfonation can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 30°C. The average emission rate for the 32 sulfonated fuel tanks is 0.35 g/gal/day; however, there was a wide range in variation in the effectiveness of the sulfonation process for these fuel tanks. Some of the data outliers were actually higher than baseline emissions. This was likely due to leaks in the fuel tank which would result in large emission increases due to pressure built up with temperature variation over the diurnal cycle. Removing these five outliers, the average permeation rate is 0.17 g/gal/day with a minimum of 0.01 g/gal/day and a maximum of 0.64 g/gal/day.

Variation can occur in the effectiveness of this surface treatment if the sulfonation process is not properly matched to the plastic and additives used in the fuel tank material. For instance, if the sulfonater does not know what UV inhibitors or plasticizers are used, they cannot maximize the effectiveness of their process. In this test program, the sulfonater was not aware of the chemical make up of the fuel tanks. This is the likely reason for the variation in the data even when the obvious outliers are removed. In support of this theory, the permeation rates were consistently low for tanks provided by two of the four tank manufacturers. For these 11 fuel tanks, the average permeation rate was 0.07 which represents more than a 90 percent reduction from baseline. Earlier data collected by ARB showed consistently high emissions from sulfonated fuel tanks; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel tanks and that these issues have since been largely resolved.[37] For this reason we do not include the earlier data in this analysis. Table 4.6-3 includes all of the permeation data, including the outliers.

Table 4.6-3: Permeation Rates for Sulfonated Plastic Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Tank Capacity [gallons]	Permeation Loss [g/gal/day]
1	0.05
1	0.05
1	0.05
1	0.06
1	0.06
1	0.06
1	0.08
1	0.12
1	0.14
1	1.23
1	1.47
1	1.87
2	0.02
2	0.02
2	0.48
2	0.54
2	1.21
2.5	0.03
2.5	0.08
2.5	0.32
2.5	0.38
2.5	0.42
2.5	0.52
2.5	0.64
2.5	0.80
5	0.01
5	0.04
5	0.05
5	0.06
5	0.11
5	0.13
5	0.15

ARB also investigated the effect of fuel slosh on the durability of sulfonated surfaces. Three sulfonated fuel tanks were tested for permeation before and after being rocked with fuel in them 1.2 million times.[38] The results of this testing show that an 85% reduction in permeation was achieved on average even after the slosh testing was performed. Table 4.6-4 presents these results which were recorded in units of $g/m^2/day$. The baseline level is an approximation based on testing of similar fuel tanks.

As with earlier tests performed by ARB, the sulfonater was not aware of the materials used in the fuel tanks sulfonated for the slosh testing. After the tests were performed, the sulfonater was able to get some information on the chemical make up of the fuel tanks and how it might affect the sulfonation process. For example, the UV inhibitor used in some of the fuel tanks is known as HALS. HALS also has the effect of reducing the effectiveness of the sulfonation process. Two other UV inhibitors, known as carbon black and adsorber UV, are also used in similar fuel tank applications. These UV inhibitors cost about the same as HALS, but have the benefit of not interfering with the sulfonation process. The sulfonater claimed that if HALS were not used in the fuel tanks, a 97% reduction in permeation would have been seen.[39] A list of resins and additives that are compatible with the sulfonation process is included in the docket.[40,41]

Table 4.6-4: Permeation Rates for Sulfonated Fuel Tanks with Slosh Testing by ARB Over a 18-41°C Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Approximate Baseline	$g/m^2/day$	10.4	10.4	10.4	10.4
Sulfonated	$g/m^2/day$ % reduction	0.73 93%	0.82 92%	1.78 83%	1.11 89%
Sulfonated & Sloshed	$g/m^2/day$ % reduction	1.04 90%	1.17 89%	2.49 76%	1.57 85%

An in-use durability testing program was also completed for sulfonated HDPE fuel tanks and bottles.[42] The fuel tank had a 25 gallon capacity and was removed from a station wagon that had been in use in southern California for five years (35,000 miles). The fuel tank was made of HDPE with carbon black used as an additive. After five years, the sulfonation level measured on the surface of the plastic fuel tank did not change. Tests before and after the aging both showed a 92 percent reduction in gasoline permeation due to the sulfonation barrier compared to the permeation rate of a new untreated tank. Testing was also done on 1 gallon bottles made of HDPE with 3% carbon black. These bottles were shown to retain over a 99 percent barrier after five years. This study also looked at other properties such as yield strength and mechanical fatigue and saw no significant deterioration.

One study looked at the effect of alcohol in the fuel on permeation rates from sulfonated fuel tanks.[43] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

4.6.2.1.2 Fluorination

We tested one fluorinated, 6 gallon, HDPE, portable marine fuel tank at 29°C (85°F) with gasoline. Prior to testing, the fuel tank had been stored with gasoline in it for about 20 weeks to stabilize the permeation rate. We measured a permeation rate of 0.05 g/gallon/day which represents more than a 95 percent reduction from baseline.

The California Air Resources Board (ARB) collected test data on permeation rates from fluorinated portable fuel containers using California certification fuel.[44,45] The results, presented in Table 4.6-5, show that fluorination can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 30°C. Four different levels of fluorination treatment were tested. The average permeation rate for the 87 fluorinated fuel tanks is 0.21 g/gal/day which represents about a 75 percent reduction from baseline. However, for the highest level of fluorination, the average permeation rate was 0.04 g/gal/day which represents a 95 percent reduction from baseline. Earlier data collected by ARB showed consistently high emissions from fluorinated fuel tanks; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel tanks and that these issues have since been largely resolved.[46] For this reason we do not include the earlier data in this analysis.

Table 4.6-5: Permeation Rates for Fluorinated Plastic Fuel Containers Tested by ARB Over a 18-41°C Diurnal

Barrier Treatment*	Tank Capacity [gallons]	Permeation Loss [g/gal/day]
Level 3	1	0.04
	1	0.06
(average = 0.27 g/gal/day)	1	0.25
	2	0.12
	2	0.15
	2	0.17
	2	0.09
	2	0.15
	2	0.12
	2	0.18
	2	0.17
	2	0.14
	2	0.18
	2	0.34
	2	0.41
	2	0.41
	2	0.36
	2	0.41
	2	0.23
	2	0.29
	2	0.31

	2	0.24
	2	0.32
	2	0.16
	2	0.19
	2	0.20
	2	0.11
	2	0.20
	5	0.06
	5	0.06
	5	0.07
	5	0.09
	5	0.10
	5	0.11
	5	0.15
	5	0.23
	5	0.31
	5	0.33
	5	0.24
	5	0.33
	5	0.33
	5	0.51
	5	0.47
	5	0.41
	5	0.45
	5	0.45
	5	0.35
	5	0.37
	5	0.28
	5	0.26
	5	0.35
	5	0.35
	5	0.37
	5	0.28
	5	0.35
	5	0.41
	5	0.47
	5	0.43
	5	0.39
	5	0.47
	5	0.55
Level 4 (average =0.09 g/gal/day)	1	0.05
	1	0.05
	1	0.06
	5	0.11
	5	0.11
	5	0.15

Level 5 (average =0.07 g/gal/day)	1	0.03
	1	0.04
	1	0.05
	1	0.05
	1	0.07
	1	0.08
	1	0.11
	1	0.11
	1	0.12
	2.5	0.04
	2.5	0.04
	2.5	0.05
	2.5	0.07
	2.5	0.07
	5	0.05
	5	0.10
	5	0.11
SPAL (average =0.04 g/gal/day)	5	0.04
	5	0.04
	5	0.04

*designations used in ARB report; shown in order of increasing treatment

All of the data on fluorinated fuel tanks presented above were based on fuel tanks fluorinated by the same company. Available data from another company that fluorinates fuel tanks shows a 98 percent reduction in gasoline permeation through a HDPE fuel tank due to fluorination.[47]

ARB investigated the effect of fuel slosh on the durability of fluorinated surfaces. Three fluorinated fuel tanks were tested for permeation before and after being rocked with fuel in them 1.2 million times.[48] The results of this testing show that an 80% reduction in permeation was achieved on average even after the slosh testing was performed. However, this data also shows that an 89 percent reduction is feasible. Table 4.6-6 presents these results which were recorded in units of $g/m^2/day$. The baseline level is an approximation based on testing of similar fuel tanks.

Table 4.6-6: Permeation Rates for Fluorinated Fuel Tanks with Slosh Testing by ARB Over a 18-41°C Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Approximate Baseline	$g/m^2/day$	10.4	10.4	10.4	10.4
Fluorinated	$g/m^2/day$ % reduction	1.17 89%	1.58 85%	0.47 96%	1.07 90%
Fluorinated & Sloshed	$g/m^2/day$ % reduction	2.38 77%	2.86 73%	1.13 89%	2.12 80%

One study looked at the effect of alcohol in the fuel on permeation rates from fluorinated fuel tanks.[49] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

4.6.2.1.3 Barrier Platelets

We tested four portable gas cans molded with low permeation non-continuous barrier platelets 29°C (85°F) with gasoline. Prior to testing, the fuel tanks had been stored with gasoline in it for more than 10 weeks to stabilize the permeation rate. Table 4.6-7 presents the emission results which represent an average of nearly an 85 percent reduction from baseline.

Table 4.6-7: Permeation Rates for Plastic Fuel Containers with Barrier Platelets Tested by EPA at 29°C

Percent Selar®*	Tank Capacity [gallons]	Permeation Loss [g/gal/day]
4%	5	0.34
4%	5.3	0.10
4%	6.6	0.14
4%	6.6	0.13

*trade name for barrier platelet technology used in test program

The California Air Resources Board (ARB) collected test data on permeation rates from portable fuel containers molded with low permeation non-continuous barrier platelets using California certification fuel. The results show that this technology can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 18-41°C which is roughly equivalent to steady-state permeation testing at 30°C. Five different percentages of the barrier material were tested. The average permeation rate for the 67 fuel tanks is 0.24 g/gal/day; however, there was a wide range in variation in the effectiveness of the barrier platelets for these fuel tanks. Some of the data outliers were actually higher than baseline emissions. This was likely due to leaks in the fuel tank which would result in large emission increases due to pressure built up with temperature variation over the diurnal cycle. Removing these six outliers, the average permeation rate is 0.15 g/gal/day with a minimum of 0.04 g/gal/day and a maximum of 0.47 g/gal/day. This represents more than an 85 percent reduction from the average baseline. Table 4.6-8 includes all of the ARB test data, including the outliers.

Table 4.6-8: Permeation Rates for Plastic Fuel Containers with Barrier Platelets Tested by ARB Over a 18-41°C Diurnal

Percent Selar®*	Tank Capacity [gallons]	Permeation Loss [g/gal/day]
4%	5.00	0.08
	5.00	0.09
(average =0.12 g/gal/day)	5.00	0.13
	5.00	0.16
	5.00	0.17
	6.00	0.08
	6.00	0.10
6%	2.00	0.06
	2.00	0.07
(average =0.16 g/gal/day)	2.00	0.10
	2.00	0.10
	2.00	0.11
	2.00	0.11
	2.00	0.28
	2.00	0.44
	2.00	0.45
	2.00	0.47
	5.00	0.07
	5.00	0.07
	5.00	0.07
	5.00	0.08
	5.00	0.12
	5.00	0.17
	6.00	0.06
	6.00	0.07

8% (average =0.32 g/gal/day)	1.00	0.14
	1.00	0.17
	1.00	0.21
	1.00	0.21
	1.00	0.21
	1.00	0.65
	1.00	0.85
	1.00	0.98
	1.00	1.66
	2.00	0.04
	2.00	0.05
	2.00	0.07
	2.00	0.09
	2.00	0.12
	2.00	0.16
	2.00	0.44
	5.00	0.08
	5.00	0.10
	6.00	0.05
	6.00	0.06
10% (average =0.28 g/gal/day)	1.00	0.15
	1.00	0.19
	1.00	0.19
	1.00	0.21
	1.00	0.23
	1.00	0.26
	1.00	0.79
	1.00	0.83
	1.00	0.88
	2.00	0.06
	2.00	0.06
	2.00	0.07
	2.00	0.08
	2.00	0.13
	2.00	0.14
	2.00	0.23
12% (average =0.21 g/gal/day)	1.00	0.13
	1.00	0.14
	1.00	0.20
	1.00	0.21
	1.00	0.23
	1.00	0.35

*trade name for barrier platelet technology used in test program

The fuel containers tested by ARB used a technology known as Selar® which uses nylon as the barrier resin. Dupont, who manufacturers Selar®, has recently developed a new resin

(Selar RB®) that uses ethylene vinyl alcohol (EVOH) as the barrier resin. EVOH has much lower permeation than nylon, especially with alcohol fuel blends (see Section 4.6.2.3). Table 4.6-9 presents permeation rates for HDPE and three Selar RB® blends when tested at 60°C on xylene.[50] Xylene is a component of gasoline and gives a rough indication of the permeation rates on gasoline. This report also shows a reduction of 99% on naptha and 98% on toluene for 8% Selar RB®.

Table 4.6-9: Xylene Permeation Results for Selar RB® at 60°C

Composition	Permeation, g mm/m^2/day	% Reduction
100% HDPE	285	–
10% RB 215/HDPE	0.4	99.9%
10% RB 300/HDPE	3.5	98.8%
15% RB 421/HDPE	0.8	99.7%

4.6.2.1.4 Coextruded barrier

One study looks at the permeation rates, using ARB test procedures, through multi-layer fuel tanks.[51] The fuel tanks in this study were 6 layer coextruded plastic tanks with EVOH as the barrier layer (3% of wall thickness). The outer layers were HDPE and two adhesive layers were needed to bond the EVOH to the polyethylene. The sixth layer was made of recycled polyethylene. The two test fuels were a 10 percent ethanol blend (CE10) and a 15 percent methanol blend (CM15). See Table 4.6-10.

Table 4.6-10: Permeation Results for a Coextruded Fuel Tank Over a 18-41°C Diurnal

Composition	Permeation, g/day	% Reduction
100% HDPE (approximate)	6 - 8	–
3% EVOH, 10% ethanol (CE10)	0.2	97%
3% EVOH, 15% methanol (CM15)	0.3	96%

4.6.2.1.5 Alternative Materials

Permeation can also be reduced from fuel tanks by constructing them out of a lower permeation material than HDPE. For instance, an that would reduce permeation is the use of metal fuel tanks because gasoline does not permeate through metal. In addition, there are grades of plastics other than HDPE that could be molded into fuel tanks. One material that has been considered by manufacturers is nylon; however, although nylon has excellent permeation resistance on gasoline, it has poor chemical resistance to alcohol-blended fuels. As shown in Table 4.6-14, nylon would result in about a 98 percent reduction in permeation compared to HDPE for gasoline. However, for a 10 percent ethanol blend, this reduction would only be about 40-60 percent depending on the grade of nylon. For a 15 percent methanol blend, the permeation would actually be several times higher through nylon than HDPE.

Other materials, which have excellent permeation even with alcohol-blended fuels are acetal copolymers and thermoplastic polyesters. These polymers can be used to form fuel tanks in the blow-molding, rotational-molding, and injection-molding processes. An example of an acetal copolymer is known as Celcon® which has excellent chemical resistance to fuel and has been shown to be durable based on exposure to automotive fuels for 5000 hours at high temperatures.[52] As shown in Table 4.6-14, Celcon® would result in more than a 99 percent reduction in permeation compared to HDPE for gasoline. On a 10 percent ethanol blend, the use of Celcon® would result in more than a 95 percent reduction in permeation. Two thermoplastic polyesters, known as Celanex® and Vandar®, are being considered for fuel tank construction and are being evaluated for permeation resistance by the manufacturer.

4.6.2.2 Fuel Hoses

Thermoplastic fuel lines for automotive applications are generally built to SAE J2260 specifications.[53] Category 1 fuel lines under this specification have permeation rates of less than 25 g/m^2/day at 60°C on CM15 fuel. One thermoplastic used in automotive fuel line construction is polyvinylidene fluoride (PVDF). Based on the data presented in Section 4.6.2.3, a PDVF fuel line with a typical wall thickness (1 mm) would have a permeation rate of 0.2 g/m^2/day at 23°C on CM15 fuel. However, recreational vehicle manufacturers have commented that this fuel line would not be flexible enough to use in their applications because they require flexible rubber hose to fit tight radii and to resist vibration. In addition, using plastic fuel line rather than rubber hose would require the additional cost of changing hose fittings on the vehicles.

Manufacturers recommended using R9 fuel hose as a low permeation requirement. This hose is designated under SAE recommended practice J30[54] for fuel injection systems and has a maximum permeation rate of 15 g/m^2/day on ASTM Fuel C. On a fuel containing an alcohol blend, permeation would likely be much higher from these fuel hoses. SAE J30 specifically notes that "exposure of this hose to gasoline or diesel fuel which contain high levels, greater than 5% by volume, of oxygenates, i.e., ethanol, methanol, or MTBE, may result in significantly higher permeation rates than realized with ASTM Fuel C." R9 hose is made with a thin low permeation barrier sandwiched between layers of rubber. A typical barrier material used in this construction is FKM. Based on the data presented in Section 4.2.8.3 for FKM, the permeation rate is 3-5 times higher on Fuel CE10 than Fuel C. Therefore, a typical R9 hose meeting 15 g/m^2/day at 23°C on Fuel C may actually permeate at a level of 40-50 g/m^2/day on fuel with a 10 percent ethanol blend.

SAE J30 also designates R11 and R12 hose which are intended for use as low permeation fuel feed and return hose. R11 has thee classes known as A, B, and C. Of these, R11-A has the lowest permeation specification which is a maximum of 25 g/m^2/day at 40°C on CM15 fuel. Because permeation rates are generally higher on CM15 than CE10 and because they are 2-4 times higher at 40°C than at 23°C, hose designed for this specification would likely meet our permeation requirement. R12 hose has a permeation requirement of 100 g/m^2/day at 60°C on CM15 fuel. This is roughly equivalent in stringency as the R11-A permeation requirement.

There are lower permeation fuel hoses available today that are manufactured for automotive applications. These hoses are generally used either as vapor hoses or as short sections of fuel line to provide flexibility and absorb vibration. One example of such a hose[55] is labeled by General Motors as “construction 6" which is a multilayer hose with an inner layer of THV sandwiched in inner and outer layers of a rubber known as ECO.[cc] A hose of this construction would have less than 8 g/m^2/day at 40°C when tested on CE10. In look and flexibility, this hose is not significantly different than the SAE J30 R7 hose generally used in recreational vehicle applications.

Permeation data on several low permeation hose designs were provided to EPA by an automotive fuel hose manufacturer.[56] This hose, which is as flexible as R9 hose, was designed for automotive applications and is available today. Table 4.6-11 presents permeation data on three hose designs that use THV 800 as the barrier layer. The difference in the three designs is the material used on the inner layer of the hose. This material does not significantly affect permeation emissions through the hose but can affect leakage at the plug during testing (or connector in use) and fuel that passes out of the end of the hose which is known as wicking. The permeation testing was performed using the ARB 18-41°C diurnal cycle using a fuel with a 10 percent ethanol blend (E10).

Table 4.6-11: Hose Permeation Rates with THV 800 Barrier over ARB Cycle (g/m^2/day)

Hose Name	Inner Layer	Permeation	Wicking	Leaking	Total
CADBAR 9610	THV	0.16	0.00	0.02	0.18
CADBAR 9710	NBR	0.17	0.29	0.01	0.47
CADBAR 9510	FKM	0.16	0.01	0.00	0.18

The data presented above shows that there is hose available that can easily meet the hose permeation standard on E10 fuel. Although hose using THV 800 is available, it is produced for automobiles that will need to meet the tighter evaporative emission requirements in the upcoming Tier 2 standards. Hose produced in mass quantities today uses THV 500. This hose is less expensive and could be used to meet the recreational vehicle permeation requirements. Table 4.6-12 presents information comparing hose using THV 500 with the hose described above using THV 800 as a barrier layer.[57] In addition, this data shows that permeation rates more than double when tested on CE10 versus Fuel C. One recreational vehicle manufacturer has expressed concern to EPA that this hose may be too stiff to stay on the fuel line and fuel tank connectors without clamps as does their current fuel line. If a manufacturer opts to use this or a

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[cc] THV = tetrafluoroethylene hexafluoropropylene, ECO = epichlorohydrin/ethylene oxide

similar line, this problem will need to be resolved either through further testing, a change to the connector geometry, the use of an adhesive, or the use of one of any of several of different types of clamps.

Table 4.6-12: Comparison of Hose Permeation Rates with THV 500 and 800 (g/m^2/day)*

Hose Inner Diameter, mm	THV 500		THV 800	
	Fuel C	Fuel CE10	Fuel C	Fuel CE10
6	0.5	1.4	0.2	0.5
8	0.5	1.4	0.3	0.5
10	0.5	1.5	0.2	0.5

* Calculated using data from Thwing Albert materials testing (may overstate permeation)

We contracted with an independent testing laboratory to test a section of R9 hose and a section of automotive vent line hose for permeation.[58] These hoses had a six mm inner diameter. The test lab used the SAE J30 test procedures for R9 hose with both Fuel C and Fuel CE10. We purchased the R9 hose (which was labeled as such) from a local auto parts store. According to this testing, the R9 hose is well below the SAE specification of 15 g/m^2/day. In fact, it meets this limit on Fuel CE10 as well. The automotive vent line showed similar results. This data is presented in Table 4.6-13.

Table 4.6-13: Test Results on Commercially Available Hose Samples (g/m^2/day)

Hose Sample	Fuel C	Fuel CE10
R9	10.1	12.1
Automotive vent line	10.9	9.0

4.6.2.3 Material Properties

This section presents data on permeation rates for a wide range of materials that can be used in fuel tanks and hoses. The data also includes effects of temperature and fuel type on permeation. Because the data was collected from several sources, there is not complete data on each of the materials tested in terms of temperature and test fuel. Table 4.6-14 gives an overview of the fuel systems materials included in the data set. Tables 4.6-15 through 4.6-18 present permeation rates using Fuel C, a 10% ethanol blend (CE10), and a 15% methanol blend (CE15) for the test temperatures of 23, 40, 50, and 60°C.

Table 4.6-14: Fuel System Materials

Material Name	Composition
HDPE	high-density polyethylene
Nylon 12	thermoplastic
EVOH	ethylene vinyl alcohol, thermoplastic
Polyacetal	thermoplastic
PBT	polybutylene terephthalate, thermoplastic
PVDF	polyvinylidene fluoride, fluorothermoplastic
NBR	nitrile rubber
HNBR	hydrogenated nitrile rubber
FVMQ	flourosilicone
FKM	fluoroelastomer
FEB	fluorothermoplastic
PFA	fluorothermoplastic
Carilon	aliphatic poly-ketone thermoplastic
HDPE	high density polyethylene
LDPE	low density polyethylene
Celcon	acetal copolymer
THV	tetra-fluoro-ethylene, hexa-fluoro-propylene, vinyledene fluoride
E14659	fluoropolymer film
E14944	fluoropolymer film
ETFE	ethylene-tetrafluoro-ethylene, fluoroplastic
GFLT	fluoroelastomer
FEP	fluorothermoplastic
PTFE	polytetrafluoroethylene, fluoroplastic
FPA	copolymer of tetrafluoroethylene and perfluoroalkoxy monomer

Table 4.6-15: Fuel System Material Permeation Rates at 23°C by Fuel Type [59,60,61,62,63]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
HDPE	35	–	35
Nylon 12, rigid	0.2	–	64
EVOH	–	–	10
Polyacetal	–	–	3.1
PBT	–	–	0.4
PVDF	–	–	0.2
NBR (33% ACN)	669	1028	1188
HNBR (44%ACN)	230	553	828
FVMQ	455	584	635
FKM Viton A200 (66%F)	0.80	7.5	36
FKM Viton B70 (66%F)	0.80	6.7	32
FKM Viton GLT (65%F)	2.60	14	60
FKM Viton B200 (68%F)	0.70	4.1	12
FKM Viton GF (70%F)	0.70	1.1	3.0
FKM Viton GFLT (67%F)	1.80	6.5	14
FKM - 2120	8	–	44
FKM - 5830	1.1	–	8
Teflon FEB 1000L	0.03	0.03	0.03
Teflon PFA 1000LP	0.18	0.03	0.13
Tefzel ETFE 1000LZ	0.03	0.05	0.20
Nylon 12 (GM grade)	6.0	24	83
Nitrile	130	635	1150
FKM	–	16	–
FE 5620Q (65.9% fluorine)	–	7	–
FE 5840Q (70.2% fluorine)	–	4	–
PTFE	0.05	–	0.08*
ETFE	0.02	–	0.04*
PFA	0.01	–	0.05*
THV 500	0.03	–	0.3

* tested on CM20.

Table 4.6-16: Fuel System Material Permeation Rates at 40°C by Fuel Type [64,65]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
Carilon	0.06	1.5	13
EVOH - F101	<0.0001	0.013	3.5
EVOH - XEP380	<0.0001	–	5.3
HDPE	90	69	71
LDPE	420	350	330
Nylon 12 (L2101F)	2.0	28	250
Nylon 12 (L2140)	1.8	44	–
Celcon	0.38	2.7	–
Dyneon E14659	0.25	–	2.1
Dyneon E14944	0.14	–	1.7
ETFE Aflon COP	0.24	0.67	1.8
m-ETFE	0.27	–	1.6
ETFE Aflon LM730 AP	0.41	0.79	2.6
FKM-70 16286	11	35	–
GFLT 19797	13	38	–
Nitrile	–	1540	3500
FKM	–	86	120
FE 5620Q (65.9% fluorine)	–	40	180
FE 5840Q (70.2% fluorine)	–	12	45
THV-310 X	–	–	5.0
THV-500	0.31	–	3.0
THV-610 X	–	–	2.1

Table 4.6-17: Fuel System Material Permeation Rates at 50°C by Fuel Type [66]

Material Name	Fuel C g-mm/m^2/day	Fuel CE10 g-mm/m^2/day	CM15 g-mm/m^2/day
Carilon	0.2	3.6	–
HDPE	190	150	–
Nylon 12 (L2140)	4.9	83	–
Celcon	0.76	5.8	–
ETFE Afcon COP	–	1.7	–
FKM-70 16286	25	79	–
GFLT 19797	28	77	–

Table 4.6-18: Fuel System Material Permeation Rates at 60°C by Fuel Type [67,68,69,70]

Material Name	Fuel C $g\text{-}mm/m^2/day$	Fuel CE10 $g\text{-}mm/m^2/day$	CM15 $g\text{-}mm/m^2/day$
Carilon	0.55	7.5	–
HDPE	310	230	–
Nylon 12 (L2140)	9.5	140	–
Celcon	1.7	11	–
ETFE Afcon COP	–	3.8	–
FKM-70 16286	56	170	–
GFLT 19797	60	130	–
polyeurethane (bladder)	285	460	–
THV-200	–	54	–
THV-310 X	–	–	38
THV-510 ESD	6.1	18	35
THV-500	–	11	20
THV-500 G	4.1	10	22
THV-610 X	2.4	5.4	9.0
ETFE 6235 G	1.1	3.0	6.5
THV-800	1.0	2.9	6.0
FEP	0.2	0.4	1.1

4.6.3 Test Procedures

4.6.3.1 Fuel Tanks

Essentially, two options may be used to test fuel tanks for certification. The first option is to perform all of the durability tests on a fuel tank and then test the permeation rate. The second option is to test a fuel tank that has been preconditioned and adjust the results using a deterioration factor. The deterioration factor would need to be based on testing of that tank or a similar tank unless you can use good engineering judgment to apply the results of previous durability testing with a different fuel system. Figure 4.6-2 provides flow charts for these two options.

4.6.3.1.1 Option 1: full test procedure

Under the first option, the fuel tank is tested both before and after a series of durability tests. We estimate that this test procedure would take about 49 weeks to complete. Prior to the first test, the fuel tank must be preconditioned to ensure that the hydrocarbon permeation rate has stabilized. Under this step, the fuel tank must be filled with a 10 percent ethanol blend (E10), sealed, and soaked for 20 weeks at a temperature of 28 °C ± 5 °C. Once the permeation rate has stabilized, the fuel tank is drained and refilled with E10, sealed, and tested for a baseline permeation rate. The baseline permeation rate from the fuel tank is determined by measuring the weight difference the fuel tank before and after soaking at a temperature of 28 °C ± 2 °C over a period of at least 2 weeks.

To determine a permeation emission deterioration factor, we are specifying three durability tests: slosh testing, pressure-vacuum cycling, and ultra-violet (UV) light exposure. The purpose of these deterioration tests is to help ensure that the technology is durable and the measured emissions are representative of in-use permeation rates. For slosh testing, the fuel tank is filled to 40 percent capacity with E10 fuel and rocked for 1 million cycles. The pressure-vacuum testing contains 10,000 cycles from -0.5 to 2.0 psi. The slosh testing is designed to assess treatment durability as discussed above. These tests are designed to assess surface microcracking concerns. These two durability tests are based on a draft recommended SAE practice.[71] The third durability test is intended to assess potential impacts of UV sunlight (0.2 µm - 0.4 µm) on the durability of the surface treatment. In this test, the tank must be exposed to a UV light of at least 0.40 W-hr/m^2 /min on the tank surface for 15 hours per day for 30 days. Alternatively, it can be exposed to direct natural sunlight for an equivalent period of time in exposure hours.

The order of the durability tests is optional. However, we require that the fuel tank be soaked to ensure that the permeation rate is stabilized just prior to the final permeation test. If the slosh test is run last, the length of the slosh test may be considered as part of this soak period. Where possible, the deterioration tests may be run concurrently. For example, the fuel tank could be exposed to UV light during the slosh test. In addition, if a durability test can clearly be shown to not be appropriate for a given product, manufacturers may petition to have this test waived. For example, a fuel tank that is only used in vehicles where an outer shell prevents the tank from being exposed to sunlight may not benefit from UV testing.

After the durability testing, once the permeation rate has stabilized, the fuel tank is drained and refilled with E10, sealed, and tested for a final permeation rate. The final permeation rate from the fuel tank is determined using the same measurement method as for the baseline permeation rate. The final permeation rate would be used for the emission rate from this fuel tank. The difference between the baseline and final permeation rates would be used to determine a deterioration factor for use on subsequent testing of similar fuel tanks.

4.6.3.1.2 Option 2: base test with DF

Under the second option, the fuel tank is tested for baseline permeation only, then a deterioration factor (DF) is applied. We estimate that this test procedure would take about 22 weeks to complete. As with Option 1 baseline testing, the fuel tank must be preconditioned to ensure that the hydrocarbon permeation rate has stabilized. Under this step, the fuel tank must be filled with a 10 percent ethanol blend (E10), sealed, and soaked for 20 weeks at a temperature of 28 °C ± 5 °C. Once the permeation rate has stabilized, the fuel tank is drained and refilled with E10, sealed, and tested for a baseline permeation rate. The baseline permeation rate from the fuel tank is determined by measuring the weight difference the fuel tank before and after soaking at a temperature of 28 °C ± 2 °C over a period of at least 2 weeks.

The final permeation rate is then determined by applying a DF to the baseline permeation rate. The DF, in units of g/m^2/day, is added to the baseline permeation rate. This DF must be determined with testing on a fuel tank in the same emission family.

4.6.3.2 Fuel Hoses

The permeation rate from fuel hoses would be measured at a temperature of 23 °C ± 2 °C over a period of at least 2 weeks. A longer period may be necessary for an accurate measurement for hose with low permeation rates. Permeation would be measured through the weight loss technique described in SAE J30.[72] The hose must be preconditioned with a fuel soak to ensure that the permeation rate has stabilized. Based on times to achieve equilibrium for permeation measurement described in SAE J2260[73] for automotive fuel lines, and adjusting for temperature and test fuel type, we estimate a minimum soak time of 4 weeks. The fuel used for this testing would be a blend of 90 percent gasoline and ten percent ethanol. This fuel is consistent with the test fuel used for on-highway evaporative emission testing.

4.6.4 Conclusion

We believe that manufacturers will be able to meet the fuel tank permeation requirements through several design strategies that include sulfonation, fluorination, barrier platelets, and coextruded barriers. Our cost analysis, presented in Chapter 5, indicates that sulfonation would likely be the most attractive technology. However, conversations with manufacturers have revealed interest in each of these low permeation strategies. We believe the data presented above supports a final standard which requires about an 85% reduction in permeation, compared baseline HDPE fuel tanks, throughout the useful life of the recreational vehicle.

As discussed above, fuel hose is available today that meets the permeation requirements for recreational vehicles. Low permeation hose was generally developed for automotive applications; however, we believe that this fuel hose can be used in recreational vehicle applications. Even assuming that new hose clamps would be required, our analyses in Chapters 5 and 6 show that the low permeation hose would be inexpensive yet effective.

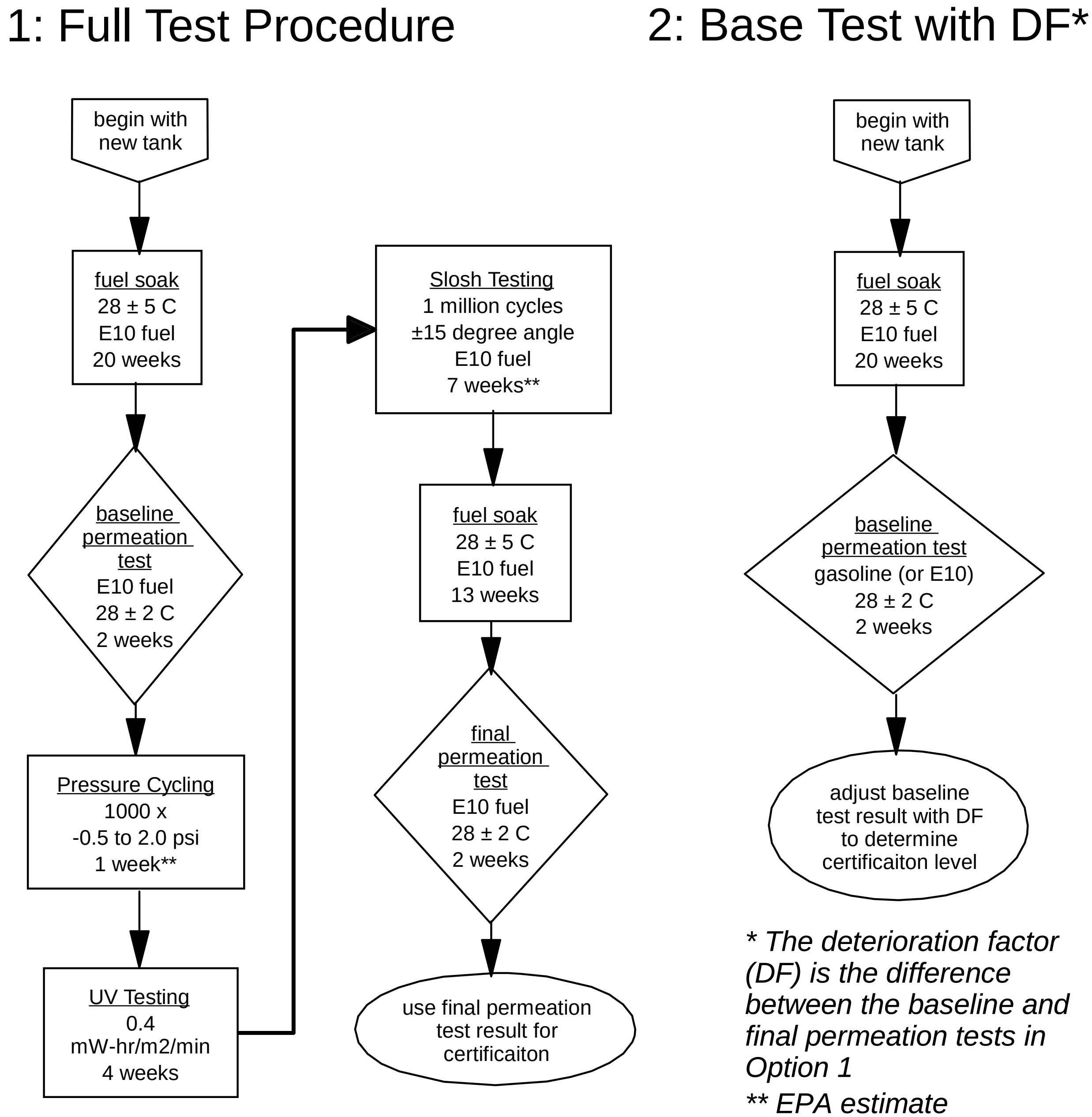
4.6.5 Impacts on Noise, Energy, and Safety

The Clean Air Act requires EPA to consider potential impacts on noise, energy, and safety when establishing the feasibility of new permeation standards for recreational vehicles. In this case, we would not expect evaporative emission controls to have any impact on noise from a vehicle because noise from the fuel system is insignificant.

We anticipate that permeation emission standards will have a positive impact on energy. By capturing or preventing the loss of fuel through permeation, we estimate that the average lifetime fuel savings will be 11.8 gallons for snowmobiles, 5.4 gallons for off-highway motorcycles and 6.5 gallons for all-terrain vehicles. This translates to a fuel savings of about 12 million gallons in 2030 when most recreational vehicles used in the U.S. are expected to have permeation emission control.

We believe that permeation emission standards will have no negative impacts on safety, and may even have some benefits due to the reduction of fuel vapor around a recreational vehicle.

Figure 4.6-2: Flow Chart of Fuel Tank Permeation Certification Test Options



** The deterioration factor (DF) is the difference between the baseline and final permeation tests in Option 1*

*** EPA estimate*

Appendix to Chapter 4: Emission Index For Recreational Vehicle Hangtags

Section1051.135(g) specifies that recreational vehicles should have consumer labels that show the emission characteristics of the vehicle using a normalized zero to ten index. The index is called a nonroad emission rating (NER). This appendix describes the derivation of those indices. The primary indices were derived based on four general principles:

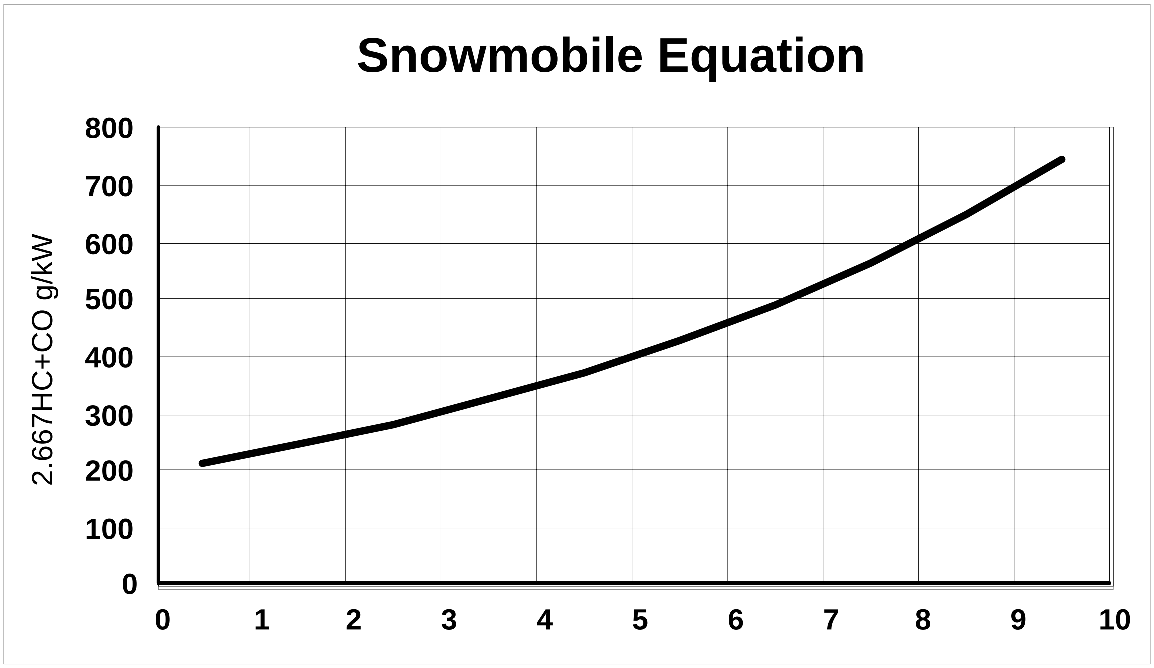
> The index should be simple for the consumer to use.
>
> A vehicle with the highest emissions allowed or expected under the regulations should have a value of ten.
>
> A vehicle with emissions equal to the average standard should be in the middle of the range. (For categories with two phases, a vehicle with emissions equal to the average Phase 2 standard under should be approximately five.)
>
> Each index should allow for vehicles that are significantly cleaner than the average. The indices should also work without adjustment if we were to establish more stringent standards in the future.

As described below, we applied these principles separately to each of the categories, considering the baseline emissions, FEL caps, average standards, and current and future technology options. In general, since the recreational vehicle programs are designed to allow different technology options, we believe that a logarithmic scale in generally appropriate. However, in some cases, a linear scale is more appropriate for all or part of the index. In some cases, it may be possible to have emissions high enough to calculate the NER as eleven or higher. In those cases, the regulations specify that the vehicle should be labeled as a ten.

4A.1 Snowmobiles

The index for snowmobiles uses a single log-linear curve to convert HC and CO emissions into normalized values between zero and ten. HC and CO emissions are weighted based on baseline values so that a 50 percent reduction in HC emissions is equivalent to a 50 percent reduction in CO emissions. (The ratio of baseline CO emissions to baseline HC emissions is 400:150, or 2.667.) The following equation gives a value of ten for vehicles with HC emissions of 150 g/kW-hr and CO emissions 400 g/kW-hr; and a value of five for vehicles with HC emissions of 75 g/kW-hr and CO emissions 200 g/kW-hr:

$$NER = 16.61 \times \log(2.667HC + CO) - 38.22$$



4A.2 Off-highway Motorcycles

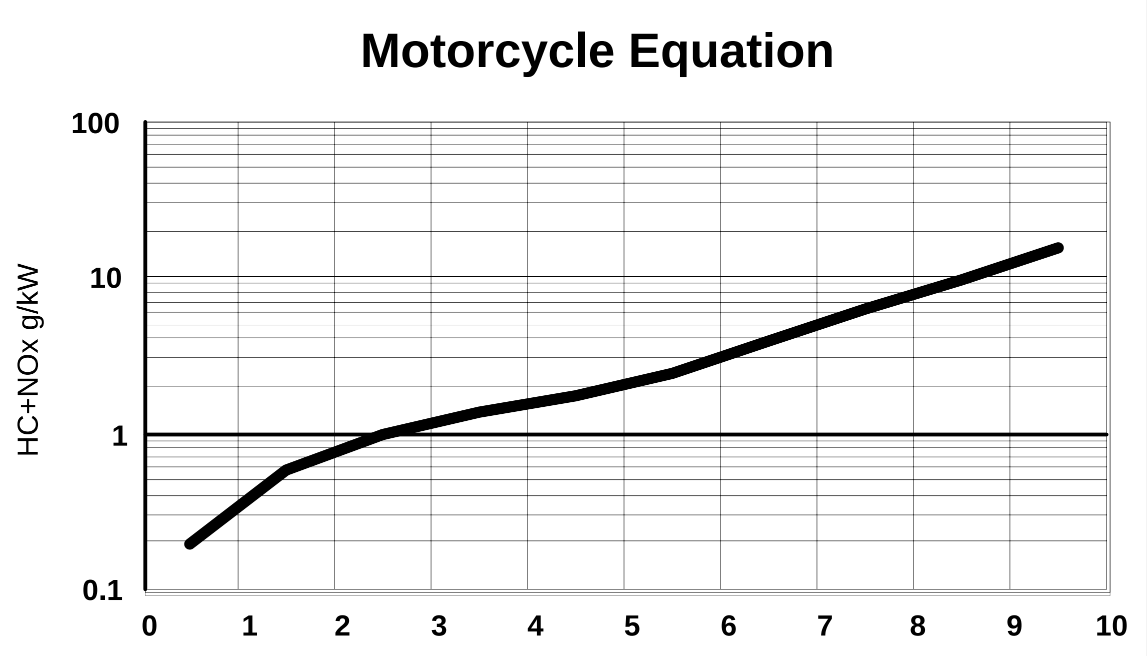
The index for off-highway motorcycles uses a combination of a linear curve and a log-linear curve to convert HC+NOx emissions into normalized values between zero and ten. The following linear equation, which applies for vehicles with below average emissions gives a value of five for vehicles with HC+NOx emissions of 2.0 g/km:

$$NER = 2.500(HC + NOx)$$

The following log-linear equation, which applies for vehicles with above average emissions gives a value of ten for vehicles with HC+NOx emissions of 20 g/km; and a value of five for vehicles with HC+NOx emissions of 2.0 g/km:

$$NER = 5.000 \times \log(HC + NOx) + 3.495$$

It was necessary to use a linear equation for the lower part of the curve to allow for more gradations just below the average, and fewer for very low levels. For example, using the log equation, it would have been necessary to have emission below 1.0 g/km to get an emission rating that would round to three, while with the linear equation, it would only be necessary to have emissions below 1.4 g/km to get an emission rating that would round to three.



4A.3 ATVs (g/km)

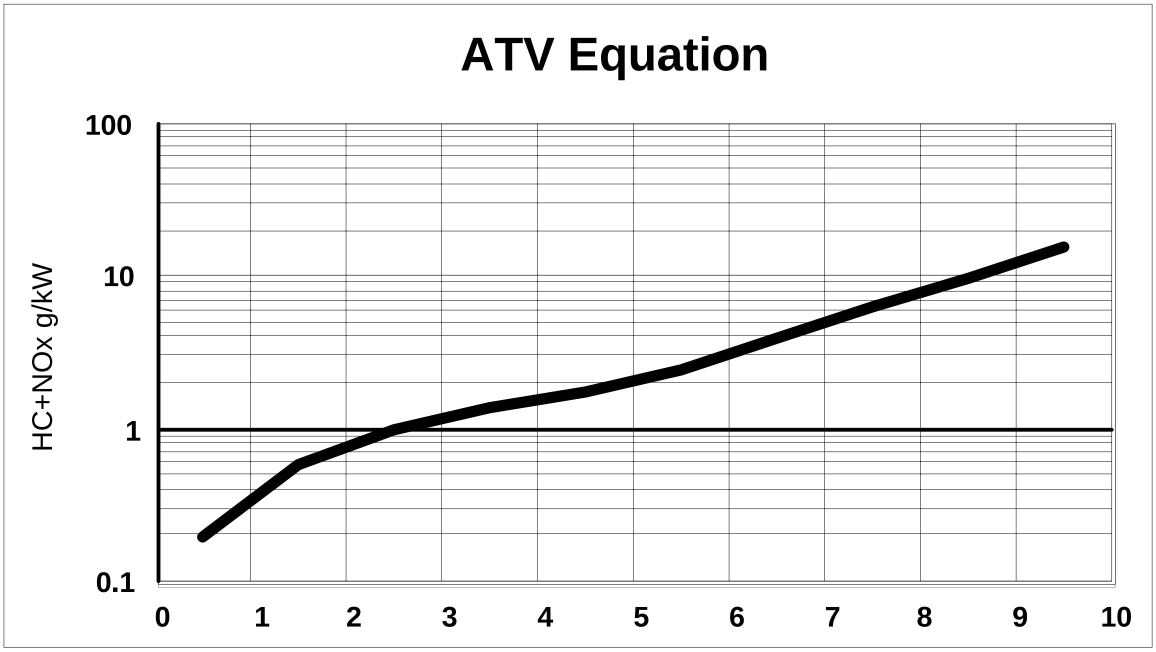
The primary index for ATVs uses a combination of a linear curve and a log-linear curve to convert HC+NOx emissions into normalized values between zero and ten. The following linear equation, which applies for vehicles with below average emissions gives a value of five for vehicles with HC+NOx emissions of 1.5 g/km:

$$NER = 3.333(HC + NOx)$$

The following log-linear equation, which applies for vehicles with above average emissions gives a value of ten for vehicles with HC+NOx emissions of 20 g/km; and a value of five for vehicles with HC+NOx emissions of 1.5 g/km:

$$NER = 4.444 \times \log(HC + NOx) + 4.217$$

It was necessary to use a linear equation for the lower part of the curve to allow for more gradations just below the average, and fewer for very low levels. For example, using the log equation, it would have been necessary to have emission below 0.7 g/km to get an emission rating that would round to three, while with the linear equation, it would only be necessary to have emissions below 1.1 g/km to get an emission rating that would round to three.
where HC +NOx is the cycle-weighted emission rates for hydrocarbons plus oxides of nitrogen in g/km.



4A.4 ATVs (g/kW)

There are two cases in which we allow ATVs to certify to g/kW emission standards based on engine testing: ATVs less than 100 cc, and ATVs built before 2009. We developed separate equations for these cases, based on the same general principles as for other ATVs. In developing these equations, we considered FEL caps, average standards, test cycle issues, and the available technology options. The following linear equation, applies for ATV with engine smaller than 100cc:

$$NER = 0.250(HC + NOx) + 0.250$$

The following log-linear equation, applies for larger ATVs certified under the interim engine testing option:

$$NER = 9.898 \times \log(HC + NOx) - 4.898$$

Chapter 4 References

1. “Emission Testing of Nonroad Compression Ignition Engines,” prepared by Southwest Research Institute for the U.S. EPA, SwRI 6886-802, September 1995, Docket A-2000-01, Document II-A-20.

2. Memorandum from Mike Brand, Cummins, to Bill Charmley, U.S. EPA, “Draft Report on *Emission Testing of Nonroad Compression Ignition Engines*,” November 13, 1995, Docket A-2000-01, Document II-A-22.

3. Letter from Jeff Carmody, Santa Barbara County Air Pollution Control District, to Mike Samulski, U.S. EPA, “Marine Engine Replacement Programs,” July 21, 1997, Docket A-2000-01, Document II-A-21.

4. Facsimile from Eric Peterson, Santa Barbara County Air Pollution Control District, to Mike Samulski, U.S. EPA, “Data on Mercury 4.2 and 2.8 Liter Engines,” April 1, 1998, Docket A-2000-01, Document II-A-24.

5. Smith, M., “Marine Diesel Engine Testing,” Prepared by Southwest Research Institute for the U.S. EPA, Contract # 68-C-98-169, WA 0-7, September 1999, Docket A-2000-01, Document II-A-26.

6. Data Submission by the Engine Manufacturers Association, July 19, 2000, Docket A-2000-01, Document II-B-11.

7. International Organization for Standardization, 8178-4, “Reciprocating internal combustion engines—Exhaust emission measurement—Part 4: Test cycles for different engine applications,” Docket A-2000-01, Document II-A-19.

8. “Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or Above 37 kW; Final Rule,” 64 FR 73300, December 29, 1999.

9. Wilbur, C., “Marine Diesel Engines,” Butterworth & Heinemann Ltd, 1984.

10. “Data Collection and Analysis of Real-World Marine Diesel Transient Duty-Cycles,” EPA memo from Matt Spears to Mike Samulski, October 15, 1999, Docket A-2000-01, Document II-B-09.

11. Memorandum from Mark Wolcott to Charles Gray, “Ambient Temperatures Associated with High Ozone Concentrations,” U.S. Environmental Protection Agency, September 6, 1984, Docket A-2000-01, Document II-B-06.

12. Smith, M., “Marine Diesel Engine Testing,” Prepared by Southwest Research Institute for the U.S. EPA, Contract # 68-C-98-169, WA 0-7, September 1999, Docket A-2000-01, Document II-A-26.

13. SAE J1937 (reaffirmed JAN1995), “Engine Testing with Low-Temperature Charge Air-Cooler Systems in a Dynamometer Test Cell,” SAE Recommended Practice, Docket A-2000-01, Document II-A-62.

14. Annex VI of MARPOL 73/78, “Technical code of control of Emissions of Nitrogen Oxides for Marine Diesel Engines,” October 22, 1997, Docket A-2000-01, Document II-A-25.

15. “Emission Factors for Compression Ignition Nonroad Engines Operated on No. 2 Highway and Nonroad Diesel Fuel,” U.S. Environmental Protection Agency, EPA420-R-98-001, March 1998, Docket A-2000-01, Document IV-A-73.

16. “Emission Data and Procedures for Large SI Engines,” EPA memorandum from Alan Stout and Chuck Moulis to Docket A-2000-01, January 2, 2001, EPA420-F-00-050, Document II-B-05.

17. “Evaluation of Emissions Durability of Off-Road LPG Engines Equipped with Three-Way Catalysts,” by Vlad Ulmet, Southwest Research Institute, SwRI 08.03661 & 08.03377, November 2000, (Docket A-2000-01, document II-A-07). This document is available through the National Technical Information Society at (703) 605-6000 (order number PB2002-101191).

18. The Mazda and GM engines are from SwRI 08.03661 & 08.03377, November 2000 (Docket A-2000-01, document II-A-07). Engine B and Engine E are from “Three-Way Catalyst Technology For Off-Road Equipment Powered by Gasoline and LPG Engines,” by Jeff White et al, Southwest Research Institute, SwRI 8778, April 1999, (Docket A-2000-01, document II-A-08).

19.“Durability Experience with Electronic Controlled CNG and LPG Engines,” A. Lawson et al., February 2, 2000, Docket A-2000-01, Document II-D-2.

20.“Exhaust Controls Available to Reduce Emissions from Nonroad Heavy-Duty Engines,” by Kevin Brown, Engine Control Systems, in *Clean Air Technology News*, Winter 1997, Docket A-2000-01, Document II-A-2.

21. “Case Study: The Results of IMPCO’s GM 3.0 liter Certified Engine Program,” presented by Josh Pietak, February 2, 2000, A-2000-01, Document II-D-11.

22.See SwRI 08.03661 & 08.03377, November 2000 for a further description of the catalyst damage observed, (Docket A-2000-01, document II-A-07).

23.“Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Document IV-B-06.

24. “Development and Validation of a Snowmobile Engine Emission Test Procedure,” Jeff J. White, Southwest Research Institute and Christopher W. Wright, Arctic Cat, Inc., SAE paper 982017, September, 1998, Docket A-2000-01, Document II-A-66.

25. 61 FR 52088, October 4, 1996.

26. Letter to Linc Wehrly from Phillip D. McDowell, Docket A-2000-01, Document IV-D-184.

27. www.arb.ca.gov/msprog/spillcon/reg.htm, Updated March 26, 2001, Copy of linked data reports available in Docket A-2000-01, Document IV-A-09.

28. “Permeation Rates of Small Off Road Engine High-Density Polyethylene Fuel Tanks (April 2001 Testing), June 8, 2001, California Air Resources Board, Docket A-2000-01, Document IV-A-101.

29. “Permeation Rates of Small Off Road Engine High-Density Polyethylene Fuel Tanks (February 2001 Testing), June 8, 2001, California Air Resources Board, Docket A-2000-01, Document IV-A-100.

30. “Permeation Rates of High-Density Polyethylene Fuel Tanks (June 2001), June 12, 2001, California Air Resources Board, Docket A-2000-01, Document IV-A-99.

31. Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, “Early Container Data,” August 29, 2002, Docket A-2000-01, Docket No. IV-A-103.

32. Lockhart, M., Nulman, M., Rossi, G., “Estimating Real Time Diurnal Permeation from Constant Temperature Measurements,” SAE Paper 2001-01-0730, 2001, Docket A-2000-01, Document IV-A-21.

33. Hopf, G., Ries, H., Gray, E., “Development of Multilayer Thermoplastic Fuel Lines with Improved Barrier Properties,” SAE Paper 940165, 1994, Docket A-2000-01, Document IV-A-22.

34. Nulman, M., Olejnik, A., Samus, M., Fead, E., Rossi, G., “Fuel Permeation Performance of Polymeric Materials,” SAE Paper 2001-01-1999, 2001, Docket A-2000-01, Document IV-A-23.

35. SAE Recommended Practice J30, “Fuel and Oil Hoses,”June 1998, Docket A-2000-01, Document IV-A-92.

36. www.arb.ca.gov/msprog/spillcon/reg.htm, Updated March 26, 2001, Copy of linked data reports available in Docket A-2000-01, Document IV-A-09.

37. Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, “Early Container Data,” August 29, 2002, Docket A-2000-01, Docket No. IV-A-103.

38. “Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks,” California Air Resources Board, June 21, 2002, Docket A-2000-01, Document IV-

A-77.

39. Conversation between Mike Samulski, U.S. EPA and Tom Schmoyer, Sulfo Technologies, June 17, 2002.

40. “Resin and Additives - SO3 Compatible,” Email from Tom Schmoyer, Sulfo Technologies to Mike Samulski and Glenn Passavant, U.S. EPA, June 19, 2002, Docket A-2000-01, Document IV-A-40.

41. Email from Jim Watson, California Air Resources Board, to Mike Samulski, U.S. EPA, “Attachment to Resin List,” August 30, 2002, Docket A-2000-01, Document IV-A-102.

42. Walles, B., Nulford, L., “Five Year Durability Tests of Plastic Gas Tanks and Bottles with Sulfonation Barrier,” Coalition Technologies, LTD, for Society of Plastics Industry, January 15, 1992, Docket A-2000-01, Document IV-A-76.

43. Kathios, D., Ziff, R., “Permeation of Gasoline and Gasoline-Alcohol Fuel Blends Through High-Density Polyethylene Fuel Tanks with Different Barrier Technologies,” SAE Paper 920164, 1992, Docket A-2000-01, Document II-A-60.

44. www.arb.ca.gov/msprog/spillcon/reg.htm, Updated March 26, 2001, Copy of linked data reports available in Docket A-2000-01, Document IV-A-09.

45. “Permeation Rates of Blitz Fluorinated High Density Polyethylene Portable Fuel Containers,” California Air Resources Board, April 5, 2002, Docket A-2000-01, Document IV-A-78.

46. Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, “Early Container Data,” August 29, 2002, Docket A-2000-01, Docket No. IV-A-103.

47. www.pensteel.co.uk/light/smp/fluorination.htm. A copy of this site is available in Docket A-2000-01, Document IV-A-86.

48. “Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks,” California Air Resources Board, June 21, 2002, Docket A-2000-01, Document IV-A-77.

49. Kathios, D., Ziff, R., “Permeation of Gasoline and Gasoline-Alcohol Fuel Blends Through High-Density Polyethylene Fuel Tanks with Different Barrier Technologies,” SAE Paper 920164, 1992, Docket A-2000-01, Document II-A-60.

50. “Selar RB Technical Information,” Faxed from David Zang, Dupont, to Mike Samulski, U.S. EPA on May 14, 2002, Docket A-2000-01, Document IV-A-88.

51. Fead, E., Vengadam, R., Rossi, G., Olejnik, A., Thorn, J., “Speciation of Evaporative Emissions from Plastic Fuel Tanks,” SAE Paper 981376, 1998, Docket A-2000-01, Document

IV-A-89.

52. E-mail from Alan Dubin, Ticona, to Mike Samulski, U.S. EPA, “Fuel Permeation Chart and Aggressive Fuels Brochure,” July 31, 2002, Docket A-2000-01, Document IV-A-97.

53. SAE Recommended Practice J2260, “Nonmetallic Fuel System Tubing with One or More Layers,”1996, Docket A-2000-01, Document IV-A-18.

54. SAE Recommended Practice J30, “Fuel and Oil Hoses,” June 1998, Docket A-2000-01, Document IV-A-92.

55. “Visit to Dyneon on June 12, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, June 17, 2002, Docket A-2000-01, Document IV-E-31.

56. “Meeting with Avon on June 27, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, August 6, 2002, Docket A-2000-01, Document IV-E-33.

57. “Meeting with Avon on June 27, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, August 6, 2002, Docket A-2000-01, Document IV-E-33.

58. Akron Rubber Development Laboratory, “TEST REPORT; PN# 49503,” Prepared for the U.S. EPA, September 3, 2002, Docket A-2000-01, Document IV-A-106.

59. Hopf, G., Ries, H., Gray, E., “Development of Multilayer Thermoplastic Fuel Lines with Improved Barrier Properties,” SAE Paper 940165, 1994, Docket A-2000-01, Document IV-A-22.

60. Stahl, W., Stevens, R., “Fuel-Alcohol Permeation Rates of Fluoroelastomers, Fluoroplastics, and Other Fuel Resistant Materials,” SAE Paper 920163, 1992, Docket A-2000-01, Document IV-A-20.

61. “Visit to Dyneon on June 12, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, June 17, 2002, Docket A-2000-01, Document IV-E-31.

62. Goldsberry, D., “Fuel Hose Permeation of Fluoropolymers,” SAE Paper 930992, 1993, Docket A-2000-01, Document IV-A-91.

63. Tuckner, P., Baker, J., “Fuel Permeation Testing Using Gravimetric Methods,” SAE Paper 20001-01-1096, 2000, Docket A-2000-01, Document IV-A-96.

64. Nulman, M., Olejnik, A., Samus, M., Fead, E., Rossi, G., “Fuel Permeation Performance of Polymeric Materials,” SAE Paper 2001-01-1999, 2001, Docket A-2000-01, Document IV-A-23.

65. Duchesne, D., Hull, D., Molnar, A., “THV Fluorothermoplastics in Automotive Fuel Management Systems,” SAE Paper 1999-01-0379, 1999, Docket A-2000-01, Document IV-A-90.

66. Nulman, M., Olejnik, A., Samus, M., Fead, E., Rossi, G., “Fuel Permeation Performance of Polymeric Materials,” SAE Paper 2001-01-1999, 2001, Docket A-2000-01, Document IV-A-23.

67. Nulman, M., Olejnik, A., Samus, M., Fead, E., Rossi, G., “Fuel Permeation Performance of Polymeric Materials,” SAE Paper 2001-01-1999, 2001, Docket A-2000-01, Document IV-A-23.

68. “Visit to Dyneon on June 12, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, June 17, 2002, Docket A-2000-01, Document IV-E-31.

69. Facsimile from Bob Hazekamp, Top Dog Systems, to Mike Samulski, U.S. EPA, “Permeation of Polyurethane versus THV Materials @ 60°C,” January 14, 2002, Docket A-2000-01, Document II-B-30.

70. Duchesne, D., Hull, D., Molnar, A., “THV Fluorothermoplastics in Automotive Fuel Management Systems,” SAE Paper 1999-01-0379, 1999, Docket A-2000-01, Document IV-A-90.

71. Draft SAE Information Report J1769, “Test Protocol for Evaluation of Long Term Permeation Barrier Durability on Non-Metallic Fuel Tanks,” Docket A-2000-01, Document IV-A-24.

72. SAE Recommended Practice J30, “Fuel and Oil Hoses,” June 1998, Docket A-2000-01, Document IV-A-92.

73. SAE Recommended Practice J2260, “Nonmetallic Fuel System Tubing with One or More Layers,”1996, Docket A-2000-01, Document IV-A-18.

Chapter 5: Costs of Control

This chapter describes our approach to estimating the cost of complying with emission standards. We start with a general description of the approach to estimating costs, then describe the technology changes we expect and assign costs to them. We also present an analysis of the estimated aggregate cost to society.

5.1 Methodology

We developed the costs for individual technologies using information provided by ICF, Incorporated and Arthur D. Little, as cited below with further consideration to any information provided in the public comments. The technology characterization and cost figures reflect our current best judgment based on engineering analysis, information from manufacturers, and the published literature. The analysis combines cost figures including markups to the retail level.

Costs of control include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). Variable costs are marked up at a rate of 29 percent to account for the engine manufacturers' overhead and profit.[1] For technologies sold by a supplier to the engine manufacturers, an additional 29 percent markup is included for the supplier's overhead and profit. All costs are in 2001 dollars.

The analysis presents an estimate of costs that will occur in the first year of new emission standards and the corresponding long-term costs. Long-term costs decrease due to two principal factors. First, fixed costs are assessed for five years, after which they are fully amortized and are therefore no longer part of the cost calculation. Second, manufacturers are expected to learn over time to produce the engines with the new technologies at a lower cost. Because of relatively low sales volumes, manufacturers are less likely to put in the extra R&D effort for low-cost manufacturing. Learning will occur in two basic ways. As manufacturers produce more units, they will make improvements in production methods to improve efficiency. One example of this is automation. The second way learning occurs is materials learning where manufacturers reduce scrap. Scrap includes units that are produced but rejected due to inadequate quality and material scrap left over from the manufacturing process. As production starts, assemblers and production engineers will then be expected to find significant improvements in fine-tuning the designs and production processes. Consistent with analyses from other programs, we reduce estimated variable costs by 20 percent beginning with the third year of production and an additional 20 percent beginning with the sixth year of production.[2]

We believe it is appropriate to apply this factor here, given that the industries are facing emission regulations for the first time and it is reasonable to expect learning to occur with the experience of producing and improving emission-control technologies. Manufacturers do not have significant experience with most of the emissions controls that are anticipated for meeting the standards contained in the Final Rule. In cases where manufacturers have used certain technologies, such as with 4-stroke engines, they have not been required to meet standards. They will be manufacturing new 4-stroke engines or purchasing and installing 4-stroke engines in new models. Learning will likely occur for these models. Some manufacturers, especially in the youth ATV market do not have experience with 4-stroke engines. Also, the 4-strokes will need to be made to meet emissions standards. We believe that learning for these models will continue to take place.

Many of the engine technologies available to manufacturers to control emissions also have the potential to significantly improve engine performance. This is clear from the improvements in automotive technologies. As cars have continually improved emission controls, they have also greatly improved fuel economy, reliability, power, and a reduced reliance on regular maintenance. Similarly, the fuel economy improvements associated with converting from two-stroke to four-stroke engines is well understood. We attempt to quantify these expected improvements, as we describe for each type of engine below.

Even though the analysis does not reflect all the possible technology variations and options that are available to manufacturers, we believe the projections presented here provide cost estimates representative of the different approaches manufacturers may ultimately take. We expect manufacturers in many cases to find and develop approaches to achieve the emission standards at a lower cost than we describe in this analysis.

5.2 Cost of Emission Controls by Engine/Vehicle Type

5.2.1 Recreational Marine Diesel Engines

We have developed cost estimates for diesel engine technologies for several different applications in a series of reports.[3,4,5] This analysis adapts these existing cost estimates for recreational marine diesel engines with separate estimates for three different sizes of engines.

Recreational marine diesel engines invariably have counterpart engine models used for commercial application. Manufacturers will design, certify, and manufacture these commercial models to meet emission standards. The analysis projects that manufacturers will comply with the new emission standards generally by applying the same technologies for both commercial and recreational engines. The remaining effort to meet emission standards with the recreational models is therefore limited to applying new or improved hardware and conducting sufficient R&D to integrate the new technologies into marketable products. The analysis therefore does not consider fixed costs to develop the individual technologies separately.

One area where recreational engine designs differ is in turbocharging and aftercooling. To reach peak performance, recreational engines typically already use optimized turbochargers and seawater aftercooling, which offer the greatest potential for controlling NOx emissions.

We estimate the total cost impact of new emission standards by considering the cost of each of the anticipated technologies. The following paragraphs describe these technologies and their application to recreational marine engines. The analysis then combines these itemized costs into a composite estimate for the range of marine engines affected by the rulemaking.

Table 5.2.1-1 also includes information on product offerings and sales volumes, which is needed to calculate amortized fixed costs for individual engines. Estimated sales and product offerings were compiled from the PSR database based on historical 1997 information.

Table 5.2.1-1
Recreational Marine Diesel Engine Categories for Estimating Costs

Engine Power Ranges (kW)	Nominal Engine Power (kW)	Annual Sales	Models	Average Sales per Model
37 - 225	100	11,600	17	675
225 - 560	400	3,560	15	250
560 +	750	397	6	70

Manufacturers are expected to develop engine technologies not only to reduce emissions, but also to improve engine performance. While it is difficult to take into account the effect of ongoing technology development, EPA is concerned that assessing the full cost of the anticipated technologies as an impact of new emission standards inappropriately excludes from consideration the expected benefits for engine performance, fuel consumption, and durability.[dd] Short of having sufficient data to predict the future with a reasonable degree of confidence, we face the need to devise an alternate approach to quantifying the true impact of the new emission standards. As an attempt to take this into account, we present the full cost of the control technologies in this chapter, then apply an adjustment to some of these costs for calculating the cost-per-ton of the emission standards, as described in Chapter 7.

5.2.1.1 Fuel Injection Improvements

All engines are expected to see significant improvements in their fuel injection systems. The smaller engines will likely undergo incremental improvements to existing unit injector designs. The analysis projects that engines rated over 600 kW will use common rail injection technology, which greatly increases the flexibility of tailoring the injection timing and profile to varying modes of operation. Better control of injection timing and increased injection pressure contribute to reduced emissions. Table 5.2.1-2 shows the estimated costs for these fuel injection improvements.

[dd] While EPA does not anticipate widespread, marked improvements in fuel consumption, small improvements on some engines may occur.

Table 5.2.1-2: Fuel Injection Improvements

	100 kW	400 kW	750 kW
Component costs	$63	$98	$205
Assembly, markup, and warranty	$32	$46	$59
Composite Unit Cost	$95	$144	$264

5.2.1.2 Engine Modifications

Manufacturers will be optimizing basic engine parameters to control emissions while maintaining performance. Such variables include routing of the intake air, piston crown geometry, and placement and orientation of injectors and valves. Most of these variables affect the mixing of air and fuel in the combustion chamber. Small changes in injection timing are also considered in this set of modifications. We expect, however, that manufacturers will complete this work for commercial marine diesel engines, so that the remaining effort will be focused on fine-tuning designs for turbocharger matching and other calibration-related changes. Fixed costs are amortized over a five-year period, using the sales volumes developed in Table 5.2.1-1, with forward discounting incorporated to account for manufacturers incurring these costs before the emission standards begin to apply. Table 5.2.1-3 shows the estimated per-engine costs for these modifications. These costs include the consideration manufacturers must give to offsetting any crankcase emissions routed to the exhaust. There is no estimated long-term cost to the engine modifications because manufacturers can fully recover the fixed costs, and we don't expect any increase in variable costs as a result of these improvements.

Table 5.2.1-3: Engine Modifications

	100 kW	400 kW	750 kW
Total fixed costs	$200,000	$200,000	$200,000
Fixed cost per engine	$72	$195	$697
Composite Unit Cost	$72	$195	$697

As described in the preamble to the final rule, the manufacturers are responsible to comply with emissions at any speed and load that can occur on a vessel. We believe that is not appropriate to consider additional costs for manufacturers to comply with these "off-cycle" requirements. This is because we expect that manufacturers can manage engine operation to avoid unacceptable variation in emission levels by more effectively using the technologies that will be used to meet the emission limits more broadly, rather than by use of additional hardware. For example, manufacturers can adjust fuel injection parameters to avoid excessive emissions. The split-zone approach described in Chapter 4 is designed to accommodate normal variation in emission levels at different operating points. This approach involves no additional variable cost. The estimated R&D expenditures reflect the time needed to address this.

5.2.1.3 Certification and Compliance

We have significantly reduced certification procedural requirements in recent years, but manufacturers are nevertheless responsible for generating the necessary test data and other information to demonstrate compliance with emission standards. Table 5.2.1-4 lists the expected costs for different sizes of engines, including the amortization of those costs over five years of engine sales. Estimated certification costs are based on two engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information.

Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. Since these engines are currently not subject to any emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years.

Costs for production line testing are summarized in Table 5.2.1-5. These costs are based on testing 1 percent of total estimated sales, then distributing costs over the fleet. Listed costs for engine testing presume no need to build new test facilities, since we may waive production-line testing requirements for small-volume production. Few manufacturers, if any, will therefore need to build new test facilities.

Table 5.2.1-4: Certification

	100 kW	400 kW	750 kW
Total fixed costs	$30,000	$30,000	$40,000
Fixed cost per engine	$12	$29	$139
Composite Unit Cost	$12	$29	$139

Table 5.2.1-5: Costs for Production Line Testing

	100 kW	400 kW	750 kW
Cost per test	$10,000	$10,000	$15,000
Testing rate	1 %	1 %	1 %
Cost per engine	$100	$100	$150

5.2.1.4 Total Engine Costs

These individual cost elements can be combined into a calculated total for new emission standards by assessing the degree to which the different technologies will be deployed. As shown in Table 5.2.1-6, estimated costs for complying with the emission standards increase with increasing power ratings. We expect each of the listed technologies to apply to all the engines that need to meet the new emission standards. Estimated first-year cost impacts range from $300 to $1,300 for the different engine sizes, while long-term cost estimates range from $170 to $460.

Characterizing these estimated costs in the context of their fraction of the total purchase price and life-cycle operating costs is helpful in gauging the economic impact of the new standards. The estimated first-year cost increases for all engines are at most 2 percent of estimated engine prices, with even lower long-term effects, as described above.

Table 5.2.1-6: Diesel Engine Costs

	100 kW	400 kW	750 kW
Fuel injection upgrade	$95	$144	$264
Engine modifications	$72	$195	$697
Certification + PLT	$111	$129	$289
Total Engine Cost, year 1	$278	$468	$1,251
Total Engine Cost, year 6	$172	$221	$459

5.2.1.5 Marine Diesel Aggregate Costs

The above analyses developed incremental per-vessel cost recreational marine diesel engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold. Table 5.2.1-7 presents a summary of this analysis. As shown in the table, aggregate net costs stay between $3 million and $6 million.

Table 5.2.1-7
Summary of Annual Aggregate Costs for Marine Diesel Engines (millions of dollars)

	2006	2010	2015	2020	2025
Total Costs	$6.2	$7.6	$2.8	$3.1	$3.4

To project annual sales, we started with the 1998 population estimates presented in Chapter 6. We then used the engine turnover rates and growth estimates to calculate annual sales. Table 5.2.1-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.1-8
Estimated Annual Sales of Recreational Marine Diesel Engines

Engine Power Range (kW)	2000	2006	2010	2020
37 - 225	11,600	13,700	15,200	18,700
225 - 560	3,560	4,200	4,620	5,690
560 +	397	469	517	636

To calculate annual aggregate costs, the sales estimates have been multiplied by the per-unit costs discussed above. These calculations take into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.2 Large Industrial Spark-Ignition Engines

We estimated the cost of upgrading LPG-fueled and gasoline-fueled Large SI engines. We developed the costs for individual technologies in cooperation with ICF, Incorporated and Arthur D. Little.[6] The analysis combines these individual figures into a total estimated cost for each type of engine, including markups to the retail level. A composite cost based on the mix of engine types provides an estimated industry-wide estimate of the per-engine cost impact.

Gasoline-fueled Large SI engines continue to rely on traditional carburetor designs rather than incorporating the automotive technology innovations introduced to address emission controls. Since natural gas- and LPG-fueled engines use comparable technologies, the analysis presents a single set of costs for both fuels.

The anticipated technology development is generally an outgrowth of automotive technologies. Over the last thirty years, engineers in the automotive industry have made great strides in developing new and improved approaches to achieve dramatic emission reductions with high-performing engines. In more recent years, companies have started to offer these same technologies for industrial applications. Fundamental to this technology development is the electronically controlled fuel system and catalytic converters.

Electronically controlled fuel systems allow manufacturers to more carefully meter fuel into the combustion chambers. This gives the design engineer an important tool to better control power and emission characteristics over the whole range of engine operation. Careful control of air-fuel ratio is also essential for effective catalyst conversion. The catalyst reduces the concentration of pollutant gases in the exhaust stream. We also consider development time to redesign the combustion chamber and intake air routing, as well as to combine the new control technologies and optimize engine calibrations. We include these efforts under the total R&D costs for each engine.

Gasoline engines can use either throttle-body or port-fuel injection. Manufacturers can likely reach the targeted emission levels using simpler throttle-body systems. However, the performance advantages and the extra assurance for full-life emission control from the more advanced port-fuel injection systems offer a compelling advantage. The analysis therefore projects that all gasoline engines will use port-fuel injection. The analysis does not take into account the performance advantages of port-fuel injection and therefore somewhat overestimates the cost impact of adopting new emission standards.

Gaseous-fuel engines have very different fuel metering systems due to the fact that LPG and natural gas evaporate readily at typical ambient temperatures and pressures. Manufacturers of these engines face a choice between continuing with conventional mixer technology and upgrading to injection systems. We are aware that manufacturers are researching gaseous injection systems, but we believe mixer technology will be sufficient to meet the standards. All the data supporting the feasibility of emission standards for LPG engines is based on engines using mixer technology.

5.2.2.1 Engine Technology

Tables 5.2.2-1 and 5.2.2-2 show the estimated costs of upgrading each of the engine types. The cost figures are in the form of retail-price equivalent for an individual engine. The tables include individual cost estimates of the various components involved in converting a baseline engine to comply with emission standards. The cost of the catalyst is based on a precious metal loading of 2.8 g/liter (primarily palladium, with small amounts of platinum and rhodium) and a catalyst volume 60 percent of total engine displacement.

The analysis incorporates a cost for potential warranty claims related to the new technologies by adding 5 percent of the increase in hardware costs. The industry has gained enough experience with electronic fuel systems that we expect a relatively low rate of warranty claims for them. Catalysts have been used for many years, but not in Large SI applications, so these technologies may cause a somewhat higher rate of warranty claims.

Even without EPA emission standards, manufacturers will conduct the research and development needed to meet the 2004 emission standards in California. The R&D impact of new EPA standards is therefore limited to the additional burden of complying with the 2007 requirements. Estimated costs for research and development are $175,000 for each engine family. This is based on about six months of time for an engineer and a technician on each fuel type for each engine family. We expect initial efforts to be more extensive, but cumulative learning should reduce per-family development costs for subsequent models. These fixed costs are increased by 7 percent to account for forward discounting, since manufacturers incur these costs before the new standards apply. Redesigning the first engine model will likely require significantly more time than this, but we expect the estimated level of R&D to be appropriate as an average level for the range of models in a manufacturer’s product line.

Table 5.2.2-2 presents separate costs for water-cooled and air-cooled gasoline engines. While many of the components are the same, the main differences include (1) a single fuel injector and simpler intake manifold for throttle-body injection, (2) smaller sales volume for amortizing fixed costs, and (3) substantial fixed costs for meeting the 2004 standards. Air-cooled engines are generally not certified already in California, largely because most applications involving air-cooled Large SI engines are preempted from California ARB's emission standards. To take this into account, we have added an estimate of $500,000 for R&D and $100,000 for tooling costs per engine family. Discounting these costs forward two years and amortizing over five years of sales results in an additional cost of $166 per air-cooled engine.

Table 5.2.2-1
Estimated Costs for an LPG-fueled Large SI Engine

	Baseline	Controlled
Hardware Cost to Manufacturer		
Regulator/throttle body	$50	$65
Intake manifold	$37	$37
Positive crankcase ventilation		$3
Fuel filter w/ lock-off system	$15	$15
LPG vaporizor	$75	$75
Governor	$40	$60
Converter temperature control valve		$15
Oxygen sensor		$19
ECM		$100
Wiring/related hardware		$42
Fuel system total	$217	$431
Catalyst/muffler		$229
Muffler	$45	$0
Total Hardware Cost	$262	$660
Markup @ 29%	$76	$191
Warranty markup @5%		$20
Total component costs	$338	$871
2004 Fixed costs		$0
2004 Incremental costs		$533
Fixed Cost to Manufacturer		
2007 R&D costs		$175,000
Units/yr.		2,000
Amortization period (7 % discounting)		5
2007 Fixed cost/unit	$0	$26
2007 Evap costs	$0	$0
2007 Incremental costs		$0

Table 5.2.2-2
Estimated Per-Engine Costs for Gasoline-Fueled Large SI Engines

	Water-cooled		Air-cooled	
	Baseline	Controlled	Baseline	Controlled
Hardware Cost to Manufacturer				
Carburetor	$51	$0	$51	$0
Injectors (each)		$17		$19
Number of injectors		4		1
Pressure Regulator		$11		$11
Fuel filter	$3	$4	$3	$4
Intake manifold	$35	$50	$35	$37
Positive crankcase ventilation		$3		$3
Fuel rail		$13		—
Throttle body/position sensor		$60		$76
Fuel pump	$15	$30	$15	$26
Oxygen sensor		$19		$19
ECM		$150		$140
Governor	$40	$60	$40	$60
Air intake temperature sensor		$5		$5
Manifold air pressure sensor		$11		$11
Injection timing sensor		$12		$12
Wiring/related hardware		$42		$42
Fuel system total	$144	$538	$144	$465
Catalyst/muffler		$229		$229
Muffler	$45		$45	
Total Hardware Cost	$189	$767	$189	$694
Markup @ 29%	$55	$222	$55	$201
Warranty markup @5%		$29		$25
Total Component Costs	$244	$1,018	$244	$920
2004 Fixed costs		$0		$600,000
2004 Fixed cost/unit		$0		$166
2004 Incremental costs		$775		$842
Fixed Cost to Manufacturer				
2007 R&D Costs		$175,000		$175,000
Units/yr.		1,750		1,000
Amortization period (7 % discounting)		5		5
2007 Fixed cost/unit		$30		$52
2007 Evap costs	$0	$13	$0	$13
2007 Incremental costs		$43		$65

In addition to these estimated costs for addressing exhaust emissions, we have analyzed the costs associated with reducing evaporative emissions from gasoline-fueled engines and vehicles. This effort consists of three primary areas—permeation, diurnal, and boiling.

To reduce permeation losses, we expect manufacturers to upgrade plastic or rubber fuel lines to use automotive-grade materials. These fuel lines are readily available at a cost premium of about $1 per linear foot. If an installed engine has an average of four feet of fuel line, this translates into an increased cost of $4 per engine.

The standard related to diurnal emissions can be met with a fuel cap that seals the fuel tank, relieving pressure as needed to prevent the tank from bursting or collapsing. The estimated cost of upgrading to such a fuel cap is conservatively set at $8, based on the aftermarket cost of comparable automotive fuel caps. Such caps would be expected to cost much less as an original equipment upgrade of an existing cap.

Many Large SI engines are installed in equipment in a way that poses little or no risk of fuel boiling during engine operation. A few models are configured in a way that causes this to be a possibility, at least under extreme conditions. Preventing fuel boiling is primarily a matter of isolating the fuel tank from heat sources, such as the engine compartment and the exhaust pipe. Some additional material may be needed to reduce heat exposure, such as a simple metal shield or a fiberglass panel. Given several years to redesign engines and equipment, we believe that manufacturers can readily incorporate such changes into their ongoing R&D programs. To account for several hours of engineering effort and a small amount of material, we estimate that these costs averaged over the whole set of gasoline-fueled engines will come to about $1 per engine.

5.2.2.2 Operating Cost Savings

Introducing electronic closed-loop fuel control will significantly improve engine operation, with corresponding cost savings, in three areas— reduced fuel consumption, less frequent oil changes and tuneups, and delayed time until rebuild.

It may also be appropriate to quantify the benefit of longer total engine lifetimes. For example, passenger cars with low-emission engine technologies last significantly longer than they did before manufacturers developed and applied these technologies. In addition, engine performance (responsiveness, reliability, engine warm-up, etc.) will also improve with the new technologies. However, these benefits are more difficult to quantify and the analysis therefore does not take them into account.

Fuel consumption rates will improve as manufacturers no longer design engines for operation in fuel-rich conditions. Some current systems already operate at somewhat leaner air-fuel ratios than in previous years, but even in these cases, engines generally revert to richer mixtures when accelerating. Closed-loop fuel systems generally operate close to stoichiometry, which improves the engine's efficiency of converting the fuel energy into mechanical work. Information in the docket, including development testing, engineering projections, and user testimony, indicates an estimated 20-percent reduction in fuel consumption rates.[7,8,9] Table 5.2.2-3 shows the value of the estimated fuel savings. These values and calculations are generally based on our NONROAD emissions model. Since the NONROAD model does not account separately for air-cooled engines, calculated fuel savings are based on information we received during the comment period.

Table 5.2.2-3: Estimated Fuel Savings from Large SI Engines

	LPG	Natural gas	Gasoline–water-cooled	Gasoline–air-cooled
Horsepower	66	64	52	60
Load factor	0.39	0.49	0.58	0.58
Annual operating hours, hr/yr	1,368	1,164	534	1,000
Lifetime, yr	12	13	12	3
Baseline bsfc, lb/hp-hr	0.507	0.507	0.605	1.10
Improved bsfc, lb./hp-hr	0.406	0.406	0.484	0.88
Fuel density	4.2 lb./gal	0.05 g./ft^3	6.1 lb./gal	6.1 lb./gal
Fuel cost	\$0.60/gal	\$2.17/1000 ft^3	\$1.10/gal	\$1.10/gal
Annual fuel saved (gal/yr)	845	—	321	1,233
Annual fuel savings (\$/yr)	\$507	\$160	\$353	\$1,357
Lifetime Fuel Savings (NPV)	\$4,333	\$1,427	\$3,038	\$3,810

In addition to the fuel savings, we expect Large SI engines to see significant improvements in reliability and durability. Open-loop fueling systems in uncontrolled engines are prone to drifting calibrations as a result of varying fuel quality, wear in engine components, changing ambient conditions, and other factors. Emission-control systems that operate with a feedback loop to compensate for changing conditions for a near-constant air-fuel ratio significantly reduces the following problems.

-incomplete (and eventually unstable) combustion
-absorption of fuel in lubricating oil
-deposits on valves, spark plugs, pistons, and other engine surfaces
-increased exhaust temperatures

Automotive engines clearly demonstrate that modern fuel systems reduce engine wear and the need for repairs.

This analysis incorporates multiple steps to take these anticipated improvements into account. First, oil change intervals are estimated to increase by 15 percent. Reduced fuel loading in the oil (and other improvements such as piston ring design) can significantly extend its working life. Similarly, tune-up intervals are estimated to increase by 15 percent. This results largely from avoiding an accumulation of deposits on key components, which allows for longer operation between regularly scheduled maintenance. Third, we estimate that engines will last 15 percent longer before needing overhaul. The reduced operating temperatures and generally reduced engine wear associated with closed-loop fuel systems account for this extended lifetime to rebuild. These quantitative estimates of maintenance-related savings are derived from observed changes in automotive performance when upgrading from carburetion to fuel injection. Table 5.2.2-4 summarizes the details of the methodology for converting these maintenance improvements into estimated cost savings over the lifetime of the engines.

Table 5.2.2-4: Maintenance

	LPG/ natural gas	Gasoline
Baseline oil change interval (hrs)	200	150
Improved oil change interval (hrs)	230	172.5
Cost per oil change ($)	$30	$30
Baseline tune-up interval (hrs)	400	400
Improved tune-up interval (hrs)	460	460
Cost per tune-up ($)	$75	$75
Baseline rebuild interval (hrs)	7,000	5,000
Improved rebuild interval (hrs)	8,050	5,750
Rebuild cost ($)	$800	$800
Baseline lifetime maintenance cost	$2,902	$2,573
Improved lifetime maintenance cost	$2,681	$2,354
Lifetime maintenance savings (NPV)	$221	$219

These large estimated fuel and maintenance savings relative to the estimated incremental cost of producing low-emitting engines raise the question of why normal market forces have failed to induce manufacturers to design and sell engines with emission-control technologies on the basis of the expected performance improvements. Since forklifts are the strongly dominant application using Large SI engines, this question effectively applies specifically to forklifts. We have observed that forklift users generally see their purchase as an expense that doesn't add value to a company's product, whether that applies to manufacturing, warehouse, or retail facilities. While operating expenses require less internal justification or decision-making, purchasing new equipment involves extensive review and oversight by managers who are very sensitive to capital expenditures. This is reinforced by an April 2000 article in a trade publication, which quotes an engineering estimate of 20- to 40-percent improvement in fuel economy while stating that it is unclear whether purchasers will tolerate any increase in the cost of the product.[10] Market theory would predict that purchasers select products with technologies that result in the lowest net cost (with some appropriate discount for costs incurred over time). It seems that companies have historically focused on initial costs to the exclusion of potential cost savings over time, which would account for the lack of emission-control technologies on current sales of Large SI engines.

This priority given to initial cost therefore affects the competitive decisions of engine manufacturers, who will be less willing to take the business risk of developing a more costly product than its competitors, even if the product would eventually provide substantial savings to the purchaser. Also, the initial costs of changing designs and using new technologies can serve as a deterrent to including newer cost-efficient technologies in established engine types.

In addition to the engine improvements described above, the costs associated with controlling evaporative emissions would be offset by savings from retaining more fuel that can be used to power the engine. To estimate these costs, we compare the total emission reductions from diurnal, running loss, hot soak, and refueling emissions with the total gasoline-fueled engine population in 2030. The resulting reduction of 0.04 tons hydrocarbon per engine translates into estimated annual savings of $11. Spread over 13 years and discounted to the point of sale leads to a net present value of $98 saved.

5.2.2.3 Compliance Costs

We estimate that certification costs come to $70,000 per engine family. We expect manufacturers to combine similar engines using different fuels in the same family. This expands the size of engine families, but calls for several tests to complete the certification process for each family. This includes six engine tests and $10,000 worth of engineering and clerical effort to prepare and submit the required information. Until engine designs are significantly changed, engine families can be recertified each year using carryover of the original test data. This cost is therefore amortized over five years of engine sales, with an assumed volume of 3,000 engines per year from each engine family. This engine-family sales volume is larger than those presented for amortizing fixed costs above, because engine families will include multiple fuel types. The resulting cost for certification is $6 per engine. Since these engines are currently not subject to any EPA emission requirements, the analysis includes a cost to recertify an upgraded engine model every five years. Since manufacturers already need to submit data for California certification, they will incur most of these costs independent of EPA requirements.

Manufacturers must generally do production-line testing on a quarterly basis, but reduced testing rates apply if engine testing shows consistently good test results. Manufacturers must generate and submit this test data to comply with the requirements adopted by California ARB. The EPA requirement for production-line testing therefore adds no test burden to manufacturers. Even with a transient duty cycle for certification, manufacturers may rely on steady-state test procedures at the production line. We therefore fully expect that manufacturers will need only to send the “California” test data to EPA to satisfy requirements for production-line testing. The analysis therefore includes no cost for additional routine testing of production engines. In fact, manufacturers may pursue alternate methods to show that production engines comply with emission standards, which may lead to lower testing costs.

We may select up to 25 percent of a manufacturers’s engine families for in-use testing. This means that a manufacturer would need to have eight engine families for us to be able to select two engine families in a given year. Since this is likely to be a rare scenario, we project an annual testing rate of one engine family per year for each manufacturer to assess the cost of the in-use testing program. The analysis includes the cost of testing in-use engines on a dynamometer, which requires:

- engine removal and replacement ($4,000)

- transport ($1,000)
- steady-state and transient testing ($15,000)

Testing six engines and adding costs for administration and reporting of the testing program leads to a total cost of about $125,000 for an engine family. These costs can be spread over a manufacturer's total annual sales, which averages about 15,000 units for most companies. The resulting cost per engine is about $8.

As with production-line testing, we expect in-use emission testing to simultaneously satisfy California ARB and EPA requirements. In certain circumstances, however, we may use our discretion to direct a manufacturer to do in-use testing on an engine family separately from California ARB. Since we expect this to be the exception, this analysis likely overestimates the cost impact of adopting federal requirements to do in-use testing. In fact, manufacturers may reduce their compliance burden with the optional field-testing procedures. Table 5.2.2-5 shows the estimated costs from the various compliance programs.

In addition, we expect several manufacturers to upgrade testing facilities to allow for in-house measurement of emissions during transient engine operation. We generally expect each major manufacturer to equip one test cell with a new dynamometer and the associated controllers and analyzers. Installation of transient test cell would cost about $500,000. This consists of about $225,000 each for an electric dynamometer and the associated controllers, and $50,000 for a battery of sampling equipment and analyzers. An additional capital cost of $80 is estimated for precision calipers with digital readout to ensure dimensional accuracy of catalyst diameters. Dividing these costs over six engine families for five years leads to a calculated per-engine cost under $10.

Table 5.2.2-5
Cost of Compliance Programs

Compliance Program Element	Estimated Per-Engine Costs
Certification	$6
In-use testing	$8
Facility upgrade	$7
Total	$21

5.2.2.4 Total Costs

Table 5.2.2-6 presents the combined cost figures for the different engine types and calculates a composite cost based on their estimated distribution. The estimated 2004 costs are based on the adding component costs and compliance costs. No R&D cost is estimated for manufacturers to do additional development work beyond what is necessary to comply with

California ARB standards. Conversely, the estimated 2007 costs are based on R&D (and ongoing compliance costs), with no anticipated increase in component costs, except those related to reducing evaporative emissions. The estimated cost of complying with the emission standards is sizable, but the lifetime savings from reduced operating costs nevertheless more than compensate for the increased costs. Costs for gasoline engines are presented as a composite of air-cooled models (estimated 3 percent of total sales) and water-cooled models (estimated 20 percent of total sales).

Table 5.2.2-6
Estimated First-Year Cost Impacts of New Emission Standards

Standards	Engine Type	Sales Mix of Engine Types	Increased Production Cost per Engine*	Lifetime Operating Costs per Engine (NPV)
2004	LPG	68%	$550	$-4,330
	natural gas	9%	$550	$-1,650
	gasoline	23%	$800	$-3,140
	Composite	—	$605	$-3,815
2007	LPG	68%	$40	—
	natural gas	9%	$40	—
	gasoline	23%	$60	$-100
	Composite	—	$50	$-20

*The estimated long-term costs decrease by about 35 percent.

5.2.2.5 Large SI Aggregate Costs

The above analyses developed incremental per-vessel cost estimates for Large SI engines. Using these per-engine costs and projections of future annual sales, we have estimated total aggregate annual costs for the exhaust and evaporative emission standards. The aggregate costs are presented on a cash-flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the engines are operated over their lifetimes. Table 5.2.2-7 presents a summary of this analysis. As shown in the table, aggregate costs generally range from $70 million to $90 million. Net costs decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used. Fuel savings are projected to more than offset the costs of the program starting by the second year of the program.

Table 5.2.2-7: Summary of Annual Aggregate Costs and Fuel Savings for Large SI Engines (millions of dollars)

	2004	2005	2010	2015	2020
Total Costs	$89	$91	$71	$73	$81
Fuel Savings	($53)	($103)	($326)	($421)	($472)
Net Costs	$36	($12)	($255)	($348)	($391)

To project annual sales, we started with the number of model year 2000 engines estimated by the NONROAD model for the 2000 calendar year. We then applied a growth rate of 3 percent of year 2000 sales (increasing by 3,900 units annually) to estimate future sales. Table 5.2.2-8 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.2-8
Estimated Annual Sales of Large SI Engines

2000	2004	2010	2020
130,000	145,600	169,000	208,000

To calculate annual aggregate costs, the sales estimates have been multiplied by the per-unit costs. Annual fuel savings have been calculated based on the reduction in fuel consumption expected from the standards (as described in section 5.2.2.2 of this chapter) as calculated by the NONROAD model. The model takes into consideration vehicle sales and scrappage rates. The year-by-year results of the analysis are provided in Chapter 7.

5.2.3 Recreational Vehicles

5.2.3.1 Technologies and Estimated Costs

We estimated costs separately for snowmobiles, ATVs, and off-highway motorcycles. Individual technology costs were developed in cooperation with EPA by ICF Incorporated and Arthur D. Little - Acurex Environmental.[11] Any comments received on the rule were also evaluated and included where appropriate. Costs were prepared for a typical engine that falls within the displacement ranges noted below. Costing out multiple engine sizes allowed us to estimate significant differences in costs for smaller vs. larger engines. The costs include a mark-up to the retail level. This Chapter also provides a brief overview of the technologies, with more information provided in Chapter 4. Costs are provided for both the baseline technology and the new technology (e.g., a two-stroke engine and a four-stroke engine), with the cost of the change in technology due to the new standards being the increment between the two costs.

The R&D costs shown are average costs. The first engine line R&D cost is expected to be significantly higher but the costs would be distributed across the manufacturer's entire product line.[12] To account for any additional warranty cost associated with a change in technology, we have added 5 percent of the incremental hardware cost.[13]

As noted in section 5.1, fixed costs are spread over the first five years of sales for purposed of the cost analysis, with the exception of new facility costs for ATV testing which are spread over 10 years. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used for at least that long a time period. We estimated that R&D and facility costs will be incurred three years prior to production on average and tooling and certification costs will be incurred one year prior to production. These fixed costs were then increased seven percent for each year prior to the start of production to reflect the time value on money.

To approximate average annual sales per engine line, we divided the total 2001 annual unit sales by estimated total number of engines lines industry-wide.[ee] Based on limited sales data from individual manufacturers provided to EPA on a confidential basis, there appears to be a large distinction in sales volume between small engine and large engine displacements for ATVs. The cost analysis accounts for this difference by using a larger annual sales rate per engine line for larger displacement ATVs, as shown below.

As noted below, the fuel savings over the life of the vehicle due to some of the projected technology changes can be substantial and for snowmobiles are projected to offset the cost of the emission controls. As discussed below, these fuel savings will occur because 2-stroke powerplants are inefficient and the changes needed to reduce hydrocarbons from these engines also improve fuel consumption. Because the fuel savings outweigh up front costs, one might question why manufacturers have continued to use 2-stroke engines. Manufacturers have not made these changes in the absence of emission standards for several likely reasons. Since fuel costs are not a significant portion of the overall price of ownership, customers may not place a high value on fuel economy compared to initial cost and engine simplicity. Especially in the case of snowmobiles and off-road motorcycles, manufacturers have built a customer base over many years using 2-stroke technology; ATVs which are dominantly 4-stroke are relatively new to the recreational vehicle market.. The engines are relatively simple and the production costs are relatively low because the manufacturers have been building the engines for many years. To capture the fuel economy benefits, manufacturers would have to invest substantially in R&D and more complex powerplants in the face of uncertainty with regard to market acceptance of the new product. Such a move could also lower profits per vehicle. Considering all these factors, manufacturers have historically chosen to focus improvements in other areas such as increasing horsepower and overall vehicle design.

[ee] Based on publicly available product information for the large manufacturers, we estimated 32 engine lines for snowmobiles, 43 lines for ATVs, and 42 lines for off-highway motorcycles for the 2001 model year.

However, manufacturers are now introducing 4-strokes and direct injection 2-stroke engines into the snowmobile market. For model year 2003, all manufacturers will have at least one 4-stroke snowmobile model available and one manufacturer is introducing direct injection 2-stroke technology. This may mean that manufacturers are adjusting their perspectives on potential marketplace acceptance of advanced technologies.

5.2.3.1.1 Snowmobiles

Phase 1

Snowmobiles are currently almost exclusively powered by carbureted 2-stroke engines. However, as noted above, manufacturers are beginning to introduce 4-strokes and 2-stroke direct fuel injection. Manufacturers have also provided comment that they plan to rely more heavily on these technologies to meet Phase 1 standards than originally thought prior to proposal. For these reasons, we have adjusted our projected baseline technology mix as well as our projected technology mix for the Phase 1 standards for purposes of the cost analysis. Based on discussions with manufacturers, we believe that up to 10 percent of production will be 4-stroke and 10 percent will be direct fuel injection for Phase 1. We believe manufacturers will be ramping up the introduction of these technologies in order to obtain experience with them prior to the start of the program. These technologies will provide surplus emissions reductions which will allow the manufacturers to use lesser technologies on other models under the averaging program.

For cost purposes, we are projecting that 4-stroke engines are likely to be equipped with electronic fuel injection systems to optimize emissions and overall performance of these engines. Therefore we are including electronic fuel injection costs for 4-strokes. Tables 5.2.3-1 through 5.2.3-4 provide costs for direct injection systems (both air assisted direct injection and pump assisted direct injection) and for converting from a 2-stroke to 4-stroke engine with electronic fuel injection.

We have estimated the incremental cost of going from carbureted 2-stroke to direct injection to range from \$262 to \$342 per engine and conversion to 4-stroke to be about \$454 to \$770. Electronic fuel injection for snowmobiles is estimated to incrementally cost \$174 to \$119. Note that the overall consumer costs for these advanced technologies are substantially lower after the fuel economy improvements are taken into account. Estimates of the fuel savings are provided below. For 4-stroke snowmobiles, where possible, we have examined available price information on manufacturer web sites for the various 4-stroke models and comparable 2-stroke models and found price differences to be similar to our cost estimates in most cases. We did not receive detailed public comments on our cost estimates for the various snowmobile technologies.

Table 5.2.3-1: Air Assisted Direct Injection System Costs for Snowmobiles

	< 500 cc		> 500cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Fuel Metering Solenoid (each)		$15		$15
Number Required		2		3
Air Pump		$25		$25
Air Pump Gear		$5		$5
Air Pressure Regulator		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Electric Fuel Pump	$5	$5	$5	$5
Fuel Pressure Regulator		$3		$3
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$324	$185	$339
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$100	$55	$107
Royalty @ 3%		$10		$10
Warranty Mark-up @ 5%		$10		$8
Total Component Costs	**$164**	**$464**	**$243**	**$493**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$13**	**$0**	**$13**
Total Costs	**$164**	**$476**	**$243**	**$505**
Incremental Total Cost		**$312**		**$263**

Table 5.2.3-2: Pump-Assisted Direct Fuel Injection System Costs for Snowmobiles

	< 500cc		**> 500cc**	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Nozzle/Accumulator (each)		$33		$33
Number Required		2		3
High-Pressure Cam Fuel Pump		$20		$25
Cam Pump Gear		$5		$5
Throttle Body/Position Sensor		$35		$35
Intake Manifold		$30		$30
Fuel Transfer Pump	$5	$5	$5	$5
ECM		$140		$140
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$11		$11
Injection Timing Sensor/Timing Wheel		$10		$10
Wiring/Related Hardware		$20		$20
Hardware Cost to Manufacturer	$125	$347	$185	$385
Labor @ $28 per hour	$1	$14	$2	$21
Labor overhead @ 40%	$1	$6	$1	$8
OEM mark-up @ 29%	$37	$106	$55	$120
Royalty @ 3%		$10		$12
Warranty Mark-up @ 5%		$11		$10
Total Component Costs	**$164**	**$494**	**$243**	**$556**
Fixed Cost to Manufacturer				
R&D Costs	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$13**	**$0**	**$13**
Total Costs	**$164**	**$506**	**$243**	**$568**
Incremental Total Cost		**$343**		**$327**

Table 5.2.3-3: Two-Stroke to Four Stroke Conversion Costs for Snowmobiles

	< 500 cc		> 500 cc	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4-Stroke**
Engine	$400	$700	$650	$1,170
Clutch	$50	$75	$80	$120
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$136	$233	$217	$383
Warranty Mark up @ 5%		$16		$28
Total Component Costs	**$606**	**$1,053**	**$967**	**$1,730**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$20,000	$0	$20,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$7**	**$0**	**$7**
Total Costs	**$606**	**$1,060**	**$967**	**$1,737**
Incremental Total Cost		**$455**		**$770**

Table 5.2.3-4: Electronic Fuel Injection Costs for Snowmobiles

Fuel Injection Costs	400cc		700cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60		$60	
Number Required	2		3	
Injectors (each)		$12		$12
Number Required		2		3
Pressure Regulator		$10		$10
Intake Manifold		$30		$35
Throttle Body/Position Sensor		$35		$35
Fuel Pump	$5	$20	$5	$20
ECM		$100		$100
Air Intake Temperature Sensor		$5		$5
Manifold Air Pressure Sensor		$10		$10
Injection Timing Sensor		$5		$5
Wiring/Related Hardware		$10		$10
Hardware Cost to Manufacturer	**$125**	**$249**	**$185**	**$266**
Labor @ $28 per hour	$1	$4	$2	$6
Labor Overhead @ 40%	$1	$2	$1	$3
Manufacturer Mark-up @ 29%	$37	$72	$54	$77
Warranty Mark-up[a] @ 5%		$6		$4
Total Component Costs	**$164**	**$333**	**$242**	**$356**
Fixed Cost to Manufacturer				
R&D Costs	$0	$69,417	$0	$69,417
Tooling Costs	$0	$10,000	$0	$10,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$5**
Total Costs ($)	**$164**	**$338**	**$242**	**$361**
Incremental Total Cost ($)		**$175**		**$119**

In addition to the advanced technologies, we are also basing the cost analysis for Phase 1 standards on some use of engine modifications, carburetor improvements, and recalibration. We are projecting lower usage of this approach compared to the proposal (60% compared to 100%) based on the comments we received concerning the use of advanced technology to meet Phase 1 standards. Manufacturers are likely to be able to reduce emissions for some models by leaning out the air/fuel mixture, improving carburetors for better fuel control and less production variation, and modifying the engine to withstand higher temperatures and potential misfire episodes attributed to enleanment. Engine modifications are also likely to be made to improve air/fuel mixing and combustion. The cost estimates for engine modifications and carburetor improvements are provided in Tables 5.2.3-5 and 5.2.3-6. Recalibration work is included as part of the R&D for the technologies. The incremental cost per unit for engine modifications is estimated to be $18 to $25, with modifications to the carburetor estimated to cost an additional $18 to $24 per engine.

Table 5.2.3-5: Snowmobile Engine Modification Costs for Two-Stroke Engines

	< 500 cc		> 500 cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Improved Pistons	$10	$12	$12	$15
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$20	$24	$36	$45
Labor @ $28 per hour	$6	$6	$8	$8
Labor Overhead @ 40%	$2	$2	$3	$3
Manufacturer Mark-up @ 29%	$6	$7	$10	$13
Warranty Mark-up @ 5%		$0		$0
Total Component Costs	$34	$39	$57	$69
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$178,500	$0	$178,500
Tooling Costs	$0	$25,000	$0	$25,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	$0	$13	$0	$13
Total Costs	$34	$51	$57	$81
Incremental Total Cost		$18		$25

Table 5.2.3-6: Modified Carburetor Costs for Snowmobiles

	< 500 cc		> 500 cc	
	Baseline	Modified	Baseline	Modified
Hardware Costs				
Carburetor	$60	$65	$60	$65
Number Required	2	2	3	3
Hardware Cost to Manufacturer	$120	$130	$180	$195
Labor @ $28 per hour	$1	$1	$2	$2
Labor Overhead @ 40%	$1	$1	$1	$1
Manufacturer Mark-up @ 29%	$35	$38	$53	$57
Warranty Mark-up @ 5%		$1		$1
Total Component Costs	**$157**	**$171**	**$236**	**$256**
Fixed Cost to Manufacturer				
R&D Costs per line	$0	$61,875	$0	$61,875
Tooling Costs	$0	$5,000	$0	$5,000
Units/yr.	4,400	4,400	4,400	4,400
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$4**	**$0**	**$4**
Total Costs	**$157**	**$175**	**$236**	**$260**
Incremental Total Cost		**$18**		**$24**

Phase 2 and Phase 3

We have based the cost analysis for the Phase 2 and Phase 3 standards primarily on the expanded use of direct fuel injection 2-stroke engines and 4-stroke engines. We expect that by the 2010 time frame these two technologies will be fully developed and able to be used on a larger fraction of the fleet. Our projections that these later Phases will be met primarily through the expanded use of these technologies is consistent with our discussions with manufacturers. This chapter provides a cost analysis for the primary Phase 2 program which calls for a 50 percent reduction from baseline levels for both HC and a 30 percent reduction for CO emissions in 2010. The Phase 3 standard begins in 2012 and requires a further reduction in CO from 30 percent to 50 percent. Manufacturers have some flexibility in meeting the Phase 3 standards which allows them to meet less stringent CO requirements if additional HC reductions are achieved. We would expect the same technologies to be used to meet these all of these programs but in somewhat different combinations. For example, some manufacturers may rely on 4-stroke technology more so than direct injection 2-stroke technology. This is discussed in detail in Chapter 4. With averaging, manufacturers, will optimize their technology paths for each phase of standards and each manufacturer will have somewhat different mixes of technology.

For Phase 2 and Phase 3, we are projecting that 50 and 70 percent of models, respectively, will be equipped with either direct injection 2-stroke or 4-stroke engines. We anticipate that remaining models will consist of 2-stroke technologies with some further optimization. One additional technology that may be used is pulse air. We are projecting the use of pulse air systems with recalibration on a portion of the snowmobile engines that are not equipped with advanced technology systems. Pulse air provides a small incremental emission reduction for these engines and would help manufacturers meet the Phase 2 and Phase 3 average HC and CO standards. As shown in Table 5.2.3-7, we have estimated pulse air to cost about $40. Catalysts are also a potential option for snowmobiles but would entail a significant R&D effort and may not be available for snowmobile applications in the 2010 time frame. However, we believe manufacturers are more likely to focus on developing the advanced technologies noted above, which provide the consumer with benefits in addition to lower emissions. Therefore, we have not included catalyst costs in our cost estimates.

Table 5.2.3-7: Calibration/Pulse-Air Costs for Snowmobiles

	Baseline	**Modified**
Hardware Costs		
Pulse Air Valve		$18
Labor @ $28 per hour		$1
Labor overhead @ 40%		$0
Markup @ 29%		$5
Warranty Mark up @ 5%		$0
Total Component Costs	**$0**	**$25**
Fixed Cost to Manufacturer		
R&D Costs		$54,750
Tooling Costs		$200,000
Units/yr.		4,400
Years to recover		5
Fixed cost/unit		**$15**
Total Costs	**$0**	**$40**
Incremental Total Cost		**$40**

5.2.3.1.2 All-terrain Vehicles (ATVs)

ATVs are equipped primarily with carbureted 4-strokes, with 2-stroke engines used mostly in small displacement and sport models. We expect manufacturers to take several steps in response to the standards and test cycle requirements. Beginning in 2006, we expect most manufacturers will take some advantage of the transitional interim test procedures and standards offered from 2006-2008 but will need to phase out the use of 2-stroke engines. In addition, for the 4-stroke ATVs, we are also projecting that as manufacturers transition to the chassis test cycle, recalibration will be needed and that pulse air systems will be used on about 50 percent of the models to ensure that the fleet meets the standards on average. Pulse air systems are currently used on a few ATV and off-highway motorcycles models to meet California standards. We do not believe that the level of the standards will require the use of pulse air beyond 50 percent, given that only a few models in California are currently equipped with the technology. Using pulse air may give the manufacturer more flexibility in calibrating for performance on some models. Technological feasibility is discussed in Chapter 4.

We are basing our technology projection on what manufacturers have done to meet the California emissions standards. We believe this to be the most likely technology path for manufacturers, because 4-strokes are accepted in the market and provide consumers with fuel economy and reliability benefits. Beyond using 4-stroke engines, we expect manufacturers to undertake an R&D effort to recalibrate models and select and optimize pulse air systems. Some recalibration is likely, due to the change in test procedures. We received comments that we underestimated the amount of R&D necessary for ATVs and, upon evaluation, have adjusted the estimates upwards. We continue to believe manufacturers will approach this effort in an orderly manner and we would expect them to focus R&D on a first engine line and then apply what they learn to subsequent lines.[ff] Table 5.2.3-8 provides the estimated R&D for ATVs. We believe the increased level of R&D shown below is substantial considering the technological difficulty of the final standards. We believe the estimated amounts also are sufficient because manufacturers have already invested in R&D and technology to meet the California program which contains standards that are similar in stringency.

Table 5.2.3-8: R&D Cost Estimate for ATVs

	< 200 cc	**> 200 cc**
Base R&D Costs for 1st engine line	$724,000	$724,000
Engine lines per manufacturer	8	8
Base R&D per line	$90,500	$90,500
Individual Engine Line R&D	$238,000	$238,000
Total R&D per line	328,500	$328,500
Units/yr.	5,600	20,000
Years to recover	5	5
R&D Fixed cost/unit	**$16.40**	**$4.59**

Tables 5.2.3-9 and 5.2.3-10 provide cost estimates for the ATV technologies discussed above. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $219 to $349, depending on engine size. Costs for a mechanical pulse air system is estimated to be about $27 to $33 per unit. As shown in the tables below, fixed costs

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[ff] We have estimated a base R&D effort of 12 months for the first engine line and 6 additional months for subsequent lines and have used the costing methodology provided in the Arthur D. Little - Acurex cost report to calculate the increased R&D cost.

for larger displacement models are spread over a significantly larger annual unit sales volume to account for the relatively high average number of unit sales per engine line for these products.

Table 5.2.3-9: Two-Stroke to Four Stroke Conversion Costs for ATVs

	< 200 cc		**> 200 cc**	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4 Stroke**
Hardware Costs				
Engine	$400	$550	$500	$750
Labor @ $28 per hour	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8
Markup @ 29%	$122	$168	$151	$226
Warranty Mark up @ 5%		$8		$13
Total Component Costs	**$542**	**$755**	**$671**	**$1,018**
Fixed Cost to Manufacturer				
R&D Costs	$0	$94,416	$0	$94,416
Tooling Costs	$0	$15,000	$0	$18,000
Units/yr.	5,6200	5,600	20,000	20,000
Years to recover	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$2**
Total Costs	**$541**	**$760**	**$670**	**$1,019**
Incremental Total Cost		**$219**		**$349**

Table 5.2.3-10: Pulse-Air Costs for Four-Stroke ATVs

	< 200 cc		> 200 cc	
	Baseline	**Modified**	**Baseline**	**Modified**
Hardware Costs				
Pulse Air Valve		$18		$18
Labor @ $28 per hour		$1		$1
Labor overhead @ 40%		$0		$0
Markup @ 29%		$5		$5
Warranty Mark up @ 5%		$0		$0
Total Component Costs	**$0**	**$25**	**$0**	**$25**
Fixed Cost to Manufacturer				
Tooling Costs		$159,091		$159,091
Units/yr.		5,600		20,000
Years to recover		5		5
Fixed cost/unit		**$7**		**$2**
Total Costs	**$0**	**$33**	**$0**	**$27**
Incremental Total Cost		**$33**		**$27**

5.2.3.1.3 Off-highway Motorcycles

Currently, off-highway motorcycles are about 65 percent 2-stroke, with many of the 2-stroke engines used in competition and youth models. As with ATVs, we expect that manufacturers will meet standards primarily by using 4-stroke engines. Manufacturers may also use pulse air systems and recalibration on a relatively small fraction of their models to ensure their overall fleet meets the standards. We have estimated their use for off-highway motorcycles at about 25 percent for purposes of the cost analysis. The R&D efforts will likely be lower for off-highway motorcycles than for ATVs because the level of the standard is less stringent and there is no change in the test procedure from what is now required in California. We do not believe the standards will require pulse air technology in more than 25 percent of models, given that only a few models in California are currently equipped with this technology. As discussed in 5.2.3.4 below, vehicles used solely for competition are exempt from standards and we expect some 2-stroke competition models to remain in the market.

Tables 5.2.3-11 and 5.2.3-12 provide cost estimates for off-highway motorcycle technologies for three engine displacement ranges. We estimate the incremental cost per unit of replacing a 2-stroke engine with a 4-stroke engine to be about $219 to $353, depending on engine size. Costs for a mechanical pulse air valve system and recalibration is estimated to be about $39 per unit.

Table 5.2.3-11: Two-Stroke to Four Stroke Conversion Costs for Off-highway Motorcycles

	< 125 cc		**125cc < 250 cc**		**≥ 250cc**	
	2-Stroke	**4-Stroke**	**2-Stroke**	**4-Stroke**	**2-Stroke**	**4-Stroke**
Hardware Costs						
Engine	$400	$550	$450	$650	$500	$750
Labor @ $28 per hour	$14	$21	$14	$21	$14	$21
Labor overhead @ 40%	$6	$8	$6	$8	$6	$8
Markup @ 29%	$122	$168	$136	$197	$151	$226
Warranty Mark up @ 5%		$8		$10		$13
Total Component Costs	**$542**	**$755**	**$606**	**$886**	**$671**	**$1,018**
Fixed Cost to Manufacturer						
R&D Costs	$0	$94,416	$0	$94,416	$0	$94,416
Tooling Costs	$0	$15,000	$0	$15,000	$0	$15,000
Units/yr.	6,000	6,000	6,000	6,000	6,000	6,000
Years to recover	5	5	5	5	5	5
Fixed cost/unit	**$0**	**$5**	**$0**	**$5**	**$0**	**$5**
Total Costs	**$542**	**$760**	**$606**	**$891**	**$670**	**$1,023**
Incremental Total Cost		**$219**		**$286**		**$353**

Table 5.2.3-12: Four-stroke Calibration/Pulse-Air Costs for Off-highway Motorcycles

	< 125 cc		125 < 250 cc		≥ 250cc	
	Baseline	**Modified**	**Baseline**	**Modified**	**Baseline**	**Modified**
Hardware Costs						
Pulse Air Valve		$18		$18		$18
Labor @ $28 per hour		$1		$1		$1
Labor overhead @ 40%		$0		$0		$0
Markup @ 29%		$5		$5		$5
Warranty Mark up @ 5%		$1		$1		$1
Total Component Costs	**$0**	**$25**	**$0**	**$25**	**$0**	**$25**
Fixed Cost to Manufacturer						
R&D Costs		$54,750		$54,750		$54,750
Tooling Costs		$250,000		$250,000		$250,000
Units/yr.		6,000		6,000		6,000
Years to recover		5		5		5
Fixed cost/unit		**$14**		**$14**		**$14**
Total Costs ($)	**$0**	**$39**	**$0**	**$39**	**$0**	**$39**
Incremental Total Cost ($)		**$39**		**$39**		**$39**

5.2.3.1.4 Crankcase Controls

The proposal included a requirement for crankcase emission controls for recreational vehicles. Crankcase controls have been required on passenger cars for more than 30 years, and it is normally a simple process of routing crankcase exhaust emissions to the engine intake to be burned as part of normal engine operation. Most current 4-stroke recreational vehicle engines use positive crankcase ventilation systems today; crankcase emissions are not significant in current 2-stroke engines. For those converting to 4-stroke in the future, crankcase controls will be required at a cost of about $3 per engine. These are included in the 2-stroke to 4-stroke conversion and replacement costs.

5.2.3.1.5 Permeation Control from Recreational Vehicles

As discussed in earlier chapters, we believe that there are several technologies that could be used to meet the permeation emission standards. Table 5.2.3-13 presents our best estimates of the costs of applying various evaporative emission control technologies to recreational vehicles using the average fuel tank sizes and hose lengths discussed in Chapter 6.

The cost for including low permeation barrier platelets in blow-molded fuel tanks (generally known as Selar®) is based on increased material costs. No changes should be necessary to the blow-molding equipment. We used 10 percent EVOH which is about $3 per pound and 90 percent HDPE which is about $0.50 per pound. This equates to a price increase of about $0.30 per pound. Depending on the shape of the fuel tank and the wall thickness, recreational vehicle fuel tanks weigh about 1-1.3 pounds per gallon of capacity. Costs for multi-layer fuel tanks with continuous barriers are not included, but would be expected to be higher because two additional injection screws would be necessary for the barrier and adhesion layers. Another option would be to mold the entire fuel tank of a low permeation material such as nylon, an acetal copolymer, or a thermoplastic polyester. These materials have list prices of about $2.00 per pound; therefore, the cost of using these alternative materials would be about 7 times higher than presented below for barrier platelets with 10% EVOH.

Surface treatment costs are based on price quotes from a companies that specialize in this fluorination[14] and sulfonation.[15] The fluorination costs are a function of the geometry of the fuel tanks because they are based on how many fuel tanks can be fit in a treatment chamber. The price sheet referenced for our fluorination prices assumes rectangular shaped containers. For irregular shaped fuel tanks, the costs would be higher because they would have to be fit into baskets with volumes larger than the volume of the fuel tanks. Therefore, we consider a void space equal to about 25 percent of the volume of the fuel tank. For sulfonation, the shape of the fuel tanks is less of an issue because the treatment process is limited only by the spacing on the production line which is roughly the same for the range of fuel tank sizes used in recreational vehicles. These prices do not include the cost of transporting the tanks; we estimated that shipping, handling and overhead costs would be an additional $0.22 to $0.81 per fuel tank depending on tank size.[16]

Barrier fuel hose incremental costs estimates are based on costs of existing products used in marine and automotive applications.[17,18,19] We estimate that the cost increment compared to R7 hose used in most recreational applications today is about $0.60 per foot. Some manufacturers have commented that they do not use hose clamps today, but would need them if they use barrier hose. Other manufacturers already use hose clamps, but may need to upgrade them in some applications. To be conservative, we consider the cost of adding hose clamps to all applications. These hose clamps cost about $0.20 each.[20] For ATVs and OHMCs, we include the costs of two hose clamps for each vehicle (one for each end of the hose). Snowmobiles can require 4 to 8 hose clamps depending on the fuel pump configuration, number of carburetors, and if a fuel return line is included. We include the cost of 6 hose clamps for snowmobiles in this analysis.

Table 5.2.3-13: Permeation Control Technologies and Incremental Costs

Technology		*Snowmobiles* *11 gallon tank* *3.5 ft. hose*	*ATVs*** *4 gallon tank* *1 ft. hose*	*OHMCs* *3 gallon tank* *1.5 ft. hose*
barrier platelets (10% EVOH)		$3.30	$1.50	$1.20
sulfonation	treatment*	$1.50	$1.20	$1.20
	shipping/handling	$0.81	$0.30	$0.22
fluorination	treatment*	$8.39	$3.23	$2.42
	shipping/handling	$0.81	$0.30	$0.22
1/4" I.D. hose	barrier fuel hose*	$2.71	$0.77	$1.16
	hose clamps*	$1.55	$0.52	$0.52

* includes a 29% markup for overhead and profit

** includes utility vehicles

Manufacturers, with high enough production volumes, could reduce the costs of sulfonating fuel tanks by constructing an in-house treatment facility. The cost of a sulfonation production line facility that could treat 150-500 thousand fuel tanks per year would be approximately $800,000.[21] This facility, which is designed to last at least 10 years, is made up of a SO_3 generator, a scrubber to clean up used gas, a conveyor belt, and injection systems for the SO_3 gas and for the neutralizing agent (ammonia solution). The manufacturer of this equipment estimates that the operating costs, which includes electricity and chemicals, would be about 3 cents per tank. Based on a production capacity of 150,000 units per year, and a 10 year life, the average sulfonation cost per fuel tank would be about $0.60. These costs would be lower for higher production volumes. In addition, if a manufacturer were to sulfonate their fuel tanks in-house, they would not need to pay shipping and handling costs.

To determine the total costs per recreational vehicle we use the scenario that all manufacturers use sulfonation to reduce permeation from their fuel tanks and use barrier fuel hose. For this analysis, we consider the cost of shipping fuel tanks to an outside vendor for treatment rather than using the lower cost of in-house sulfonation. For competition off-highway motorcycles, which make up about 29 percent of OHMC sales, we assume that no low permeation technology would be used. We estimate the total per vehicle costs to be $6.56 for snowmobiles, $2.79 for ATVs, and $3.10 for non-competition OHMCs. Weighting a cost of $0 for competition OHMCs, we get an average cost of $2.14 per off-highway motorcycle. These costs do not include the fuel savings associated with a reduction permeation which is discussed below in section 5.2.3.2.3.

As a sensitivity analysis, we estimated what the costs would be if the fuel tank permeation control technology applied by manufacturers were equally distributed by barrier platelets, sulfonation, and fluorination. Not considering fuel costs, the estimated fuel tank costs, under this scenario, would be $4.93 for snowmobiles, $2.18 for ATVs, and $1.75 for non-competition OHMCs. This represents about a 20-100% increase in the cost estimates for fuel tanks (no change in fuel hose costs). However, we believe that manufacturers are likely to use sulfonation to meet the fuel tank permeation standards because it appears to be the most cost effective strategy in most cases. Although barrier platelets and fluorination could likely be applied earlier, we believe that we are providing adequate lead time for manufacturers to incorporate sulfonation into their commercial processes.

5.2.3.2 Operating Cost Savings

5.2.3.2.1 Snowmobiles

Both direct injection and conversion from two-stroke to 4-stroke yield substantial fuel economy benefits. Typical 2-stroke engines have relatively poor fuel economy performance because a portion of the combustion mixture passes through the engines unburned. Because 4-stroke and direct injection 2-stroke engine designs essentially do not allow this to occur, they provide better fuel economy as well as substantially lower HC emissions. We have estimated fuel savings based on a 25 percent reduction in fuel consumption, based on typical performance of these technologies. Lifetime fuel costs are provided in Table 5.2.3-14.[22, 23]

Table 5.2.3-14: Fuel Cost for Snowmobiles

Engine	Baseline 2-Stroke		Advanced Technology Engines (25% savings)	
	small	large	small	large
Engine power	45	100	45	100
Load Factor	0.34	0.34	0.34	0.34
Annual Operating Hours, hr/yr	57	57	57	57
Lifetime, yr	12	12	12	12
BSFC, lb/bhp-hr	1.66	1.25	1.66	1.25
Fuel Density (lbs/gal)	6.17	6.17	6.17	6.17
Fuel Cost ($/gal)*	$1.10	$1.10	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	235	521	176	391
Yearly Fuel Cost ($/yr)	$258	$574	$194	$430
Lifetime Fuel Cost (NPV)	**$2,050**	**$4,556**	**$1,537**	**$3,417**

* Excluding taxes

5.2.3.2.2 ATVs and Off-highway Motorcycles

Conversion from 2-stroke to 4-stroke engines yields a fuel economy improvement for ATVs and off-highway motorcycles as well. Tables 5.2.3-15 and 5.2.3-16 provide estimates of fuel consumption for both 2-stroke and 4-stroke engines. We have estimated that switching from a 2-stroke to a 4-stroke engine reduces fuel consumption by about 25 percent. Lifetime fuel savings for ATVs resulting from switching from a 2-stroke to a 4-stroke engine is estimated to be $124. For off-highway motorcycles, the projected lifetime fuel savings is $140.

Table 5.2.3-15: Fuel Cost for ATVs

Engine	2-Stroke	4-Stroke
Annual Miles	1,570	1,570
Lifetime, yr	13	13
BSFC, lb/mile	0.213	0.160
Fuel Density (lbs/gal)	6.17	6.17
Fuel Cost ($/gal)*	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	54	41
Yearly Fuel Cost ($/yr)	$60	$45
Lifetime Fuel Cost (NPV)	**$498**	**$374**

* Excluding taxes

Table 5.2.3-16: Fuel Cost Savings for Off-highway Motorcycles

Engine	2-Stroke	4-Stroke
Annual Miles	1,600	1,600
Lifetime, yr	12	12
BSFC, lb/mile	0.268	0.201
Fuel Density (lbs/gal)	6.17	6.17
Fuel Cost ($/gal)*	$1.10	$1.10
Yearly Fuel Consumption (gal/yr)	68	52
Yearly Fuel Cost ($/yr)	$75	$57
Lifetime Fuel Cost (NPV)	**$594**	**$454**

* Excluding taxes

5.2.3.2.3 Permeation Control Fuel Savings

Evaporative emissions are essentially fuel that is lost to the atmosphere. Over a the lifetime of a typical recreational vehicle, this can result in a significant loss in fuel. The anticipated reduction in evaporative emissions due to the permeation standards will result in significant fuel savings. Table 5.2.3-17 presents the value of the fuel savings for control of permeation emissions. These numbers are calculated using an estimated fuel cost of $1.10 per gallon and fuel density of 6 lbs/gallon (for lighter hydrocarbons which evaporate first). The figures in Table 5.2.3-17 are based on the per vehicle emissions described in Chapter 6.

Table 5.2.3-17: Fuel Savings Per Vehicle Due to the Proposed Standards

Average Parameters	Snowmobiles	ATVs	OHMCs
Evaporative HC reduced [tons/life]	0.0396	0.0221	0.0177
Fuel savings [gallons/life]	13	7	6
Undiscounted savings [$/life @$1.10/gal]	$14	$8	$6
Lifetime fuel savings (NPV, 7%)	$11	$6	$5

5.2.3.3 Compliance Costs

We estimate ATV and off-highway motorcycle chassis-based certification to cost about $25,000 per engine line, including $10,000 for engineering and clerical work and $15,000 for durability and certification testing. For snowmobile engine-based certification, we estimate costs to be about $30,000, recognizing that engine testing is somewhat more expensive than vehicle testing due to the time needed to set up the engine on the test stand. As with other fixed costs, we amortized the cost over 5 years of engine sales to calculate per unit certification costs shown in Table 5.2.3-18. The actual certification costs for ATVs and off-highway motorcycles are likely to be lower than those shown in the table above because manufacturers are likely to use certification data generated for the California program.

Table 5.2.3-18: Estimated Per Unit Certification Costs

	Snowmobiles	ATVs		Off-highway Motorcycles
units/year/family	4,400	5,600	20,000	6,000
certification costs	$1.78	$1.17	$0.21	$1.09

We have estimated that manufacturers must test about 0.2 percent of their production to meet production-line testing requirements. Using per test costs of $2,500 for vehicle testing and $5,000 per test for engine testing, we estimate a per unit cost for production line testing of $5 for off-road motorcycles and ATVs and $10 for snowmobiles.

In general, we expect manufacturers to use existing test facilities. For manufacturers with insufficient chassis testing capabilities for ATVs, we expect them to carry over engine-based certifications from the California program during the transition period, but to phase-in chassis-based certification during the transition time frame. Because the option of engine-based testing is available for only three years, manufacturers will need to do chassis testing of ATVs by 2009. We have therefore estimated the cost of new chassis testing facilities to be included in the cost of the standards. The costs are based on an estimate provided by one manufacturer that a full test cell would cost $2 million to build. We have estimated that on average manufacturers will need two such facilities to conduct testing. The costs will vary somewhat among manufacturers depending on the state of their existing facilities and the number of vehicle families that must be certified. However, we believe that this is a generous estimate because some manufacturers will likely be able to upgrade existing test facilities instead of building new facilities.

By estimating $4 million per manufacturer, with 7 manufacturers, and amortizing the costs over 10 years (10 years x 729,000 units), we estimate an average per unit cost of $6.70. We have used 10 years for amortization rather than 5 years because we believe it is more representative for a capital investment that will be used at least that long.

5.2.3.4 Recreational Vehicle Total Costs

The analysis below combines the costs estimated above for various technologies into a total composite or average cost for each vehicle type. The composite analysis weights the costs by projecting the percentage of the use of various technologies, both in the baseline and control scenario, to project industry-wide average per vehicle costs. The technologies and the mix projections are discussed in Chapter 4 and are based largely on discussions with individual manufacturers and in some cases on confidential business information.

A summary of the estimated near-term and long-term per unit average incremental costs and fuel savings for recreational vehicles is provided in Table 5.2.3-19. Long-term costs do not include fixed costs, which are retired, and include cost reductions due to the learning curve.

Table 5.2.3-19: Total Average Per Unit Costs and Fuel Savings

	Snowmobile Phase 1	Snowmobile Phase 2	Snowmobile Phase 3	ATV	Off-highway Motorcycle
near-term costs	$80	$131	$89	$87	$158
long-term costs	$47	$77	$54	$45	$98
fuel savings (NPV)	($67)	($286)	($191)	($29)	($53)

Tables 5.2.3-20 through 5.2.3-24 provide the detailed average, or composite, per unit costs for snowmobiles, ATVs, and off-highway motorcycles. For snowmobiles, where there are three phases of standards, the costs are incremental to the previous standard. The composite costs are based on the estimated distribution of the different engine displacement ranges. We estimated an approximate distribution of sales among the displacement ranges using limited sales data provided by some manufacturers on a confidential basis and production data from Power Systems Research. Incremental costs are shown both for the near-term and long-term. Long term costs reflect the retirement of fixed costs and the affect of the learning curve, described in section 5.1.

Table 5.2.3-20: Estimated Average Costs For Snowmobiles (Phase 1)

		Cost	Lifetime Fuel Savings	Baseline	Phase 1	Incrementa l Cost	Incremental Fuel Savings
< 500 cc (30%)	engine modifications	$18	$0	0%	60%	$11	$0
	modified carburetor	$18	$0	0%	60%	$11	$0
	direct injection*	$328	($512)	7%	10%	$10	($15)
	electronic fuel injection	$175	$0	12%	15%	$5	$0
	4-stroke engine	$455	($512)	7%	10%	$14	($15)
	permeation control	$7	($11)	0%	100%	$7	($11)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$69	($41)
≥ 500 cc (70%)	engine modifications	$25	$0	0%	60%	$15	$0
	modified carburetor	$24	$0	0%	60%	$14	$0
	direct injection*	$295	($1,139)	7%	10%	$9	($34)
	electronic fuel injection	$119	$0	12%	15%	$4	$0
	4-stroke engine	$770	($1,139)	7%	10%	$23	($34)
	permeation control	$7	($11)	0%	100%	$7	($11)
	compliance	$12	$0	0%	100%	$12	$0
	total	--	--	--	--	$84	($79)
Near Term Composite Incremental Cost		--	--	--	--	**$80**	**($67)**
Long Term Composite Incremental Cost		--	--	--	--	**$47**	**($67)**

Table 5.2.3-21: Estimated Average Costs For Snowmobiles For Phase 2 Incremental to Phase 1

		Cost	Lifetime Fuel Savings	Phase 1	Phase 2	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	0%	30%	$12	$0
	direct injection*	$328	($512)	10%	35%	$82	($128)
	electronic fuel injection	$175	$0	15%	20%	$9	$0
	4-stroke engine	$455	($512)	10%	15%	$23	($26)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$128	($154)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	0%	30%	$12	$0
	direct injection*	$295	($1,139)	10%	35%	$74	($285)
	electronic fuel injection	$119	$0	15%	20%	$6	$0
	4-stroke engine	$770	($1,139)	10%	15%	$39	($57)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$132	($342)
Near Term Composite Incremental Cost		--	--	--	--	$131	($286)
Long Term Composite Incremental Cost		--	--	--	--	$77	($286)

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 5.2.3-22: Estimated Average Costs For Snowmobiles Phase 3 Incremental to Phase 2

		Cost	Lifetime Fuel Savings	Phase 2	Phase 3	Incrementa l Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	30%	30%	$0	$0
	direct injection*	$328	($512)	35%	50%	$49	($77)
	electronic fuel injection	$175	$0	20%	25%	$9	$0
	4-stroke engine	$455	($512)	15%	20%	$23	($26)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$83	($103)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	30%	30%	$0	$0
	direct injection*	$295	($1,139)	35%	50%	$44	($171)
	electronic fuel injection	$119	$0	20%	25%	$6	$0
	4-stroke engine	$770	($1,139)	15%	20%	$39	($57)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$91	($228)
Near Term Composite Incremental Cost		--	--	--	--	**$89**	**($191)**
Long Term Composite Incremental Cost		--	--	--	--	**$54**	**($191)**

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 5.2.3-23: Estimated Average Costs For ATVs

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$219	($124)	8%	100%	$202	($114)
	pulse air	$33	$0	0%	50%	$17	$0
	R&D for exhaust including recalibration	$16	$0	0%	100%	$16	$0
	permeation control	$3	($6)	0%	100%	$3	($6)
	compliance	$13	--	0%	100%	$13	--
	total	--	--	--	--	$251	($119)
> 200 cc (85%)	4-stroke engine	$349	($124)	93%	100%	$24	($9)
	pulse air/recalibration	$27	$0	0%	50%	$14	$0
	R&D for exhaust including recalibration	$5	$0	0%	100%	$5	$0
	permeation control	$3	($6)	0%	100%	$3	($6)
	compliance	$12	--	0%	100%	$12	--
	total	--	--	--	--	$58	($14)
Near Term Composite Incremental Cost		--	--	--	--	**$87**	**($29)**
Long Term Composite Incremental Cost		--	--	--	--	**$45**	**($29)**

Table 5.2.3-24: Estimated Average Costs For Off-highway Motorcycles (Non-competition models only)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 125 cc (37%)	4-stroke engine	$219	($140)	82%	100%	$39	($11)
	pulse air/recalibration	$39	$0	0%	25%	$10	$0
	permeation control	$3	($5)	0%	100%	$3	($5)
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$59	($16)
125 < 250 cc (21%)	4-stroke engine	$286	($140)	30%	100%	$200	($98)
	pulse air/recalibration	$39	$0	0%	25%	$10	$0
	permeation control	$3	($5)	0%	100%	$3	($5)
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$220	($103)
≥ 250 cc (42%)	4-stroke engine	$353	($140)	45%	100%	$194	($77)
	pulse air/recalibration	$39	$0	0%	25%	$10	$0
	permeation control	$3	($5)	0%	100%	$3	($5)
	compliance	$7	--	0%	100%	$7	--
	total					$214	($82)
Near Term Composite Incremental Cost		--	--	--	--	**$158**	**($53)**
Long Term Composite Incremental Cost		--	--	--	--	**$98**	**($53)**

The above table for off-highway motorcycles shows the anticipated split between two-stroke and 4-stroke models in the various engine size categories. Currently, off-highway motorcycles are about 63 percent 2-stroke with many of the 2-stroke engines used in competition and youth models. In recent years, more high performance and competition models have been successfully introduced with 4-stroke engines and there appears to be a trend toward increased use of 4-stroke engines. Models used solely for competition are exempt from emission standards. We expect some 2-stroke competition models to continue to be available under this exemption. For purposes of the cost analysis, we have estimated that 29 percent of all off-highway motorcycles will be exempt as competition models and that these models will be equipped with 2-stroke engines. We have based the estimate of exempt models on the our estimate of the current use of 2-strokes in the motocross market. We believe the emissions standards will be achievable for 4-stroke engines, especially with averaging, and that manufacturers would elect to certify all 4-stroke models to market them to the widest possible consumer base.

To account for the competition model exemption in the calculation of average costs, we have adjusted the percentage of 2-stroke engines from the overall baseline percentage of off-highway motorcycle sales using the 29 percent estimate noted above. This adjustment is necessary to determine average costs only for those off-highway motorcycles covered by the program. Table 5.2.3-25 provides our estimate of the baseline percentage of 2-strokes in overall sales and the percentage of the non-competition model sales.

Table 5.2.3-25: Estimated Off-highway Motorcycle Percent 2-stroke Engine Usage

Displacement	Overall Baseline 2-stroke percentage	Baseline 2-stroke percentage Excluding Competition Models
< 125 cc	42%	18%
125 to 249 cc	79%	70%
> 250 cc	68%	55%

5.2.3.5 Recreational Vehicle Aggregate Costs

The above analyses developed incremental per vehicle cost estimates for snowmobiles, ATVs, and off-highway motorcycles. Using these per vehicle costs and projections of future annual sales, we have estimated total aggregate annual costs for the recreational vehicles standards. The aggregate costs are presented on a cash flow basis, with hardware and fixed costs incurred in the year the vehicle is sold and fuel savings occurring as the vehicle is operated over its life. This may understate the time-value of the fixed costs because they are likely to be incurred before the vehicle is sold; however, this has a negligible effect on the results of this analysis. Table 5.2.3-26 presents a summary o f the results of this analysis. As shown in the table, aggregate net costs increase from about $65 million in 2006 to about $129 million in 2010. Net costs are projected then to decline as fuel savings continue to ramp-up as more vehicles meeting the standards are sold and used and fixed costs are amortized. Fuel savings are projected to more than offset the costs of the program starting in 2015.

Table 5.2.3-26
Summary of Annual Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
Snowmobiles	$6.58	$37.55	$41.91	$41.56	$41.56
ATVs	$42.46	$62.55	$49.69	$44.81	$44.81
Off-highway Motorcycles	$16.27	$24.24	$21.53	$22.63	$23.79
Permeation control	--	$4.59	$4.72	$4.83	$4.86
Total	$65.31	$128.93	$117.85	$113.83	$115.02
Fuel Savings	($1.60)	($39.90)	($121.70)	($187.00)	($212.60)
Net Costs	$63.71	$89.03	($3.85)	($73.17)	($97.58)

To project annual sales, we started with 2001 sales estimates provided by industry organizations. We then adjusted the numbers and applied sales growth estimates consistent with the modeling performed to estimate total emissions (see Section 6.2.4.1.1). For ATVs, we added 70,000 units to account for sales from companies not included in the industry organization estimates. Sales growth for snowmobiles and off-highway motorcycle sales is projected to be about one percent per year. The off-road motorcycle sales were reduced by 29 percent to account for the exemption of competition models. ATVs are modeled differently because recent sales growth rates have been significantly higher than one percent but are at rates not likely to be sustained indefinitely. We project that ATV sales will continue to grow at a higher rate over the next few years but will level off by 2006. Table 5.2.3-27 provides a summary of the sales estimates used in the aggregate cost analysis.

Table 5.2.3-27: Estimated Annual Recreational Vehicle Sales

	2001	2006	2010	2020
Snowmobiles	140,629	189,497	210,367	240,162
ATVs	880,000	985,754	985,754	985,754
Off-highway motorcycles*	195,250	205,210	213,542	235,883

* Non-competition only

To calculated annual aggregate costs, the sales estimates have been multiplied by the per unit costs. Fuel savings have been calculated using the NONROAD model to calculate the shift in use from 2-stroke to 4-stroke vehicles, and also direct injection 2-strokes for snowmobiles, over time. The model takes into consideration vehicle sales and scrappage rates. The standards phase-in schedule for off-highway motorcycles and ATVs (50/100% in 2006/2007) has also been taken into account. The detailed year-by-year analysis is provided in Chapter 7.

Chapter 5 References

1."Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula," Jack Faucett Associates, Report No. JACKFAU-85-322-3, September 1985 (Docket A-2000-01, document II-A-54).

2.For further information on learning curves, see Chapter 5 of the Economic Impact, from Regulatory Impact Analysis - Control if Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, EPA420-R-99-023, December 1999. A copy of this document is included in Air Docket A-2000-01, at Document No. II-A-83. The interested reader should also refer to previous final rules for Tier 2 highway vehicles (65 FR 6698, February 10, 2000), marine diesel engines (64 FR 73300, December 29, 1999), nonroad diesel engines (63 FR 56968, October 23, 1998), and highway diesel engines (62 FR 54694, October 21, 1997).

3.“Estimated Economic Impact of New Emission Standards for Heavy-Duty Highway Engines,” by Lou Browning, Acurex Environmental Corporation Final Report (FR 97-103), March 31, 1997, Docket A-2000-01, document II-A-51.

4.“Incremental Costs for Nonroad Engines: Mechanical to Electronic,” Memorandum from Lou Browning, Acurex Environmental, to Alan Stout, EPA, April 1, 1997 (Docket A-2000-01, document II-A-52).

5.“Incremental Cost Estimates for Marine Diesel Engine Technology Improvements,” Memorandum from Louis Browning and Kassandra Genovesi, Arcadis Geraghty & Miller, to Alan Stout, EPA, September 30, 1998 (Docket A-2000-01, document II-A-53).

6.“Large SI Engine Technologies and Costs,” by Lou Browning, Arthur D. Little - Acurex Environmental, Final Report, September 2000, Docket A-2000-01, document II-A-15.

7. “Exhaust Controls Available to Reduce Emissions from Nonroad Heavy-Duty Engines,” in Clean Air Technology News, Winter 1997, p. 1 (Docket A-98-01; item II-A-02).

8. “It’s Not Easy Being Green,” Modern Materials Handling, April 2000 (Docket A-2000-01; item II-A-06).

9. Letter from William Platz, Western Propane Gas Association, January 24, 2001 (Docket A-2000-01; item II-D-40).

10. “It’s Not Easy Being Green,” Modern Materials Handling, April 2000 (Docket A-2000-01; item II-A-06).

11. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31)..

12. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31).

13. “Nonroad Recreational Vehicle Technologies and Costs”, Arthur D. Little - Acurex Environmental, Draft Final Report, July 2001 (Docket A-2000-01, document II-A-31).

14. “Information on Costs and Effectiveness of Fluorination Received from Fluoroseal,” Memorandum from Mike Samulski to Docket A-2000-1, March 27, 2002, Docket A-2000-01, Document IV-B-03.

15. “Visit to Sulfo Technologies LLC on April 18, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, April 22, 2002, Document IV-B-07.

16. “Shipping Costs,” Memorandum from Glenn Passavant, U.S. EPA to Docket A-2000-01, March 27, 2002, Document IV-B-01.

17. Trident Marine Hose, “Retail Price List 2001,” Docket A-2000-01, Document No. IV-A-15.

18. Denbow, R., Browning, L., Coleman, D., “Report Submitted for WA 2-9, Evaluation of the Costs and Capabilities of Vehicle Evaporative Emission Control Technologies,” ICF, ARCADIS Geraghty & Miller, March 22, 1999, Docket A-2000-01, Document No. IV-B-05.

19. “Meeting with Avon on June 27, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, August 6, 2002, Docket A-2000-01, Document IV-E-33.

20. Denbow, R., Browning, L., Coleman, D., “Report Submitted for WA 2-9, Evaluation of the Costs and Capabilities of Vehicle Evaporative Emission Control Technologies,” ICF, ARCADIS Geraghty & Miller, March 22, 1999, Docket A-2000-01, Document No. IV-B-05.

21. “Visit to Sulfo Technologies LLC on April 18, 2002,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, April 22, 2002, Document IV-B-07.

22. Brake-specific fuel consumption (BSFC) based on 4-stroke BSFC estimates provided by Power Systems Research.

23. “Monthly Energy Review”, Calendar year 2000 average Refiner Prices of Petroleum Products to End Users (Cents per gallon, excluding taxes), Energy Information Administration.

Chapter 6: Emissions Inventory

6.1 Methodology

The following chapter presents our analysis of the emission impact of the standards for recreational marine, large spark-ignition equipment, snowmobiles, all-terrain vehicles, and off-highway motorcycles. We first present an overview of the methodology used to generate the emissions inventories, followed by a discussion of the specific information used in generating the inventories for each of the regulated categories of engines as well as the emission inventories. Emissions from a typical piece of equipment are also presented.

6.1.1 Off-highway Exhaust Emissions

We are in the process of developing an emission model that will calculate emissions inventories for most off-highway vehicle categories, including those in this rule. This draft model is called NONROAD. For this effort we use the most recent version of the draft NONROAD model publicly available with some updates that we anticipate will be included in the next draft release. This section gives a brief overview of the calculation methodology used in NONROAD for calculating exhaust emission inventories. Inputs and results specific to each of the off-highway categories in this rule are discussed in more detail later in this chapter. For more detailed information on the draft NONROAD model, see our website at www.epa.gov/otaq/nonrdmdl.htm.

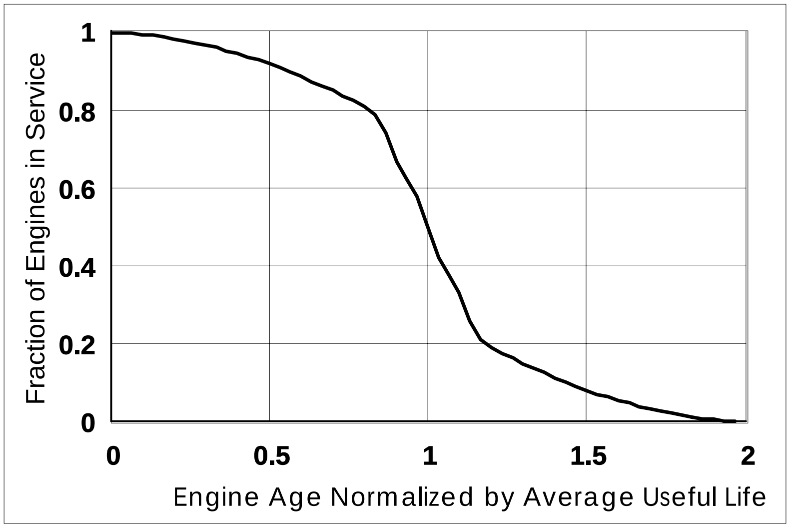
For the inventory calculations in this rule, each class of off-highway engines was divided into power ranges to distinguish between technology or usage differences in each category. Each of the engine applications and power ranges were modeled with distinct annual hours of operation, load factors, and average engine lives. The basic equation for determining the exhaust emissions inventory, for a single year, from off-highway engines is shown below:

$$Emissions = \sum_{ranges} (population \times power \times load \times annual\,use \times emission\,factor) \qquad \textbf{(Eq. 6-1)}$$

This equation sums the total emissions for each of the power ranges for a given calendar year. “Population” refers to the number of engines estimated to be in the U.S. in a given year. “Power” refers to the population-weighted average rated power for a given power range. Two usage factors are included; “load” is the ratio between the average operational power output and the rated power, and “annual use” is the average hours of operation per year. Emission factors are applied on a brake-specific basis (g/kW-hr) and represent the weighted value between levels from baseline and controlled engines operating in a given calendar year. Exhaust emission inventories were calculated for HC, CO, and NOx from all engines and additionally for PM from compression-ignition engines. Although some of the emission standards combine HC and NOx, it is useful to consider the HC and NOx emission impacts separately. (As described throughout this document, the standards for all-terrain vehicles (ATVs) and off-highway motorcycles are based on a chassis test, with the standards in grams per kilometer. For these two categories of equipment, the equation used by the NONROAD model for calculating emissions is similar to Equation 6-1 except that the "load factor" and "power" terms are not included in the calculation, the "annual use" is input on a miles/year basis, and the "emission factors" are entered on a gram per mile basis.)

To be able to determine the mix between baseline and controlled engines, we need to determine the turnover of the fleet. Through the combination of historical population and scrappage rates, historical sales and retirement of engines can be estimated. We use a normalized scrappage rate and fit it to the data for each engine type on average operating life. Figure 6.1.1-1 presents the normalized scrappage curve used in the draft NONROAD model. For further discussion of this scrappage curve, see our report titled "Calculation of Age Distributions -- Growth and Scrappage," (NR-007).

Figure 6.1.1-1: Normalized Scrappage Curve



6.1.2 Off-highway Evaporative Emissions

Evaporative emissions refer to hydrocarbons released into the atmosphere when gasoline, or other volatile fuels, evaporate from a vehicle. For this analysis, we model three types of evaporative emissions:

- <u>permeation</u>: These emissions are due to fuel that works its way through the material used in the fuel system. Permeation is most common through plastic fuel tanks and rubber hoses.

- diurnal: These emissions are due to temperature changes throughout the day. As the day gets warmer, the fuel heats up and begins to evaporate.

- refueling: These emissions are the vapors displaced from the fuel tank when fuel is dispensed into the tank.

We are currently in the process of revising the inputs to the calculations for evaporative emissions in the draft NONROAD model. The analysis for this rule includes the inputs that we anticipate will be used in the draft NONROAD model. The evaporative emission calculations are available in spreadsheet form in the docket.[1]

Because diurnal and refueling emissions are dependent on ambient temperatures and fuel properties which vary through the nation and through the year, we divided the nation into six regions and modeled each region individually for each day of the year. The daily temperatures by region are based on a report which summarizes a survey of dispensed fuel and ambient temperatures in the United States.[2]

6.1.2.1 Permeation Emissions

For our permeation emissions modeling, we used the emission data presented in Chapter 4 to determine the mass of hydrocarbons permeated through plastic fuel tanks and rubber fuel hoses on recreational vehicles. No permeation occurs through metal fuel tanks. Because permeation is very sensitive to temperature, we used Arrhenius' relationship[3] to adjust the emission factors by temperature:

$$P(T) = P_0 \times \mathrm{EXP}(-\alpha / T) \qquad \textbf{(Eq. 6-2)}$$

where:

T = absolute temperature
$P(T)$ = permeation rate at T
P_0 and α are constants

We determined the constants by relating the equation to the known properties of materials used in fuel tanks and hoses (presented in Chapter 4). Based on data presented in Chapter 4, permeation increases by about 80 percent with each 10°C increase in temperature for high density polyethylene (HDPE). We do not have similar data for nitrile rubber used in hoses; however, in general, permeation doubles with every 10°C increase in temperature.[4] In addition, we have data on the effect of temperature on permeation through FKM which is a fluoroelastomer commonly used as a permeation barrier in hoses. This data, presented in Chapter 4, supports using the general relationship, in our modeling, of doubling permeation through hoses for every 10°C increase in temperature.

6.1.2.2 Diurnal Emissions

For diurnal emission estimates, we used the Wade equations[5,6,7] to calculate grams of hydrocarbons emitted per day per volume of fuel tank capacity. The Wade equations are well established and are used in both the MOBILE and draft NONROAD models with an adjustment based on empirical data. These calculations are a function of vapor space, fuel vapor pressure, and daily temperature variation and are as follows:

$$\text{Vapor space (ft}^3\text{)} = ((1.15 - \text{tank fill}) \times \text{tank size}) / 7.841 \qquad \textbf{(Eq. 6-3)}$$

where:

tank fill = fuel in tank/fuel tank capacity
tank size = fuel tank capacity in gallons

$$T_1\ (°\text{F}) = (T_{max} - T_{min}) \times 0.922 + \text{Tmin} \qquad \textbf{(Eq. 6-4)}$$

where:

T_{max} = maximum diurnal temperature (°F)
T_{min} = minimum diurnal temperature (°F)

$$V_{100}\ (\text{psi}) = 1.0223 \times \text{RVP} + [(0.0357 \text{ X RVP})/(1-0.0368 \times \text{RVP})] \qquad \textbf{(Eq. 6-5)}$$

where:

V_{100} = vapor pressure at 100°F
RVP = Reid Vapor Pressure of the fuel

$$E_{100}\ (\%) = 66.401-12.718 \times V_{100} + 1.3067 \times V_{100}^2 - 0.077934 \times V_{100}^3 + 0.0018407 \times V_{100}^4 \qquad \textbf{(Eq. 6-6)}$$

$$D_{min}\ (\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113] \times (100 - T_{min}) \qquad \textbf{(Eq. 6-7a)}$$

$$D_{max}\ (\%) = E_{100} + [(262 / (0.1667 * E_{100} + 560) - 0.113] \times (100 - T_1) \qquad \textbf{(Eq. 6-7b)}$$

where:

$D_{min/max}$ = distillation percent at the max/min temperatures in the fuel tank
E_{100} = percent of fuel evaporated at 100°F from equation 6-6

$$P_I\ (\text{psi}) = 14.697 - 0.53089 \times D_{min} + 0.0077215 \times D_{min}^2 - 0.000055631 \times D_{min}^3 + 0.0000001769 \times D_{min}^4 \qquad \textbf{(Eq. 6-8a)}$$

$$P_F\ (\text{psi}) = 14.697 - 0.53089 \times D_{max} + 0.0077215 \times D_{max}^2 - 0.000055631 \times D_{max}^3 + 0.0000001769 \times D_{max}^4 \qquad \textbf{(Eq. 6-8b)}$$

$$\text{Density (lb/gal)} = 6.386 - 0.0186 \times \text{RVP} \qquad \textbf{(Eq. 6-9)}$$

$$\text{MW (lb/lb mole)} = (73.23 - 1.274 \times \text{RVP}) + [0.5 \times (T_{min} + T_1) - 60] \times 0.059 \qquad \textbf{(Eq. 6-10)}$$

$$\begin{aligned}\text{Diurnal emissions (grams)} = {} & \text{vapor space} \times 454 \times \text{density} \times [520 / (690 - 4 \times \text{MW})] \\ & \times 0.5 \times [P_I / (14.7 - P_I) + P_F / (14.7 - P_F)] \\ & \times [(14.7 - P_I) / (T_{min} + 460) - (14.7 - P_F) / (T_1 + 460)] \qquad \textbf{(Eq. 6-11)}\end{aligned}$$

where:

MW = molecular weight of hydrocarbons from equation 6-10
$P_{I/F}$ = initial and final pressures from equation 6-8

We use these same equations in our modeling of evaporative emissions from on-highway vehicles. However for on-highway applications we make a correction of 0.78 based on empirical data.[8] Because this correction is based on automotive applications we do not apply this correction factor here. Instead we use a correction factor of 0.65 which is based on the data we collected on exposed fuel tanks vented through a hose. This test data is presented in Table 6.1.2-1 compared to calculated theoretical results.

Table 6.1.2-1
Baseline Diurnal Evaporative Emission Results (varied temperature)

Fuel Tank Capacity	Evaporative HC [g/gallon/day]	Wade HC [g/gallon/day]	ratio of measured to Wade
17 gallons	1.39	2.3	0.6
24 gallons	1.5	2.3	0.65

Title 40, Section 80.27 of the Code of Federal Regulations specifies the maximum allowable fuel vapor pressure allowed for each state in the U.S. for each month of the year. We used these limits as an estimate of fuel vapor pressure in our calculations.

6.1.2.3 Refueling Vapor Displacement

We used the draft NONROAD model to determine the amount of fuel consumed by recreational vehicles. To calculate refueling emissions, we used an empirical equation to calculate grams of vapor displaced during refueling events. This equation was developed based on testing of 22 highway vehicles under various refueling scenarios and in the benefits calculations for our onboard refueling vapor recovery rulemaking for cars and trucks.[9] These calculations are a function of fuel vapor pressure, ambient temperature, and dispensed fuel temperature. The refueling vapor generation equation is as follows:

$$\text{Refueling vapor (g/gal)} = \text{EXP}(-1.2798 - 0.0049 \times (\text{Td} - \text{Ta}) + 0.0203 \times \text{Td} + 0.1315 \times \text{RVP}) \qquad \textbf{(Eq. 6-12)}$$

where:

Td = dispensed fuel temperature (°F)
Ta = ambient fuel temperature (°F)
RVP = Reid Vapor Pressure of the fuel

6.2 Effect of Emission Controls by Engine/Vehicle Type

The remainder of this chapter discusses the inventory results for each of the classes of engines/vehicles included in this document. These inventory projections include both exhaust and evaporative emissions. Also, this section describes inputs and methodologies used for the inventory calculations that are specific to each engine/vehicle class.

6.2.1 Compression-Ignition Recreational Marine

We projected the annual tons of exhaust HC, CO, NOx, and PM from CI recreational marine engines using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to CI recreational marine engines then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.1.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for CI recreational marine exhaust emissions. These inputs are load factor, annual use, average operating life, and population. Based on data collected in developing the draft NONROAD model, we use a load factor of 35 percent, an annual usage factor of 200 hours, and an average operating life of 20 years. The draft NONROAD model includes current and projected engine populations. Table 6.2.1-1 presents these population estimates for selected years. These population estimates have been updated since the NPRM using new data collected from the boating industry discussed in Chapter 2.

Table 6.2.1-1
Projected CI Recreational Marine Population by Year

Year	2000	2005	2010	2020	2030
population	261,000	301,000	340,000	419,000	497,000

We used the data presented in Chapter 4 to develop the baseline emission factors. For the control emission factors, we projected that the manufacturers will design their engines to meet the standard at regulatory useful life with a small compliance margin. (The regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards.) To determine the HC and NOx split for the standards, we used the HC and NOx data presented in Chapter 4 from CI recreational marine engines near the standards. Consistent with our modeling of heavy-duty highway emissions, we assumed a compliance margin of 8 percent. This compliance margin is based on historical practices for highway and nonroad engines with similar technology. Engine manufacturers give themselves some cushion below the certification level on average so that engine-to-engine variability will not cause a significant number of engines to exceed the standard. Also, we used the deterioration factors in the draft NONROAD model which have been updated since the NPRM; the only significant update is to the PM deterioration factor which is now larger. Table 6.2.1-2 presents the emission factors used in this analysis for new engines and for engines deteriorated to the regulatory useful life (10 years).

Table 6.2.1-2
Emission Factors for CI Recreational Marine Engines

Engine Technology	HC [g/kW-hr]		NOx [g/kW-hr]		CO [g/kW-hr]		PM [g/kW-hr]	
	new	10 yrs	new	10 yrs	new	10 yrs	new	10 yrs
baseline	0.295	0.300	8.94	9.05	1.27	1.39	0.219	0.270
controlled:								
< 0.9 liters/cylinder	0.181	0.184	6.69	6.72	1.27	1.39	0.219	0.270
0.9-1.2 liters/cylinder	0.181	0.184	6.41	6.44	1.27	1.39	0.219	0.270
≥ 1.2 liters/cylinder	0.182	0.184	6.42	6.44	1.27	1.39	0.181	0.184

In our analysis of the CI recreational marine engine emissions inventory, we may underestimate emissions, especially PM, due to engine deterioration in-use. We believe that current modeling only represents properly maintained engines, but may not be representative of in-use tampering or malmaintenance. However, we have not fully evaluated the limited data currently available and we are in the process of collecting more data on in-use emission deterioration. Once this has been completed we will decide whether or not we need to update our deterioration rates both in this analysis and in the Draft NONROAD model.

6.2.1.2 Reductions Due to the Standard

We anticipate that the standards will result in a 28 percent reduction in HC+NOx and a 25 percent reduction in PM in 2030. We are not claiming any benefits from the cap on CO emissions. The following tables present our projected exhaust emission inventories for CI recreational marine engines and the anticipated emission reductions.

Table 6.2.1-3
Projected HC Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	1,270	1,270	0	0%
2005	1,460	1,460	0	0%
2010	1,650	1,490	159	10%
2020	2,030	1,450	575	28%
2030	2,410	1,510	899	37%

Table 6.2.1-4
Projected NOx Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	38,000	38,000	0	0%
2005	43,600	43,600	0	0%
2010	49,400	45,800	3,550	7%
2020	60,800	48,000	12,800	21%
2030	72,200	52,200	20,000	28%

Table 6.2.1-5
Projected PM Reductions for CI Recreational Marine Engines [short tons]

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	1,000	1,000	0	0%
2005	1,150	1,150	0	0%
2010	1,300	1,230	75	6%
2020	1,600	1,310	294	18%
2030	1,900	1,420	478	25%

6.2.1.3 Per Vessel Emissions from CI Recreational Marine Engines

This section describes the development of the HC plus NOx emission estimates on a per engine basis over the average lifetime of typical CI recreational marine engines. As in the cost analysis in Chapter 5, we look at three engine sizes for this analysis (100, 400, and 750 kW) as well as a composite of all engine sizes. The emission estimates were developed to estimate the cost per ton of the standards as presented in Chapter 7.

The new and deteriorated emission factors used to calculate the HC and NOx emissions from typical CI recreational marine engines were presented in Table 6.2.1-2. A brand new engine emits at the zero-mile level presented in the table. As the engine ages, the emission levels increase based on the pollutant-specific deterioration factor. The load factor for these engines is estimated to be 0.35, the annual usage rate is estimated to be 200 hours per year, and the average lifetime is estimated to be 20 years.

Using the information described above and the equation used for calculating emissions from nonroad engines (see Equation 6-1), we calculated the lifetime HC+NOx emissions from typical marine engines both baseline and controlled engines. Table 6.2.1-6 presents these results with and without the consideration of a 7 percent per year discount on the value of emission reductions.

Table 6.2.1-6
Lifetime HC+NOx Emissions from Typical CI Recreational Marine Engines (tons)

Engine Size	Baseline		Control		Reduction	
	Undiscounted	Discounted	Undiscounted	Discounted	Undiscounted	Discounted
100 kW	1.44	0.82	1.01	0.57	0.43	0.24
400 kW	5.78	3.26	4.06	2.30	1.72	0.97
750 kW	7.18	4.53	5.08	3.20	2.10	1.32
Composite	2.58	1.47	1.81	1.03	0.77	0.44

6.2.1.4 Crankcase Emissions from CI Recreational Marine Engines

We anticipate some benefits in HC, NOx, and PM from the closed crankcase requirements for CI recreational marine engines. Based on limited engine testing, we estimate that crankcase emissions of HC and PM diesel engines are each about 0.013 g/kW-hr.[10] NOx data varies, but crankcase NOx emissions may be as high as HC and PM. Therefore, we use the same crankcase emission factor of 0.013 g/kW-hr for each of the three constituents.

For this analysis, we assume that manufacturers will use the low cost option of routing crankcase emissions to the exhaust and including them in the total exhaust emissions when the engine is designed to the standards. Because exhaust emissions must be reduced slightly to offset any crankcase emissions, the crankcase emission control is functionally equivalent to a 100 percent reduction in crankcase emissions.

The engine data we use to determine crankcase emission levels is based on new heavy-duty engines. We do not have data on the effect of in-use deterioration of crankcase emissions. However, we expect that these emissions increase as the engine wears. Therefore, this analysis may underestimate the benefits that would result from our crankcase emission requirements. Table 6.2.1-7 presents our estimates of the fleetwide reductions crankcase emissions from CI recreational marine engines.

Table 6.2.1-7
Crankcase Emissions Reductions from CI Recreational Marine Engines [short tons]

Calendar Year	HC+NOx	PM
2000	0	0
2005	0	0
2010	39	19
2020	145	73
2030	260	130

6.2.2 Large Spark-Ignition Equipment

6.2.2.1 Exhaust Emissions from Large SI Equipment

We projected the annual tons of exhaust HC, CO, and NOx from large industrial spark-ignition (SI) engines using the draft NONROAD model described above. This section describes inputs to the calculations that are specific to these engines then presents the results of the modeling.

6.2.2.1.1 Inputs for Exhaust Inventory Calculations

Several usage inputs are specific to the calculations for Large SI engines. These inputs are load factor, annual use, average operating life, and population. Because the Large SI category is made up of many applications, the NONROAD model contains application-specific information for each of the applications making up the Large SI category. Table 6.2.2-1 presents the inputs used in the NONROAD model for each of the Large SI applications. (The average operating life for a given application can vary within an application by power category. In such cases, the average operating life value presented in Table 6.2.2-1 is based on the average operating life estimate for the engine with the average horsepower listed in the table.)

The NONROAD model generally uses population data based on information from Power Systems Research, which is based on historical sales information adjusted according to survival and scrappage rates. We are, however, using different population estimates for forklifts based on a recent market study.[11] That study identified a 1996 population of 491,321 for Class 4 through 6 forklifts, which includes all forklifts powered by internal combustion engines. Approximately 80 percent of those were estimated to be fueled by propane, with the rest running on either gasoline or diesel fuel. Assuming an even split between gasoline and diesel for these remaining forklifts leads to a total population of spark-ignition forklifts of 442,000. The NONROAD model therefore uses this estimate for the forklift population, which is significantly higher than that estimated by Power Systems Research. Table 6.2.2-1 shows the estimated population figures used in the NONROAD model for each application, adjusted for the year 2000.

The split between LPG and gasoline in various applications warrants further attention. Engines are typically sold without fuel systems, which makes it difficult to assess the distribution of engines sales by fuel type. Also, engines are often retrofitted for a different fuel after a period of operation, making it still more difficult to estimate the prevalence of the different fuels. The high percentage of propane systems for forklifts, compared with about 60 percent estimated by Power Systems Research, can be largely attributed to expenses related to maintaining fuel supplies. LPG cylinders can be readily exchanged with minimal infrastructure cost as compared to gasoline storage. Natural gas systems typically offer the advantage of pipeline service, but the cost of installing high-pressure refueling equipment is an obstacle to increased use of natural gas systems.

Some applications of nonroad SI equipment face much different refueling situations.

Lawn and garden equipment is usually not centrally fueled and therefore operates almost exclusively on gasoline, which is more readily available. Agriculture equipment is predominantly powered by diesel engines. Most of these operators likely have storage tanks for diesel fuel. For those who use spark-ignition engines in addition to, or instead of, the diesel models, we expect them in many cases to be ready to invest in gasoline storage tanks as well, resulting in little or no use of LPG or natural gas for those applications. For construction, general industrial, and other equipment, there may be a mix of central and noncentral fueling, and motive and portable equipment. We therefore believe that estimating an even mix of LPG and gasoline for these engines is most appropriate. The approximate distribution of fuel types for the individual applications used in the NONROAD model are listed in Table 6.2.2-1.

Table 6.2.2-1
Operating Parameters and Population Estimates for Various Large SI Applications

Application	Avg. Rated HP	Load Factor	Hours per Year	Average Operating Life (yrs)	2000 Population	Percent LPG/CNG
Forklift	69	0.30	1800	8.3	499,693	95
Generator	59	0.68	115	25.0	143,705	100
Commercial turf	28	0.60	682	3.7	55,433	0
Aerial lift	52	0.46	361	18.1	38,637	50
Pump	45	0.69	221	9.8	35,541	50
Welder	67	0.68	408	12.7	19,006	50
Baler	44	0.62	68	25.0	18,635	0
Air compressor	65	0.56	484	11.1	17,261	50
Scrubber/sweeper	49	0.71	516	4.1	13,272	50
Chipper/grinder	66	0.78	488	7.9	13,000	50
Swathers	95	0.52	95	25.0	12,030	0
Leaf blower/vacuum	79	0.94	282	11.3	11,797	0
Sprayers	66	0.65	80	25.0	9,429	0
Specialty vehicle/cart	66	0.58	65	25.0	9,145	50
Oil field equipment	44	0.90	1104	1.5	7,855	100
Skid/steer loader	47	0.58	310	8.3	7,427	50
Other agriculture equipment	162	0.55	124	25.0	5,488	0
Irrigation set	97	0.60	716	7.0	5,176	50

Application	Avg. Rated HP	Load Factor	Hours per Year	Average Operating Life (yrs)	2000 Population	Percent LPG/CNG
Trencher	54	0.66	402	11.3	3,622	50
Rubber-tired loader	71	0.71	512	8.8	3,172	50
Other general industrial	82	0.54	713	7.8	2,922	50
Terminal tractor	93	0.78	827	4.7	2,698	50
Bore/drill rig	78	0.79	107	25.0	2,604	50
Concrete/industrial saw	46	0.78	610	3.2	2,264	50
Rough terrain forklift	66	0.63	413	11.5	1,923	50
Other material handling	67	0.53	386	7.3	1,594	50
Ag. tractor	82	0.62	550	8.8	1,597	0
Paver	48	0.66	392	5.8	1,365	50
Roller	55	0.62	621	7.8	1,360	50
Other construction	126	0.48	371	16.8	1,275	50
Crane	75	0.47	415	15.4	1,239	50
Pressure washer	39	0.85	115	15.3	1,212	50
Paving equipment	39	0.59	175	14.5	1,107	50
Aircraft support	99	0.56	681	7.9	904	50
Gas compressor	110	0.85	6000	0.8	783	100
Front mowers	32	0.65	86	25.0	658	0
Other lawn & garden	61	0.58	61	25.0	402	0
Tractor/loader/backhoe	58	0.48	870	7.2	359	50
Hydro power unit	50	0.56	450	6.0	331	50
Surfacing equipment	40	0.49	488	6.3	313	50
Railway maintenance	33	0.62	184	13.1	276	50
Crushing/processing equip	63	0.85	241	14.6	235	50
Refrigeration/AC	55	0.46	605	10.8	169	100
Dumpers/tenders	66	0.41	127	25.0	124	0
Combines	123	0.74	125	25.0	31	0

An additional issue related to population figures is the level of growth factored into emission estimates for the future. The NONROAD model incorporates application-specific growth figures based on projections from Power Systems Research. The model projects growth rates separately for the different fuels for each application. Table 6.2.2-2 presents the population estimates of Large SI engines (rounded to the nearest 1,000 units) by fuel type for selected years.

Table 6.2.2-2
Projected Large SI Population by Year

Category	2000	2005	2010	2020	2030
Gasoline LSI	224,000	232,000	240,000	261,000	294,000
LPG LSI	645,000	766,000	890,000	1,132,000	1,364,000
CNG LSI	88,000	97,000	108,000	132,000	155,000
Total LSI	957,000	1,095,000	1,238,000	1,525,000	1,813,000

Southwest Research Institute recently compiled a listing of test data from past and current testing projects.[12] These tests were all conducted on new or nearly new engines and are used in the NONROAD model as zero-mile levels (ZML). Table 6.2.2-3 summarizes this test data by fuel type. (The emission levels for gasoline engines are a population-weighted average of the water-cooled and air-cooled average emission levels, assuming air-cooled engines are 3 percent of all large spark-ignition engines, or 13 percent of gasoline large spark-ignition engines.) All engines were operated on the steady-state ISO C2 duty cycle, except for two engines that were tested on the steady-state D2 cycle. The results from the different duty cycles were comparable. Lacking adequate test data for engines fueled by natural gas, we model those engines to have the same emission levels as those fueled by liquefied petroleum gas (LPG), based on the similarity between engines using the two fuels (in the case of hydrocarbon emissions, the equivalence is based on non-methane hydrocarbons).

Emission levels often change as an engine ages. In most cases, emission levels increase with time, especially for engines equipped with technologies for controlling emissions. We developed deterioration factors for uncontrolled Large SI engines based on measurements with comparable highway engines.[13] Table 6.2.2-3 also shows the deterioration factors that apply at the median lifetime estimated for each type of equipment. For example, a deterioration factor of 1.26 for hydrocarbons multiplied by the emission factor of 6.2 g/hp-hr for new gasoline engines indicates that modeled emission levels increase to 7.8 g/hp-hr when the engine reaches its median lifetime. The deterioration factors are linear multipliers, so the modeled deterioration at different points can be calculated by simple interpolation.

Emissions during transient operation can be significantly higher than during steady-state operation. Based on emission measurements from highway engines comparable to uncontrolled

Large SI engines, we have measured transient emission levels that are 30 percent higher for HC and 45 percent higher for CO relative to steady-state measurements.[14] The NONROAD model therefore multiplies steady-state emission factors by a transient adjustment factor (TAF) of 1.3 for HC and 1.45 for CO to estimate emission levels during normal, transient operation. Test data do not support adjusting NOx emission levels for transient operation and so a TAF of 1.0 is used for NOx emissions. Also, the model applies no transient adjustment factor for generators, pumps, or compressors, since engines in these applications are less likely to experience transient operation.

Table 6.2.2-3
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Pre-Control Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	3.9	1.26	1.3	107.2	1.35	1.45	8.4	1.03	1.0
LPG	1.7	1.26	1.3	28.2	1.35	1.45	12.0	1.03	1.0
CNG	24.6	1.26	1.3	28.2	1.35	1.45	12.0	1.03	1.0

As manufacturers comply with the Phase 1 emission standards for Large SI engines, we expect the emission factors, deterioration factors and transient adjustment factors will be affected. To estimate the Phase 1 deterioration factors, we relied upon deterioration information for current Class IIb heavy-duty gasoline engines developed for the MOBILE6 emission model. Class IIb engines are the smallest heavy-duty engines and are comparable in size to many Large SI engines. They also employ catalyst/fuel system technology similar to the technologies we expect to be used on Large SI engines. To estimate the Phase 1 emission factors at zero miles, we back-calculated the emission levels based on the standards and the estimated deterioration factors, assuming manufacturers will design to meet a level 10 percent below the standard to account for variability. (The emission levels for Phase 1 gasoline engines were back-calculated from a population-weighted average of the Phase 1 standards for water-cooled and air-cooled engines, assuming 13 percent of gasoline engines are air-cooled.) Given that these engines will employ a catalyst to meet the standards, we believe a 10 percent compliance margin is appropriate. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines meet emission standards in the event of a compliance audit.) Because the standards include an HC+NOx standard, we assumed the HC/NOx split would stay the same as pre-control engines at the end of the regulated useful life. Table 6.2.2-4 presents the zero-mile levels, deterioration factors used in the analysis of today's Phase 1 standards for Large SI engines. The Phase 1 standards are to take effect in 2004 for all engines.

The transient adjustment factors for Phase 1 engines were based on testing performed at Southwest Research Institute on engines that are similar to those expected to be certified under the Phase 1 standards. The testing was performed on one gasoline fueled engine and two LPG-fueled engines. A complete description of the testing performed and the results of the testing is summarized in the docket for the rulemaking.[15] Because we did not have any test results for CNG-fueled engines, the same transient adjustment factors for LPG-fueled engines were used.

Table 6.2.2-4
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Phase 1 Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	0.59	1.64	1.7	29.9	1.36	1.7	1.5	1.15	1.4
LPG	0.25	1.64	2.9	24.5	1.36	1.45	2.1	1.15	1.5
CNG	3.7	1.64	2.9	24.5	1.36	1.45	2.1	1.15	1.5

In a similar manner, as manufacturers comply with the Phase 2 emission standards for Large SI engines, we expect the emission factors, deterioration factors and transient adjustment factors will be affected. To estimate the Phase 2 deterioration factors, we relied upon the same information noted above for Phase 1 engines. The technologies used to comply with the Phase 2 standards are expected to be further refinements of the technologies we expect to be used on Phase 1 Large SI engines. For that reason, we are applying the Phase 1 deterioration factors to the Phase 2 engines. To estimate the Phase 2 emission factors at zero miles, we back-calculated the emission levels based on the standards and the estimated deterioration factors, assuming manufacturers will design to meet a level 10 percent below the standard to account for variability. Given that these engines will employ a catalyst to meet the standards, we believe a 10 percent compliance margin is appropriate. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines meet emission standards in the event of a compliance audit.) As noted in Chapter 4, the Phase 2 CO standard for all engines (except air-cooled gasoline engines) is dependent on the HC+NOx level of the engine. For modeling purposes, we have assumed that all engines (except air-cooled gasoline engines) will certify at an equivalent HC+NOx standard of 1.7 g/kW-hr, yielding a CO standard of 7.9 g/kW-hr. Again, because the standards include an HC+NOx standard, we assumed the HC/NOx split would stay the same as pre-control engines at the end of the regulated useful life. (As with the Phase 1 emission factors, the emission levels for Phase 2 gasoline engines were back-calculated from a population-weighted average of the Phase 2 standards for water-cooled and air-cooled engines, assuming 13 percent of gasoline engines are air-cooled.) Table 6.2.2-5 present the zero-mile levels, deterioration factors used in the analysis of today's Phase 2 standards for Large SI engines. The Phase 2 standards are to take effect in 2004 for all engines.

Under the Phase 2 program for Large SI engines, the test procedure will be switched from a steady-state test to a transient test. Therefore, the in-use emission performance of Phase 2 engines should be similar to the emissions performance over the test cycle. For this reason, the transient adjustment factors for Phase 2 engines is set at 1.0 for all pollutants.

Table 6.2.2-5
Zero-Mile Level Emission Factors (g/hp-hr), Deterioration Factors (at Median Life) and Transient Adjustment Factors for Phase 2 Large SI Engines

Fuel Category	THC			CO			NOx		
	ZML	DF	TAF	ZML	DF	TAF	ZML	DF	TAF
Gasoline	0.3	1.64	1.0	11.9	1.36	1.0	0.7	1.15	1.0
LPG	0.1	1.64	1.0	3.9	1.36	1.0	0.9	1.15	1.0
CNG	1.6	1.64	1.0	3.9	1.36	1.0	0.9	1.15	1.0

6.2.2.1.2 Exhaust Emission Reductions Due to the Standards

Tables 6.2.2-6 through 6.2.2-8 present the projected HC, CO, and NOx exhaust emissions inventories respectively, assuming engines remain uncontrolled and assuming we adopt the Phase 1 and Phase 2 standards. The tables also contain estimated emission reductions for each of the pollutants. We anticipate that the standards will result in a 92 percent reduction in exhaust HC, 91 percent reduction in NOx, and a 88 percent reduction in CO by 2020

Table 6.2.2-6
Projected HC Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	166,000	166,000	0	0%
2005	180,000	136,000	44,000	24%
2010	197,000	59,000	138,000	70%
2020	235,000	19,000	216,000	92%
2030	274,000	17,000	257,000	94%

Table 6.2.2-7
Projected CO Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	1,734,000	1,734,000	0	0%
2005	1,873,000	1,712,000	161,000	9%
2010	2,022,000	945,000	1,077,000	53%
2020	2,336,000	277,000	2,059,000	88%
2030	2,703,000	265,000	2,438,000	90%

Table 6.2.2-8
Projected NOx Inventories and Reductions for Large SI Engines (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	308,000	308,000	0	0%
2005	348,000	273,000	75,000	21%
2010	389,000	118,000	271,000	70%
2020	472,000	43,000	429,000	91%
2030	553,000	44,000	509,000	92%

6.2.2.2 Evaporative and Crankcase Emission Control from Large SI Equipment

We projected the annual tons of hydrocarbons evaporated into the atmosphere from Large SI gasoline engines using the methodology discussed above in Section 6.1.2. These evaporative emissions include diurnal and refueling emissions. Although the standards do not specifically require the control of refueling emissions, we have included them in the modeling for completeness. We have also calculated estimates of hot-soak and running losses for Large SI gasoline engines using separate information on those emissions. Finally, we present crankcase emissions for all Large SI engines based on the NONROAD model. This section describes inputs to the calculations that are specific to Large SI engines and presents our baseline and controlled national inventory projections for evaporative and crankcase emissions.

6.2.2.2.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the evaporative emission calculations for Large SI engines. These inputs are fuel tank sizes, population, and distribution throughout the nation. The draft NONROAD model includes current and projected engine populations for each state and we used this distribution as the national fuel tank distribution. Table 6.2.2-9 presents the population of Large SI gasoline engines for 1998.

Table 6.2.2-9
1998 Population of Large SI Gasoline Engines by Region

Region	Total
Northeast	87,200
Southeast	38,300
Southwest	22,700
Midwest	35,000
West	28,600
Northwest	9,200
Total	221,000

The draft NONROAD model breaks this engine distribution further into ranges of engine sizes. For each of these power ranges we apply a fuel tank size for our evaporative emission calculations based on the fuel tank sizes used in the NONROAD model.

Table 6.2.2-10 presents the baseline diurnal emission factors for the certification test conditions and a typical summer day with low vapor pressure fuel and a half-full tank.

Table 6.2.2-10
Diurnal Emission Factors for Test Conditions and Typical Summer Day

Evaporative Control	72-96°F, 9 RVP* Fuel, 40% fill	60-84°F, 8 RVP* Fuel, 50% fill
baseline	1.5 g/gallon/day	0.55 g/gallon/day

* Reid Vapor Pressure

We used the draft NONROAD model to determine the amount of fuel consumed by Large SI gasoline engines. As detailed earlier in Table 6.2.2-1, the NONROAD model has annual usage rates for all Large SI applications. Table 6.2.2-11 presents the fuel consumption estimates we used in our modeling. For 1998, the draft NONROAD model estimated that Large SI gasoline engines consumed about 300 million gallons of gasoline.

Table 6.2.2-11
Fuel Consumption Estimates used in Refueling Calculations for Large SI Gasoline Engines

Technology	BSFC, lb/hp-hr
Pre-control	0.605
Tier 1/Tier 2	0.484

To estimate inventories of hot-soak and running loss emissions from Large SI gasoline engines, we applied a factor to the diurnal emissions inventory estimates based on evaporative emission inventories prepared for the South Coast Air Quality Management District.[16] The hot soak inventory was estimated to be 3.9 times as high as the diurnal inventory, and the running loss inventory was estimated to be two-thirds of the diurnal inventory. Finally, crankcase emissions (from all Large SI engines) were generated using the draft NONROAD model.

Table 6.2.2-12 contains the baseline evaporative emission and crankcase emission inventories for Large SI engines.

Table 6.2.2-12
Baseline Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	Diurnal	Refueling	Hot-Soak	Running Loss	Crankcase
2000	700	1,400	2,720	470	54,550
2005	720	1,430	2,820	480	59,100
2010	750	1,520	2,920	500	64,950
2020	810	1,680	3,171	540	77,340
2030	920	1,900	3,577	610	90,180

6.2.2.2.2 Evaporative and Crankcase Emission Reductions Due to the Requirements

We anticipate that the evaporative emission requirements for Large SI engines will result in about a 90 percent reduction in diurnal, running loss emissions, and hot soak emissions. The new requirements for Large SI equipment includes an evaporative emission standard of 0.2 grams per gallon of fuel tank capacity for 24-hour day when temperatures cycle between 72° and 96° F. In our modeling, we consider a 3.0 psi pressure relief valve. In this case, the model only accounts for hydrocarbon emissions generated at pressures greater than 3.0 psi (see Equation 7). The evaporative emission requirements are scheduled to take effect in 2007 with the Tier 2 requirements, except for the hot-soak requirements which will take effect in 2004 with the Tier 1 requirements. In addition, because the fuel consumption of Large SI engines will be reduced by 20 percent, the refueling emissions will be reduced proportionally as well. The refueling benefits will be realized beginning in 2004 as the Tier 1 standards take effect. Finally, the standards also require that engines have a closed crankcase. We expect the crankcase emissions will generally be routed to the engine and combusted, nearly eliminating crankcase emissions. For modeling purposes, we have assumed that the crankcase emissions are reduced by 90 percent. The crankcase requirements are schedule to take effect in 2004 with the Tier 1 requirements.

Table 6.2.2-13 present the evaporative emission inventories and crankcase emissions inventories for Large SI engines based on the reductions in emissions noted above. The reductions are achieved over time as the fleet turns over to Tier 1 or Tier 2 engines. Table 6.2.2-14 presents the corresponding reductions in evaporative and crankcase emissions for Large SI engines due to the requirements.

Table 6.2.2-13
Control Case Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	Diurnal	Refueling	Hot-Soak	*Running Loss*	Crankcase
2000	700	1,400	2,720	470	54,550
2005	720	1,380	2,440	480	44,930
2010	550	1,360	1,600	370	25,170
2020	150	1,360	410	100	12,880
2030	70	1,520	260	50	9,020

Table 6.2.2-14
Reductions in Evaporative and Crankcase Emissions from Large SI Equipment [short tons]

Calendar Year	Diurnal	Refueling	Hot-Soak	Running Loss	Crankcase
2000	0	0	0	0	0
2005	0	50	380	0	14,200
2010	200	160	1,320	130	39,800
2020	670	320	2,760	450	64,500
2030	850	380	3,316	570	81,200

6.2.2.3 Per Equipment Emissions from Large SI Equipment

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or typical Large SI piece of equipment. The emission estimates were developed to estimate the cost per ton of the standards as presented in Chapter 7. The estimates are made for an average piece of Large SI equipment for each of the three fuel groupings (gasoline, LPG, and CNG). Although the emissions vary from one nonroad application to another, we are presenting the average numbers for the purpose of determining the emission reductions associated with the standards from a typical piece of Large SI equipment over its lifetime.

In order to estimate the emission from a piece of Large SI equipment, information on the emission level of the engine, the power of the engine, the load factor of the engine, the annual hours of use of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical piece of Large SI equipment were presented in Table

6.2.2-3 through Table 6.2.2-5. A brand new piece of equipment emits at the zero-mile level presented in the tables. As the equipment ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life of that equipment type. The deterioration factors presented in Table 6.2.2-3 through Table 6.2.2-5 when applied to the zero-mile levels presented in the same tables, represent the emission level of the engine at the end of its median life. The emissions at any point in time in between can be determined through interpolation. (For this analysis, the HC emissions from CNG engines is calculated on an NMHC+NOx basis, with NMHC emissions estimated to be 4.08 percent of THC emissions.)

To estimate the average power for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the average horsepower information presented in Table 6.2.2-1. To simplify the calculations, we used the most common applications within each category that represent 80 percent or more of the fuel grouping population. For gasoline engines, the top ten applications with the highest populations were used. For LPG and CNG, the top four applications with the highest populations were used. Table 6.2.2-15 lists the applications used in the analysis.

Table 6.2.2-15
Large SI Applications Used in Per Equipment Analysis

Gasoline	LPG	CNG
Commercial Turf Equipment Balers Forklifts Aerial Lifts Pumps Swathers Leafblowers/Vacuums Sprayers Welders Air Compressors	Forklifts Generator Sets Aerial Lifts Pumps	Forklifts Generator Sets Other Oil Field Equipment Irrigation Sets

Based on the applications noted above for each fuel, we calculated the population-weighted average horsepower for Large SI equipment to be 51.6 hp for gasoline equipment, 65.7 hp for LPG equipment, and 64.5 hp for CNG equipment.

To estimate the average load factor for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the load factors as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80 percent or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average load factor for Large SI equipment to be 0.58 for gasoline equipment, 0.39 for LPG equipment, and 0.49 for CNG equipment.

To estimate the average annual hours of use for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the hours per year levels as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80 percent or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average annual hours of use for Large SI equipment to be 534 hours for gasoline equipment, 1368 hours for LPG equipment, and 1164 hours for CNG equipment.

Finally, to estimate the average lifetime for equipment in each of the Large SI fuel groupings, we used the population estimates contained in the NONROAD model and the average operating life information as presented in Table 6.2.2-1. As noted above, to simplify the calculations, we used the most common applications within each category that represent 80 percent or more of the fuel grouping population. Based on the most populous applications noted above, we calculated the population-weighted average lifetime for Large SI equipment to be 12.3 years for gasoline equipment, 12 years for LPG equipment, and 13 years for CNG equipment.

Using the information described above and the equation used for calculating emissions from nonroad equipment (see Equation 6-1), we calculated the lifetime HC+NOx emissions from typical Large SI equipment for both pre-control engines and engines meeting the Tier 1 and Tier 2 standards. Table 6.2.2-16 presents the lifetime HC+NOx emissions for Large SI equipment on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.2-17 presents the corresponding lifetime HC+NOx emission reductions for the Tier 1 and Tier 2 standards.

Table 6.2.2-16
Lifetime HC+NOx Emissions from Typical Large SI Equipment (tons)*

Control Level	Gasoline		LPG		CNG	
	Un-discounted	Discounted	Un-discounted	Discounted	Un-discounted	Discounted
Pre-control	3.05	2.13	6.81	4.79	7.06	4.85
Tier 1	0.74	0.51	1.86	1.30	1.83	1.24
Tier 2	0.24	0.17	0.49	0.34	0.55	0.37

* For CNG engines only, the emissions are calculated on the basis of NMHC+NOx.

Table 6.2.2-17
Lifetime HC+NOx Emission Reductions from Typical Large SI Equipment (tons)*

Control Increment	Gasoline		LPG		CNG	
	Un-discounted	Discounted	Un-discounted	Discounted	Un-discounted	Discounted
Pre-control to Tier 1	2.31	1.62	4.94	3.50	5.24	3.61
Tier 1 to Tier 2	0.50	0.34	1.37	0.95	1.28	0.87

* For CNG engines only, the reductions are calculated on the basis of NMHC+NOx.

We also calculated per equipment lifetime evaporative emission reductions using an average lifetime of 13 years. For this analysis, we only consider gasoline powered equipment. We determine annual per vehicle evaporative emissions by dividing the total annual evaporative emissions for 2000 by the recreational vehicle populations shown in Table 6.2.2-9 (grown to 2000). Per vehicle emission reductions are based on the modeling described above. Table 6.2.2-18 presents these results with and without the consideration of a 7 percent per year discount on the value of emission reductions.

Table 6.2.2-18
Typical Lifetime Evaporative Emissions Per Large SI Gasoline Equipment(tons)

Evaporative Component	Baseline		Control		Reduction	
	Undiscounted	Discounted	Undiscounted	Discounted	Undiscounted	Discounted
Diurnal	0.041	0.028	0.003	0.002	0.038	0.026
Refueling	0.081	0.056	0.065	0.045	0.016	0.011
Hot Soak	0.158	0.109	0.011	0.008	0.147	0.101
Running Loss	0.027	0.019	0.002	0.001	0.025	0.017
Total	0.307	0.211	0.081	0.056	0.225	0.155

6.2.3 Snowmobile Exhaust Emissions

We projected the annual tons of exhaust HC, CO, NOx, and PM from snowmobiles using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to snowmobiles then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.3.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for snowmobile exhaust emissions. These inputs are load factor, annual use, average operating life, and population. Based on data developed for our Final Finding for recreational equipment and Large SI equipment, we use a load factor of 34 percent and an annual usage factor of 57 hours.[17] Using historical snowmobile sales information for 1970 through 2001 and nationwide snowmobile registrations, both provided by ISMA, and the scrappage curve used in the NONROAD model, we have updated our estimate of average life from 9 years (as used in the proposal) to 13 years for this analysis.[18] The draft NONROAD model includes current and projected engine populations. The growth rates used in the NONROAD model have been updated based on historical sales information (provided by ISMA) and sales projections (developed by NERA in an analysis of the proposed snowmobile standards for ISMA).[19,20] Table 6.2.3-1 presents the snowmobile population estimates (rounded to the nearest 1,000 units) for selected years.

Table 6.2.3-1
Projected Snowmobile Populations by Year

Year	2000	2005	2010	2020	2030
Population	1,622,000	2,000,000	2,407,000	3,089,000	3,377,000

The emission factors and deterioration factors for pre-control 2-stroke engines were developed for the Final Finding as noted above. For the control case emission factors (i.e., engines designed to comply with the Phase 1, Phase 2, or Phase 3 standards), we are projecting that manufacturers will use a mix of several different technologies that have significantly different emission characteristics. The three control technologies we believe will be used are a modified 2-stroke design, a direct injection 2-stroke engine, and a 4-stroke engine.

For the modified 2-stroke engine we assumed that manufacturers will design their engines to meet the Phase 1 standards at regulatory useful life with a small compliance margin. (Because we are not adopting a NOx standard for snowmobiles, we have assumed that NOx levels will remain at the pre-control levels for modified 2-stroke engines.) In determining the zero-mile levels of modified 2-stroke engines, we assumed a compliance margin of 20 percent to account for variability. (The standards for snowmobiles are not based on the use of catalysts. Engine out emissions tend to have more variability than the emissions coming from an engine equipped with a catalyst. For this reason, we are using a compliance margin of 20 percent. As noted earlier, including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines meet emission standards in the event of a compliance audit.) We have assumed that the deterioration rates of modified 2-strokes will stay the same as the deterioration rates for pre-control 2-stroke engines. Table 6.2.3-2 presents the emission factors used in this analysis for new engines and the maximum deterioration factors applied to snowmobiles operated out to their median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 300 hours for snowmobiles. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.)

Table 6.2.3-2
Zero-Mile Level Emission Factors (g/hp-hr) and Deterioration Factors (at Median Lifetime) for Snowmobile Engines

Engine Category/ Technology	THC		CO		NOx		PM	
	ZML	Max DF	ZML	Max DF	ZML	Max DF	ZML	Max DF
Pre-control 2-stroke	111	1.2	296	1.2	0.9	1.0	2.7	1.2
Modified 2-stroke	53.7	1.2	147	1.2	0.9	1.0	2.7	1.2
Direct Injection 2-stroke	21.8	1.2	90	1.2	2.8	1.0	0.57	1.2
4-stroke	7.8	1.15	123	1.17	9.2	1.0	0.15	1.15

Table 6.2.3-2 contains the zero-mile level and deterioration factors for direct injection 2-stroke engines and 4-stroke engines as well. The emission levels were based on the results of testing of prototype snowmobile engines employing these technologies or other similarly sized engines employing these technologies.[21]

The Phase 1 standards are phased-in with 50% of engines for 2006 and 100% of enignes for 2007. The Phase 2 standards take effect in 2010 for all engines. The Phase 3 standards take effect in 2012 for all engines. For modeling purposes, we estimated the percent of engines that will employ each of the control technologies to comply with the Phase 1, Phase 2, and Phase 3 standards. Table 6.2.3-3 contains the technology assumptions for the base case and under the Phase 1, Phase 2, and Phase 3 standards. Currently, all engines are 2-strokes. Based on discussions with manufacturers, we have assumed that manufacturers will begin introducing a limited number of direct injection 2-strokes and some 4-strokes in the coming years.

Table 6.2.3-3
Snowmobile Engine Technology Mix Under the Base and Control Cases

Scenario	Uncontrolled 2-strokes	Modified 2-stroke	Direct Injection 2-stroke	4-stroke
Current Baseline	100%	-	-	-
2006 Baseline	86%	-	7%	7%
Phase 1 (2006)	53%	30%	8.5%	8.5%
Phase 1 (2007)	20%	60%	10%	10%
Phase 2	20%	30%	35%	15%
Phase 3	10%	20%	50%	20%

6.2.3.2 Reductions Due to the Standards

We anticipate that the standards for snowmobiles will result in a 57 percent reduction in HC, a 46 percent reduction in CO, and a 42 percent reduction in PM by the year 2020. As manufacturers adopt advanced technologies that result in significant HC, CO and PM emissions, we expect the relatively limited amount of NOx from snowmobiles to increase under the program. Tables 6.2.3-4 through 6.2.3.-7 present our projected HC, CO, NOx, and PM exhaust emission inventories for snowmobiles and the anticipated emission reductions from the Phase 1, Phase 2 and Phase 3 standards.

Table 6.2.3-4
Projected HC Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	205,000	205,000	0	0%
2005	250,000	250,000	0	0%
2010	286,000	243,000	43,000	15%
2020	345,000	148,000	197,000	57%
2030	375,000	133,000	242,000	65%

Table 6.2.3-5
Projected CO Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	546,000	546,000	0	0%
2005	668,000	668,000	0	0%
2010	775,000	670,000	105,000	14%
2020	950,000	508,000	442,000	46%
2030	1,035,000	497,000	538,000	52%

Table 6.2.3-6
Projected NOx Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	1,400	1,400	0	0%
2005	1,900	1,900	0	0%
2010	3,000	3,500	(500)	-16%
2020	5,000	10,000	(5,000)	-101%
2030	5,500	12,100	(6,600)	-121%

Table 6.2.3-7
Projected PM Inventories and Reductions for Snowmobiles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	5,000	5,000	0	0%
2005	6,100	6,100	0	0%
2010	7,000	6,700	300	4%
2020	8,400	4,900	3,500	42%
2030	9,100	4,400	4,700	52%

6.2.3.3 Per Equipment Emissions from Snowmobiles

The following section describes the development of the HC and CO emission estimates on a per piece of equipment basis over the average lifetime or a typical snowmobile. The emission estimates were developed to estimate the cost per ton of the standards as presented in

Chapter 7.

In order to estimate the emission from a snowmobile, information on the emission level of the engine, the power of the engine, the load factor of the engine, the annual hours of use of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and CO emission levels of a piece of equipment over the lifetime of a typical snowmobile were presented in Table 6.2.3-2. A brand new snowmobile emits at the zero-mile level presented in the table. As the snowmobile ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.3-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the snowmobile at the end of its median life. The emissions at any point in time in between can be determined through interpolation.

To estimate the average power for snowmobiles, we used the population and power distribution information contained in the NONROAD model and determined the population-weighted average horsepower for snowmobiles. The population-weighted horsepower for snowmobiles was calculated to be 48.3 hp.

As described earlier in this section, the load factor for snowmobiles is estimated to be 0.34, the annual usage rate is estimated to be 57 hours per year, and the average lifetime is estimated to be 13 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment (see Equation 6-1), we calculated the lifetime HC and CO emissions from a typical snowmobile for both pre-control engines and engines meeting the Phase 1, Phase 2, and Phase 3 standards. (The per vehicle estimates are a weighted-average of the different technologies assumed under the base and control cases as presented earlier in Table 6.2.3-3.) Table 6.2.3-8 presents the lifetime HC and CO emissions for a typical snowmobile on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.3-9 presents the corresponding lifetime HC and CO emission reductions for the Phase 1, Phase 2 and Phase 3 standards.

Table 6.2.3-8
Lifetime HC and CO Emissions from a Typical Snowmobile (tons)

Control Level	HC		CO	
	Undiscounted	Discounted	Undiscounted	Discounted
Pre-control	1.45	0.98	3.99	2.71
Phase 1	0.85	0.57	2.50	1.70
Phase 2	0.70	0.47	2.27	1.54
Phase 3	0.51	0.34	1.90	1.29

Table 6.2.3-9
Lifetime HC and CO Emission Reductions from a Typical Snowmobile (tons)

Control Increment	HC		CO	
	Undiscounted	Discounted	Undiscounted	Discounted
Pre-control to Phase 1	0.60	0.40	1.49	1.01
Phase 1 to Phase 2	0.15	0.10	0.23	0.16
Phase 2 to Phase 3	0.19	0.14	0.37	0.25

6.2.4 All-Terrain Vehicle Exhaust Emissions

We projected the annual tons of exhaust HC, CO, NOx, and PM from all-terrain vehicles (ATVs) using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to ATVs then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.4.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for ATV exhaust emissions. These inputs are annual use, average operating life, and population. Based on data developed for our Final Finding for recreational equipment and Large SI equipment, we use an average operating life of 13 years for ATVs.[22] Based on several surveys of ATV operators, we have revised the an annual usage factor for ATVs for this analysis to 1,570 miles per year.[23] The updated mileage analysis for ATVs is presented in detail in the appendix to this chapter. (Because the ATV standards are chassis-based standards instead of engine-based, the NONROAD model has been revised to model ATVs on the basis of gram per mile emission factors and annual mileage accumulation rates. Load factor is not needed for such calculations.)

The draft NONROAD model includes current and projected engine populations. Table

6.2.4-1 presents these population estimates (rounded to the nearest 1,000 units) for selected years. The ATV population growth rates used in the NONROAD model have been updated for this analysis to reflect the expected growth in ATV populations based on updated ATV sales information and sales growth projections supplied by the Motorcycle Industry Council (MIC), an industry trade organization. The growth rates were developed separately for 2-stroke and 4-stroke ATVs. Based on the sales information from MIC, sales of ATVs have been growing substantially throughout the 1990s, averaging 25 percent growth per year over the last 6 years. MIC estimates that growth in sales will continue for the next few years, although at lower levels of ten percent or less, with no growth in sales projected by 2005. Combining the sales history, growth projections, and information on equipment scrappage, we have estimated that the population of ATVs will grow significantly through 2010, and then grow at much lower levels.[24] (The population of 2-stroke ATVs presented in Table 6.2.4-1 are for baseline population estimates. Under the ATV standards, 2-stroke designs are expected to be phased-out as they are converted to 4-stroke designs.)

Table 6.2.4-1
Projected ATV Populations by Year

Category	2000	2005	2010	2020	2030
4-stroke ATVs	3,919,000	6,240,000	8,453,000	10,080,000	10,188,000
2-stroke ATVs*	690,000	1,678,000	2,461,000	3,001,000	3,036,000
All ATVs	4,609,000	7,918,000	10,914,000	13,081,000	13,224,000

* - The projected population estimates for 2-stroke ATVs are for baseline calculations only. Under the Phase 1 standards, we expect all 2-stroke engines will be converted to 4-stroke designs.

The baseline HC, CO, and NOx emission factors used in the NONROAD model for ATVs have been updated based on recent testing of ATVs and off-highway motorcycles as presented in Chapter 4. PM emissions were not measured in the test program. Therefore, baseline PM emission factors were based on testing of both off-highway motorcycles and pre-control on-highway motorcycles.[25] The baseline deterioration factors (for pre-control engines) were developed for the Final Finding as noted above. For the control emission factors (i.e., engines complying with the Phase 1 standards), we assumed that the manufacturers will design their engines to meet the standards at regulatory useful life with a small compliance margin. Because we are adopting a HC+NOx standard for ATVs, we have assumed that the Phase 1 HC/NOx split will remain the same as the pre-control HC/NOx split. For the Phase 1 standards for ATVs, we assumed a compliance margin of 20 percent to account for variability. (As noted earlier, including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines will meet emission standards in the event of a compliance audit.) Because the standards for ATVs are expected to be met by 4-stroke designs, we assumed that the deterioration rates will stay the same as the deterioration rates for pre-control 4-stroke ATVs. Table 6.2.4-2 presents the emission factors used in this analysis for new ATVs and the maximum deterioration factors for ATVs which applies at the median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 6,214 miles (10,000 kilometers) for ATVs. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.)

Table 6.2.4-2
Zero-Mile Level Emission Factors (g/mi) and Deterioration Factors (at Median Lifetime) for ATVs

Engine Category	THC		CO		NOx		PM	
	ZML	Max DF	ZML	Max DF	ZML	Max DF	ZML	Max DF
Baseline/Pre-control 2-stroke	53.9	1.2	54.1	1.2	0.15	1.0	2.1	1.2
Baseline/Pre-control 4-stroke	2.4	1.15	48.5	1.17	0.41	1.0	0.06	1.2
Control/Phase 1 - 4-stroke	1.6	1.15	42.9	1.17	0.26	1.0	0.06	1.15

The Phase 1 standards are to be phased in at 50 percent in 2007 and 100 percent in 2008. However, because there are a significant number of small volume manufacturers that produce 2-stroke ATVs, and because we have compliance flexibilities for such manufacturers, we have modeled the phase in of the standards for the current 2-stroke ATVs based on the schedule contained in Table 6.2.4-3.

Table 6.2.4-3
Assumed Phase-In Schedule for Current 2-Stroke ATVs Used in the Modeling Runs

Model Year	Pre-control 2-stroke	Phase 1 4-stroke
2005	100%	0%
2006	65%	35%
2007	30%	70%
2008	15%	85%
2009	0%	100%

6.2.4.2 Reductions Due to the Standards

We anticipate that the standards for ATVs will result in a 86 percent reduction in HC, a 37 percent reduction in CO, and a 86 percent reduction in PM by the year 2020. As manufacturers convert their engines from 2-stroke to 4-stroke design and achieve these significant reductions, we expect there may be a minimal increase in NOx. Tables 6.2.4-4 through 6.2.4-7 present our projected HC, CO, NOx, and PM exhaust emission inventories for ATVs and the anticipated emission reductions from the Phase 1 standards.

Table 6.2.4-4
Projected HC Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	89,000	89,000	0	0%
2005	200,000	200,000	0	0%
2010	291,000	198,000	92,000	32%
2020	353,000	49,000	304,000	86%
2030	357,000	40,000	317,000	89%

Table 6.2.4-5
Projected CO Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	437,000	437,000	0	0%
2005	755,000	755,000	0	0%
2010	1,042,000	989,000	53,000	5%
2020	1,250,000	1,085,000	165,000	13%
2030	1,263,000	1,092,000	171,000	14%

Table 6.2.4-6
Projected NOx Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	3,000	3,000	0	0%
2005	4,900	4,900	0	0%
2010	6,600	5,900	(700)	-11%
2020	7,900	5,900	(2,000)	-25%
2030	8,000	6,000	(2,000)	-26%

Table 6.2.4-7
Projected PM Inventories and Reductions for ATVs (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	3,200	3,200	0	0%
2005	7,400	7,400	0	0%
2010	10,800	7,400	3,400	32%
2020	13,100	1,800	11,300	86%
2030	13,300	1,500	11,800	89%

6.2.4.3 Per Equipment Emissions from All-Terrain Vehicles

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or a typical ATV. The emission estimates were developed to estimate the cost per ton of the standards as presented in Chapter 7.

In order to estimate the emissions from an ATV, information on the emission level of the vehicle, the annual usage rate of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical ATV were presented in Table 6.2.4-2. A brand new ATV emits at the zero-mile level presented in the table. As the ATV ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.4-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the ATV at the end of its median life. The emissions at any point in time in between can be determined through interpolation.

As described earlier in this section, the annual usage rate for an ATV is estimated to be 1,570 miles per year and the average lifetime is estimated to be 13 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment modified to remove the power and load variables (see Equation 6-1), we calculated the lifetime HC+NOx emissions from a typical ATV for both pre-control engines (shown separately for 2-stroke and 4-stroke engines and a composite weighted value) and engines meeting the Phase 1 standards. Table 6.2.4-8 presents the lifetime HC+NOx emissions for a typical ATV on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.4-9 presents the corresponding lifetime HC+NOx emission reductions for the Phase 1.

Table 6.2.4-8
Lifetime HC+NOx Emissions from a Typical ATV (tons)

Control Level	HC+NOx	
	Undiscounted	Discounted
Pre-control (2-stroke)	1.37	0.93
Pre-control (4-stroke)	0.07	0.05
Pre-control (Composite)	0.35	0.24
Phase 1	0.05	0.03

Table 6.2.4-9
Lifetime HC+NOx Emission Reductions from a Typical ATV (tons)

Control Increment	HC+NOx	
	Undiscounted	Discounted
Pre-control (Composite) to Phase 1	0.30	0.21

6.2.5 Off-highway Motorcycle Exhaust Emissions

We projected the annual tons of exhaust HC, CO, NOx, and PM from off-highway motorcycles using the draft NONROAD model discussed above. This section describes inputs to the calculations that are specific to off-highway motorcycles then presents the results. These results are for the nation as a whole and include baseline and control inventory projections.

6.2.5.1 Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations for off-highway motorcycles exhaust emissions. These inputs are annual use, average operating life, and population. Based on an updated analysis of fuel consumption and fuel use, we have revised our estimate of annual usage for off-highway motorcycles to 1,600 miles per year.[26] (The updated mileage analysis for off-highway motorcycles is presented in detail in the appendix to this chapter.) We have also revised our estimate of the average operating life of off-highway motorcycles to 12 years based on historical sales and population information provided by the Motorcycle Industry Council.[27] (Because the off-highway motorcycle standards are chassis-based standard instead of engine-based, the NONROAD model has been revised to model off-highway motorcycles on the basis of gram per mile emission factors and annual mileage accumulation rates. Load factor is not needed for such calculations.)

The draft NONROAD model includes current and projected engine populations. Table 6.2.5-1 presents these population estimates (rounded to the nearest 1,000 units) for selected years. (The population of 2-stroke off-highway motorcycles presented in Table 6.2.5-1 are for baseline population estimates. Under the off-highway motorcycle standards, non-competition 2-stroke designs are expected to be phased-out as they are converted to 4-stroke designs. Competition models will remain 2-stroke designs.) The population growth rates used in the NONROAD model have been updated based on historical sales information provided by MIC and a projected one percent growth in sales.[28]

Table 6.2.5-1
Projected Off-Highway Motorcycle Populations by Year

Category	2000	2005	2010	2020	2030
4-stroke Off-highway Motorcycles	444,000	656,000	862,000	1,038,000	1,133,000
2-stroke Off-highway Motorcycles*	902,000	1,333,000	1,750,000	2,108,000	2,300,000
All Off-highway Motorcycles	1,346,000	1,989,000	2,612,000	3,146,000	3,433,000

* - The projected population estimates for 2-stroke off-highway motorcycles are for baseline calculations only. To meet the standards, we expect all non-competition 2-strokes will be converted to 4-stroke designs. All 2-stroke competition models are assumed to remain 2-strokes.

The baseline HC, CO, and NOx emission factors used in the NONROAD model for off-highway motorcycles have been updated based on recent testing of ATVs and off-highway motorcycles as presented in Chapter 4. PM emissions were not measured in the test program. Therefore, baseline PM emission factors were based on testing of both off-highway motorcycles and pre-control on-highway motorcycles.[29] The baseline deterioration factors (for pre-control engines) were developed for the Final Finding as noted above. For the control emission factors (i.e., Phase 1 off-highway motorcycles), we assumed that the manufacturers will design their engines to meet the standards at regulatory useful life with a small compliance margin. Because we are adopting a HC+NOx standard for off-highway motorcycles, we have assumed that the Phase 1 HC/NOx split will remain the same as the pre-control HC/NOx split. For the Phase 1 standards for off-highway motorcycles, we assumed a compliance margin of 20 percent to account for variability. (Including a margin of compliance below the standards is a practice that manufacturers have followed historically to provide greater assurance that their engines will meet emission standards in the event of a compliance audit.) Because the standards for off-highway motorcycles are expected to be met by 4-stroke designs, we assumed that the deterioration rates will stay the same as the deterioration rates for pre-control 4-stroke off-highway motorcycles. Table 6.2.5-2 presents the emission factors used in this analysis for new off-highway motorcycles and the maximum deterioration factors applied to off-highway motorcycles operated out to their median lifetime. (For the calculations, the zero-mile levels were determined based on the pro-rated amount of deterioration expected at the regulatory lifetime, which is 6,210 miles (10,000 kilometers) for off-highway motorcycles. As noted earlier, the regulatory useful life is the period of time for which a manufacturer must demonstrate compliance with the emission standards. The median lifetime of in-use equipment is longer than the regulatory life.)

Table 6.2.5-2
Zero-Mile Level Emission Factors (g/mi) and Deterioration Factors (at Median Lifetime) for Off-Highway Motorcycles

Engine Category	THC		CO		NOx		PM	
	ZML	Max DF	ZML	Max DF	ZML	Max DF	ZML	Max DF
Baseline/Pre-control 2-stroke*	53.9	1.2	54.1	1.2	0.15	1.0	2.1	1.2
Baseline/Pre-control 4-stroke	2.4	1.15	48.5	1.17	0.41	1.0	0.06	1.15
Control/Phase 1 4-stroke	2.1	1.15	30.6	1.17	0.34	1.0	0.06	1.15

* - Competition models are assumed to remain at pre-control levels under the final program for off-highway motorcycles.

The Phase 1 standards phase in at 50 percent in 2007 and 100 percent in 2008. However, because there are a significant number of small volume manufacturers that produce off-highway motorcycles (who can take advantage of compliance flexibilities), and because competition off-highway motorcycles are exempt from the standards, we have modeled the phase in of the standards for off-highway motorcycles based on the schedule contained in Table 6.2.5-3.

Table 6.2.5-3
Assumed Phase-In Schedule for Current Off-Highway Motorcycles Used in the Modeling Runs

Model Year	Current 4-stroke Off-highway Motorcycles		Current 2-stroke Off-highway Motorcycles	
	Pre-control	Phase 1	Pre-control	Phase 1
2005	100%	0%	100%	0%
2006	56%	44%	76%	24%
2007	12%	88%	53%	47%
2008	6%	94%	49%	51%
2009+	0%	100%	46%	54%

6.2.5.2 Reductions Due to the Standards

We anticipate that the standards for off-highway motorcycles will result in a 49 percent reduction in HC, a 26 percent reduction in CO, and a 50 percent reduction in PM by the year 2020. As manufacturers convert their engines from 2-stroke to 4-stroke design and achieve these significant emission reductions, we project there may be a small increase in NOx inventories. Tables 6.2.5-4 through 6.2.5.-7 present our projected HC, CO, NOx, and PM exhaust emission inventories for off-highway motorcycles and the anticipated emission reductions from the Phase 1 standards. (The emission inventories presented below for off-highway motorcycles include competition motorcycles that will be exempt from the standards.)

Table 6.2.5-4
Projected HC Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	97,000	97,000	0	0%
2005	143,000	143,000	0	0%
2010	188,000	151,000	36,000	19%
2020	226,000	115,000	111,000	49%
2030	246,000	121,000	126,000	51%

Table 6.2.5-5
Projected CO Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	137,000	137,000	0	0%
2005	203,000	203,000	0	0%
2010	226,000	239,000	27,000	10%
2020	321,000	236,000	84,000	26%
2030	350,000	254,000	96,000	27%

Table 6.2.5-6
Projected NOx Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	600	600	0	0%
2005	800	800	0	0%
2010	1,100	1,200	(100)	-8%
2020	1,300	1,500	(200)	-19%
2030	1,400	1,700	(300)	-19%

Table 6.2.5-7
Projected PM Inventories and Reductions for Off-Highway Motorcycles (short tons)

Calendar Year	Baseline	Control	Reduction	% Reduction
2000	3,700	3,700	0	0%
2005	5,500	5,500	0	0%
2010	7,300	5,900	1,400	20%
2020	8,700	4,400	4,300	50%
2030	9,500	4,600	4,900	52%

6.2.5.3 Per Equipment Emissions from Off-highway Motorcycles

The following section describes the development of the HC+NOx emission estimates on a per piece of equipment basis over the average lifetime or a typical off-highway motorcycle. The emission estimates were developed to estimate the cost per ton of the standards as presented in Chapter 7.

In order to estimate the emissions from an off-highway motorcycle, information on the emission level of the vehicle, the annual usage rate of the engine, and the lifetime of the engine are needed. The values used to predict the per piece of equipment emissions for this analysis and the methodology for determining the values are described below.

The information necessary to calculate the HC and NOx emission levels of a piece of equipment over the lifetime of a typical off-highway motorcycle were presented in Table 6.2.5-2. A brand new off-highway motorcycle emits at the zero-mile level presented in the table. As the off-highway motorcycle ages, the emission levels increase based on the pollutant-specific deterioration factor. Deterioration, as modeled in the NONROAD model, continues until the equipment reaches the median life. The deterioration factors presented in Table 6.2.5-2 when applied to the zero-mile levels presented in the same table, represent the emission level of the off-highway motorcycle at the end of its median life. The emissions at any point in time in between can be determined through interpolation.

As described earlier in this section, the annual usage rate for an off-highway motorcycle is estimated to be 1,600 miles per year and the average lifetime is estimated to be 12 years.

Using the information described above and the equation used for calculating emissions from nonroad equipment modified to remove the power and load variables (see Equation 6-1), we calculated the lifetime HC+NOx emissions from a typical off-highway motorcycle for both pre-control engines (shown separately for 2-stroke and 4-stroke engines and a composite weighted value) and engines under the Phase 1 standards. (Competition bikes, which are exempt from the standards, are not included in the calculations.) Table 6.2.5-8 presents the lifetime HC+NOx emissions for a typical off-highway motorcycle on both an undiscounted and discounted basis (using a discount rate of 7 percent). Table 6.2.5-9 presents the corresponding lifetime HC+NOx emission reductions for the Phase 1 standards.

Table 6.2.5-8
Lifetime HC+NOx Emissions from a Typical Off-highway Motorcycle (tons)*

Control Level	HC+NOx	
	Undiscounted	Discounted
Pre-control (2-stroke)	1.27	0.89
Pre-control (4-stroke)	0.06	0.04
Pre-control (Composite)	0.60	0.42
Phase 1	0.06	0.04

* The emission estimates do not include competition off-highway motorcycles that remain at pre-control emission levels.

Table 6.2.5-9
Lifetime HC+NOx Emission Reductions from a Typical Off-highway Motorcycle (tons)*

Control Increment	HC+NOx	
	Undiscounted	Discounted
Pre-control (Composite) to Phase 1	0.54	0.38

* The reduction estimates do not include competition off-highway motorcycles that remain uncontrolled, and therefore do not realize any emission reductions under the new standards.

6.2.6 Evaporative Emissions from Recreational Vehicles

We projected the annual tons of hydrocarbons evaporated into the atmosphere from snowmobiles, ATVs, off-highway motorcycles using the methodology discussed above in Section 6.1.2. These evaporative emissions include permeation, diurnal and refueling emissions. Although the standards do not specifically require the control of diurnal and refueling emissions, we have included them in the modeling for completeness. This section describes inputs to the calculations that are specific to each of the recreational vehicle types and presents our baseline and controlled national evaporative inventory projections.

6.2.6.1 General Inputs for the Inventory Calculations

Several usage inputs are specific to the calculations of evaporative emissions from ATVs. These inputs are fuel tank sizes, population, and distribution throughout the nation. The draft NONROAD model includes current and projected engine populations for each state and we used this distribution as the national fuel tank distribution. Table 6.2.6-1 presents the population of recreational vehicles for 1998.

Table 6.2.6-1
1998 Population of Recreational Vehicles by Region

Region	Snowmobiles	ATVs	Off-Highway Motorcycles
Northeast	954,000	1,420,000	427,000
Southeast	0	1,010,000	304,000
Southwest	11,000	363,000	109,000
Midwest	419,000	457,000	137,000
West	40,000	423,000	127,000
Northwest	140,000	249,000	75,000
Total	1,560,000	3,930,000	1,180,000

We based average fuel tank sizes on sales literature for recreational vehicles. Snowmobile fuel tanks range from 10 gallons to about 12 gallons. For ATVs, fuel tanks range from one gallon for the smaller youth models to five gallons for the larger utility models.

Finally, off-highway motorcycle fuel tanks range in capacity from approximately one gallon on some smaller youth models to about three gallons on some enduro motorcycles. For this analysis, we used average fuel tank sizes of 11 gallons for snowmobiles, 4 gallons for ATVs, and 3 gallons for off-highway motorcycles.

Based on our examination of recreational vehicles, we have found that fuel hoses generally have an inside diameter of about 6 mm (1/4 inch). For ATVs, we estimate one foot of fuel line on average. For off-highway motorcycles, we estimate that they use approximately one to two feet of fuel line on average. We use 1.5 feet in our analysis. Snowmobiles are a little more complex because they use multi-cylinder engines (either two or three cylinders). For two cylinder engines we estimate two to three feet of fuel line and for three cylinder engines we estimate three to four feet of fuel line. We use 3.5 feet in our analysis.

6.2.6.2 Permeation Emissions Inventory and Reductions

Based on the data presented in Chapter 4, we developed the emission factors presented in Table 6.2.6-2. For the purposes of this modeling, fuel tank permeation rates are expressed in terms of g/gallon/day because the defining characteristic of the fuel tanks in our model is capacity. The standard requires that the fuel tanks meet an 85 percent reduction in permeation throughout its useful life. For this modeling, we assume that manufacturers will strive to achieve a 95 percent reductions from new tanks and that the permeation control will deteriorate to 85 percent by the end of the life of an average tank. Hose permeation rates are based on g/m^2/day. We believe that hoses designed to meet the 15 g/m^2/day standard on 10 percent ethanol fuel will permeate at least 50 percent less when gasoline is used. Therefore, we model permeation from this hose to be about half of the permeation from fuel hose designed to meet 15 g/m^2/day on gasoline.[gg] To show the effect of temperature on permeation rates, we present emission rates at three temperatures.

Table 6.2.6-2
Fuel Tank and Hose Permeation Emission Factors

Material	23°C (73°F)	29°C (85°F)	40°C (104°F)
Polyethylene fuel tanks	0.78 g/gal/day	1.12 g/gal/day	2.08 g/gal/day
New barrier treated HDPE fuel tank	0.04 g/gal/day	0.06 g/gal/day	0.10 g/gal/day
Aged barrier treated HDPE fuel tank	0.11 g/gal/day	0.17 g/gal/day	0.31 g/gal/day
SAE R7 fuel hose	550 g/m^2/day	873 g/m^2/day	1800 g/m^2/day
SAE R9 barrier fuel hose	15 g/m^2/day	24 g/m^2/day	49 g/m^2/day
Alcohol resistant barrier fuel hose	7.5 g/m^2/day	12 g/m^2/day	25 g/m^2/day

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[gg] This is appropriate because the baseline emissions are modeled based on the use of gasoline as a fuel. If we were to consider that a fraction of the fuel contains oxygenates, both the baseline and control emission inventory projections would increase.

Using the vehicle populations and temperature distributions discussed above, we calculated baseline and controlled permeation emission inventories for recreational vehicles. Tables 6.2.6-3 and 6.2.6-4 present our projected permeation reductions from fuel tanks and hoses.

Table 6.2.6-3
Projected Fuel Tank Permeation Emissions from Recreational Vehicles [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	3,389	4,181	5,032	6,456	7,061
	control	3,389	4,181	3,586	901	746
	reduction	0	0	1,446	5,555	6,315
ATVs	baseline	3,985	6,751	9,275	11,109	11,231
	control	3,985	6,751	7,388	2,602	1,249
	reduction	0	0	1,887	8,507	9,982
OHMCs	baseline	882	1,303	1,710	2,061	2,248
	control	882	1,303	1,370	834	857
	reduction	0	0	340	1,227	1,391
Total	baseline	8,255	12,234	16,016	19,626	20,539
	control	8,255	12,234	12,343	4,337	2,851
	reduction	0	0	3,673	15,288	17,688

Table 6.2.6-4
Projected Fuel Hose Permeation Emissions from Recreational Vehicles [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	4,471	5,516	6,638	8,517	9,315
	control	4,471	5,516	4,361	452	127
	reduction	0	0	2,007	8,065	9,188
ATVs	baseline	4,243	7,189	9,876	11,829	11,959
	control	4,243	7,189	7,771	1,931	245
	reduction	0	0	2,105	9,898	11,714
OHMCs	baseline	1,878	2,774	3,642	4,389	4,787
	control	1,878	2,774	2,880	1,513	1,520
	reduction	0	0	762	2,876	3,268
Total	baseline	10,592	15,478	20,156	24,735	26,061
	control	10,592	15,478	15,282	3,896	1,891
	reduction	0	0	4,873	20,838	24,169

6.2.6.3 Per Vehicle Permeation Emissions

In developing the cost per ton estimates in Chapter 7, we need to know the lifetime emissions per recreational vehicle. The lifetime emissions are based on the projected lives of 9 years for snowmobiles, 13 years for ATVs, and 9 years for off-highway motorcycles. We determine annual per vehicle evaporative emissions by dividing the total annual evaporative emissions for 2000 by the recreational vehicle populations shown in Table 6.2.6-1 (grown to 2000). Competition motorcycles, which are exempt form the standards, are not included in these calculations. Per vehicle emission reductions are based on the modeling described above. Table 6.2.6-5 presents these results with and without the consideration of a 7 percent per year discount on the value of emission reductions.

Table 6.2.6-5
Typical Lifetime Permeation Emissions Per Recreational Vehicle (tons)

	Baseline		Control		Reduction	
	Undiscounted	Discounted	Undiscounted	Discounted	Undiscounted	Discounted
Snowmobiles						
Tank	0.0180	0.0140	0.0019	0.0015	0.0161	0.0125
Hose	0.0238	0.0184	0.0003	0.0003	0.0235	0.0182
Total	0.0418	0.0324	0.0022	0.0017	0.0396	0.0307
All Terrain Vehicles						
Tank	0.0114	0.0078	0.0012	0.0008	0.0102	0.0070
Hose	0.0121	0.0083	0.0002	0.0001	0.0119	0.0082
Total	0.0234	0.0161	0.0014	0.0009	0.0221	0.0152
Off-Highway Motorcycles						
Tank	0.0059	0.0046	0.0006	0.0005	0.0053	0.0041
Hose	0.0126	0.0097	0.0002	0.0001	0.0124	0.0096
Total	0.0184	0.0143	0.0008	0.0006	0.0177	0.0137

6.2.6.4 Other Evaporative Emissions

We calculated diurnal and refueling vapor loss emissions using the general inputs in section 6.2.6.1 and the methodology described in sections 6.1.2.2 and 6.2.1.3. Although we are not regulating these emissions, we present the inventory projections for comparison. Table 6.2.6-6 presents the baseline diurnal emission factors for the certification test conditions and a typical summer day with low vapor pressure fuel and a half-full tank. (This comparison is for illustrative purposes; as discussed above, we modeled daily temperature for 365 days over 6 regions of the U.S.) Decreasing temperature and fuel RVP and increasing fill level all have the effect of reducing the diurnal emission factor. Table 6.2.6-7 presents our diurnal emission projections.

Table 6.2.6-6
Diurnal Emission Factors for Test Conditions and Typical Summer Day

Evaporative Control	72-96°F, 9 RVP* Fuel, 40% fill	60-84°F, 8 RVP* Fuel, 50% fill
baseline	1.5 g/gallon/day	0.55 g/gallon/day

* Reid Vapor Pressure

Table 6.2.6-7
Projected Diurnal Emissions from Recreational Vehicles [short tons]

Calendar Year	Snowmobiles	ATVs	Off-Highway Motorcycles
2000	2,223	3,079	681
2005	2,743	5,216	1,006
2010	3,301	7,167	1,321
2020	4,235	8,584	1,592
2030	4,632	8,678	1,737

To calculate the refueling vapor displacement emissions from recreational vehicles, we needed to know the amount of fuel added to the fuel tank per year. Therefore, we used the draft NONROAD model to determine the amount of fuel consumed by recreational vehicles. We then used the amount of fuel consumed as the amount of fuel added to the fuel. Table 6.2.6-8 contains the projected refueling emission inventories for recreational vehicles.

Table 6.2.6-8
Projected Refueling Emissions from Recreational Vehicles [short tons]

Calendar Year	Snowmobiles	ATVs	Off-Highway Motorcycles
2000	1,814	928	368
2005	2,230	1,620	544
2010	2,596	1,185	684
2020	2,922	2,510	773
2030	3,120	2,532	840

Appendix to Chapter 6: ATV and Off-highway Motorcycle Usage Rates

This appendix presents the analyses used to determine the annual average usage rates for ATVs and off-highway motorcycles.

6A.1 ATV Usage

On October 5, 2001, EPA published proposed emission regulations for nonroad land-based recreational vehicles. These regulations covered snowmobiles, off-highway motorcycles, and all-terrain vehicles (ATVs). The Motorcycle Industry Council, Inc. (MIC) and the Specialty Vehicle Institute of America (SVIA) submitted comments suggesting that the EPA estimates for ATV usage had been substantially overestimated. They stated that our mileage estimate of 7,000 miles per year was too high and that based on some additional information that they had obtained, a more reasonable estimate was a lifetime average of 350 miles per year. As a result of these comments and the subsequent new information, EPA has revised it's estimate of annual ATV usage.

Background

On November 20, 2000 EPA published a Final Finding of Contribution and Advance Notice of Proposed Rulemaking (ANPRM) for large nonroad spark-ignition engines and land-based recreational vehicles. In this process, we developed emission inventories for the various engine and vehicle categories covered by both these documents. EPA developed inventories using NONROAD model, which computes emission estimates for nonroad engines at selected geographic and temporal scales. The model incorporates data on emission rates, usage rates, and vehicle population to determine annual emission levels of various pollutants.
For recreational vehicles, and more specifically ATVs, data on emission rates and usage rates was extremely limited. We approached members of the ATV industry to provide us with any data that they had on emission and usage rates. Unfortunately, all of the emission data industry had for ATVs was collected on the J1088 steady state engine test cycle rather than the FTP transient vehicle test cycle that we proposed. Industry also indicated that they didn't have any data on ATV usage rates. MIC provided survey data on off-highway motorcycle usage, but did not provide any information on ATV usage. Through our literature search, we ultimately found a study by the United States Consumer Product Safety Commission (CPSC) published in April of 1998 titled, “All-Terrain Vehicle Exposure, Injury, Death, and Risk Studies” that provided information on ATV usage. This study provided the basis for our estimate of ATV usage for the NPRM.

We did not receive any comments on our estimate of ATV usage during the comment period for the Final Finding and ANPRM . In fact, we did not receive any comments until after the Notice of Proposed Rulemaking (NPRM) was published in October of 2001.

ATV Usage in the ANPRM and NPRM

Because we received no comment or additional information for the ANPRM and NPRM, we determined that the CPSC study was the best source of information available. After converting hours of use to miles ridden, we estimated an annual average of 7,000 miles/year. A complete description of the modeling parameters for ATVs used in the NPRM is contained in an EPA memorandum entitled “Emission Modeling for Recreational Vehicles.”[30]

New Information

Since the publication of the October 2001 NPRM, several new pieces of information on ATV usage have become available. These new sources consist of:

- Nationwide sources
  - ATV manufacturer warranty data
  - A Honda owner survey
  - ATV Industry Panel Survey (consisting of five ATV manufacturers)

- State studies on economic impact of ATV operation on their respective states
  - California[31]
  - Colorado[32]
  - Maine[33]
  - Michigan[34]
  - Utah[35]

- Instrumented ATV Usage Data (CE-CERT)
  - Speed information

Each of these sources is discussed in more detail below.

Warranty Data

One ATV manufacturer supplied ATV mileage and hour data from some its warranty claims submitted over a period of four years. The data was substantial and represented a good cross section of the country. The data is proprietary and was provided to us as confidential business information. This manufacturer does not have odometers or hour-meters on all of their ATV models, but provided data on those models equipped with an odometer or hour-meter, which happens to be only their utility models. Thus, there is no data for any of their sport models.

Intuitively, we were concerned about using data from warranty claims because of the possibility that usage data for machines that have been experiencing problems may not be reflective of how someone actually operates an ATV. Depending on the nature of the warranty claim, the ATV owner may decide to not operate their machine as much as they want because of a mechanical problem that doesn’t allow the ATV to work or concern that the problem could be exacerbated by continued operation. Ultimately, because of the size of the data set, we felt we couldn't dismiss the data simply based on the fact that the data is from warranty claims. We did however have another concern with the data. The manufacturer indicated to us that they require mileage to be reported on the warranty claim form. However, discussions with several local dealers indicated something different. One dealer stated that the manufacturer had told them to record hours instead of mileage, so that they either didn't include hours or only casually added it when they remembered. Another dealer said that the manufacturer had indicated to them that neither input was important, since the warranty is based on time after purchase (e.g., six months) rather than usage and that they, therefore, entered data somewhat haphazardly, if at all. These inconsistencies raised concerns over the accuracy of the mileage and hour data. If dealerships don't pay close attention to what numbers they enter into the warranty claim forms, then the warranty data could be suspect.

To eliminate this concern and more in general as a means to provide a degree of validation to the data set used, we decided to only use data which contained both odometer and hour meter readings. This way we could compare the values and make sure that they appeared to be consistent with each other. Of the data points supplied, almost half of the data had only odometer readings, while the other half had only hour readings. There was, however, a smaller subset of data that included both types of data (approximately 3,000 data points). This data was further screened as discussed below.

Honda Study

Honda hired a contractor to perform a phone survey of Honda ATV owners to inquire as to how many total hours and miles were on their machines. The surveyor asked the owner if the odometer and hour meter on their ATV was functional. If so, they asked them to read the mileage and hour reading directly from their ATV. Honda only contacted people who had purchased utility models since they are the only ATV models Honda sells that are equipped with odometer and hour meters. The Honda survey does not contain data for sport models. Honda used the odometer and hour meter readings combined with the model year of each model to determine what the yearly mileage and hour usage was for each ATV in the survey. They had a sample size of 611 ATVs that were mostly distributed evenly and randomly across the country, thus the survey results appear to provide a national perspective.

The survey did not include any ATVs newer than 13 months or older than four years. Honda wanted data for ATVs older than 13 months because in order to determine the number of miles and hours ridden per year, they simply took the odometer or hour meter reading and divided it by the machines age. For example, a machine that had 2,000 miles and was two years old would average 1,000 miles per year. If they selected data from machines newer than a year old, they would have to extrapolate to at least a year to get the average yearly usage. They felt that extrapolating the data would be improper since it could either overestimate or underestimate the usage depending on how the owner rode their machine during the months involved. If the data was for a machine was only six months old, then the simplest way to extrapolate would be to double the mileage or hours from the first six months. There is no way of knowing whether the owner would have ridden more or less in the following six months, thus the concern with over- or underestimating the usage.

Industry Panel Survey

In 1997, five of the major ATV manufacturers conducted an industry panel survey to determine how well the survey information from the ATV exposure study performed by CPSC in the same year would correlate with their own independent, but similar survey. The purpose of the industry panel survey was to use a similar methodology and format as the CPSC study but to survey an independent random sample of ATV owners to replicate the CPSC survey . They aimed for the same approximate sample size gathered randomly from across the country. Relevant survey questions used phrasing almost identical to that used in the CPSC survey. The survey and data were provided to us on a confidential basis and cannot be shared here. However, it can be stated that the yearly hour usage results from the industry panel survey are very consistent with the CPSC study results.

State Studies

All of the state studies were done in 2000 or later and were not available at the time we originally developed our ATV usage estimates for the proposal, with the exception of the California study which was done in 1994. Three of the studies (Colorado, Maine, and Utah) were provided to us by MIC. The Michigan study was obtained by EPA after a literature search on ATV activity and usage. We were made aware of the California study through comments from the Blue Ribbon Coalition. The purpose of the state studies was to measure the economic impact of ATV and other recreational vehicle operation on the state economy. One of the results from the studies was an estimate of how often ATVs were used in the respective state for that particular year. The studies were based on user surveys that were typically mailed to registered ATV owners. Mileage estimates were typically based off a single question posed in the survey that asked the participant “How many miles did you ride your ATV in the past year?” All of the studies measured usage in miles per year. Maine also recorded information on hours per year. Average annual ATV usage from the state studies ranged from 320 mi/yr in Michigan to 1,270 mi/yr in Utah. It should be noted that according to the NONROAD model, these four states only represent approximately four percent of the total U.S. ATV population and only Michigan is in the top 20 states in ATV population.

The state studies were good for their intended purpose but since they weren’t designed specifically to answer the questions at hand, they each have some shortcomings that limit their value to us. For example, all four states are cold climate states with cold winters and snow accumulation that may limit the amount of annual operation, especially compared to some of the warmer states that have higher ATV populations (e.g., Texas, Georgia, Tennessee, Alabama, etc.). The ATV industry has indicated that ATV operation is becoming very prevalent in agricultural use. Two of the states, Utah and Maine, are not large agricultural states, thus potentially resulting in a lower usage estimate than could be expected from a national study. All four of the state studies focused only on registered ATV owners. This has the potential for underestimating the number of miles ridden, since it does not provide a broad spectrum of all ATV riders in the respective state. In some states, registration is only required for use on public lands. Mileage estimates from three of the four studies were based on a single question inquiring about ATV use. There was no attempt made to verify with the respondent the accuracy of their estimate, as was done in the CPSC and Industry Panel studies. Four of the studies had discrepancies between their estimates of mileage and fuel usage. In almost each of the studies, the amount of fuel the respondents estimated they used for their ATV in one year would result in mileage results far higher than the actual mileage estimates provided by the respondents, creating a level of uncertainty about the viability of the mileage estimates. Finally, the California study combined data for ATVs with off-highway motorcycles, making it impossible to discern the mileage or fuel consumption for only ATVs.

We also obtained data from a separate report done by the State of California on ATV activity data collection. California hired the University of California, College of Engineering - Center for Environmental Research and Technology (CE-CERT) to instrument 41 ATVs and have the owners operate them in several California off-road parks and measure vehicle and engine speed.[36] This work was done to help California better estimate ATV in-use operation and emissions inventories within California. At this time, California has not completed their analysis of the data, nor have they started to develop any new modeling, so their work is unavailable as a source for ATV inventories. However, the CE-CERT draft report provides a summary of ATV activity work. They focused on measuring vehicle speed and fuel consumption.

ATV Usage Derivation Methodology for the Final Rulemaking

Criteria

In attempting to reconcile the results from the various data sets, we established three guiding criteria. The ideal data set would have all of these characteristics: 1) national scope; 2) "real" data (actual measurement readings as opposed to survey results based on recollection); and 3) a broad spectrum of ATV use (sport and utility operation). None of the existing data sets meet all three criteria. Therefore, we decided that it was important to select data sets that met two of the three criteria. Four of the data sets meet two of the above criteria. The CPSC and Industry Panel Survey data have a national scope and broad spectrum of ATV use. The warranty data and the Honda survey data are both real data that provide a national scope. The state studies, however, only provide a broad spectrum of use and many have a bias towards use on public lands. They do not provide a national scope, nor are they generally based on "real" data. Therefore, our methodology to determine ATV usage is based on the CPSC, Industry Panel Survey, warranty, and Honda data. The state studies were not used because they did not meet two of out three criteria, and as was briefly summarized above, had some shortcomings we could not resolve. Of the three criteria, we felt that data which provide a national scope was the most important, since it would remove any possible regional or state bias in ATV usage that could exist. For example, some states may have higher usage levels because of unique or appealing terrain, a large amount of public and private land available for riding on, an extended riding season due to warmer climate, or greater potential for agricultural, ranching, and hunting usage, that may not be reflected if we only use data from the four states that have performed studies on ATV usage.

Utility vs. Sport ATVs

Utility ATVs are designed for multiple purposes and are most often used for hunting and fishing, camping, yard work, farm work, as well as recreational trail riding. Sport ATVs are designed for aggressive recreational riding over rough terrain and closed courses, where higher speeds and performance are desired. According to Kawasaki, currently 75% of all ATV sales are for utility models and 25% are for sport models. Ideally, we would want the population percentage of sport and utility usage rather than sales, but this data is not available.

Hours vs. Miles

The NONROAD model uses miles per year of operation, rather than hours per year of operation, as one of the main inputs in calculating the inventory estimates for HC, CO, NOx, and PM emissions. Thus, to be consistent with the needs of the model, we were required to make sure all of the data used was in miles per year of operation. Only the Honda and warranty data had mileage data. However, all four data sets have hour data. In order to convert the hour data into mileage estimates, we had to multiply the hour values by an average ATV speed estimate.

Average Speed

Ideally, we would want to develop an estimate for the average ATV speed that includes both of the different types of models (utility and sport). Unfortunately, there wasn’t a single data set that could be used to determine average speed for both types of models. The Honda and warranty data only included utility models. However, from these data sets we were able to determine average speed for a utility ATV, since the ATVs in these data sets were equipped with odometers and hour meters, which allowed us to calculate average speed. From this data we were able to determine that the average speed for utility ATVs is about 8 mi/hr.

None of the four data sets had information that would allow the calculation of average speed for sport ATV models. As discussed above, CE-CERT instrumented 41 ATVs and had the owners operate them in several California off-road parks and measure vehicle and engine speed. The off-road parks examined allowed operation over trails, desert, and sand dunes. Of the 41 instrumented ATVs, 36 were sport models and five were utility models. For the purposes of our analysis, we considered all 41 ATVs as indicative of sport operation, since the riding that occurred in these off-road parks was clearly recreational or sport, rather than utility usage. The average speed for all 41 ATVs was about 13 mi/hr.

Methodology

The data permitted us to develop a methodology that would determine fleet average miles per year by weighting separate mileage estimates for utility and sport ATVs based on average use, average speed and sales. The equation looks like this:

Utility ATVs *Sport ATVs*
(0.75)(hours/yr)(miles/hour) + (0.25)(hours/yr)(miles/hour) = Total miles/year for all ATVs

The 0.75 factor represents the percentage of total ATV sales that are for utility models, while the 0.25 factor represents the remaining percentage of sales which are for sport models. Population would have been preferable to sales, but that information was not available.

Utility ATV Estimates

To determine the mileage estimate for utility ATV models, we chose to use the data from the Honda and warranty data sets. We selected these two data sets because they both consisted entirely of data for utility ATVs. We merged both data sets and calculated the average hours per year of operation and average speed (mi/hr). Prior to merging the data sets we performed several quality checks of the data. First, we only used data that had both mileage and hour values. This was so we could calculate an average speed for utility ATVs. All of the Honda data had both values (approximately 605 data points). The warranty data had only a relatively small subset of data that contained both mileage and hours (approximately 3,000 data points). Next, we eliminated any of the warranty data that was for ATVs newer than 30 days and older than three years, consistent with MIC’s analysis. We found that for the warranty data, there appeared to a significant number of data points that were duplicates (number of instances where same entry was made twice). Since some of these duplicates were for usage rates that were either very high or very low, we decided to remove all duplicates so that they would not bias the data. We also deleted any samples that had identical miles and hours figures, on the basis that these readings were probably mistakes, since it was unlikely that a rider would ride the exact same number of miles and hours per year (e.g., 500 mi/yr and 500 hr/yr).   Finally, we deleted any data from both data sets that had an average speed greater than 25 mph, since information provided by the American Motorcycle Association (AMA) on ATV race track statistics indicates that for professional ATV racers, the average speed is 24 mph. Therefore, it did not seem reasonable to include data for speeds in excess of those achieved by professional ATV racers.

The combined sample size of the merged data set was 2,531. The average speed for utility ATVs from the merged data set was 8 miles per hour and the average hours of use was 151 hours per year. Our hours per year estimate for utility ATV use is corroborated by the CPSC study and information from MIC. A discussion of nonrecreational or utility use in the CPSC study states “..high use nonrecreational (utility) drivers tend to be older (36 years and up)..” (See page 14 of CPSC study).   MIC has stated that the average age of individuals buying utility ATV models is between 40 and 50 years old. The CPSC study indicates that for riders in the 40 to 50 year old age range, the average hourly usage was 158 hours per year (see page 27 of CPSC study).

Sport ATV Estimates

To determine the mileage estimate for sport ATV models, we used the data from the CPSC and Industry Panel Survey data sets. Since we were unable to determine average speed from these data sets, we used the average speed of 13 mph derived from the CE-CERT data for the 41 instrumented ATVs.

The CPSC and Industry Panel studies were done in 1997. Based on information from these studies, between 50%-75% of the ATVs in both studies were from the 1980-1995 model years. Between 1980 and 1990, sport ATVs were the predominant ATVs sold in the U.S. Although their sales were starting to decline in favor of utility models, sport models were still responsible for approximately 50% of all ATV sales from 1990 through 1995 and were the majority of the ATV population. Therefore, both of these studies are most likely biased towards operation with sport ATV models and should, therefore, be most representative of sport ATV operation.

The annual riding hours from both data sets was determined by multiplying results of three survey questions concerning riding patterns: (1) the number of months during which ATVs were ridden during the previous year, (2) the number of days of riding in an average month, and (3) the number of hours of riding in an average day. The total hours per year were then calculated from the following equation.

$$\frac{hours}{year} = \frac{months}{year} \cdot \frac{days}{month} \cdot \frac{hours}{day}$$

We averaged annual rider hours from the CPSC and industry panel surveys, due to their similarities in approach and results. In deriving average estimates from each, we reviewed results for the questions used in the calculation, and modified some results that we considered implausible. Specifically, for those records where the respondent claimed more than 10 hours of use on an average day of riding, we limited daily usage at a maximum of 10 hours. The resulting annual average usage rate was 216 hours per year.

In relation to their study objectives, the CPSC and Industry Panel studies both presented usage results for the average rider, rather than for the average ATV. In other words, results are presented as hours/rider/year, rather than hours/ATV/year. For the NPRM, we attempted to correct hours/rider to hours/ATV using the ratio of the national rider population to the total ATV population, as follows[hh]:

[hh] In the NPRM analysis, we also applied an adjustment to subtract “inactive” riders from the total rider population. In subsequent correspondence, the author of the CPSC study indicated that such an adjustment was unnecessary, as the national population estimated in the report was intended to represent only “active riders,” defined as riders who had reported using their ATVs in the previous year. Thus, the “inactive rider” adjustment is not presented here.

$$\frac{hours}{ATV \cdot year} = \frac{hours}{rider \cdot year} \cdot \left(\frac{national\ rider\ \ population\ (riders)}{national\ ATV\ \ population\ (ATVs)} \right)$$

In this analysis, we recalculated the average usage rate (i.e., hours per rider-year) using a data set of results for individual respondents, which enabled review of individual responses, as mentioned above. To be consistent with this approach, it would be appropriate to recalculate the "correction" using individual responses, as opposed to gross national averages, as in the equation above. However, several pieces of data needed for this calculation were unavailable, specifically, the numbers of riders and ATVs in each respondent household. Accordingly, for purposes of this analysis, we assumed that rider hours as reported in the CPSC and industry panel studies were equivalent to ATV operating hours.

Mileage Estimate

By plugging in the above values derived for utility and sport ATVs average hourly operation and average speed into the equation discussed above, we were able to determine a mileage estimate for ATVs of 1,608 mile per year.

Utility ATVs *Sport ATVs*
(0.75)(151 hr/yr)(8 mi/hr) + (0.25)(216 hr/yr)(13 mi/hr) = **1,608 mi/yr**

Conclusion

It is informative to consider the outcome from our methodology to the results of the studies we did not use, or the alternative application of some of the individual studies that we did use. The state studies do not have the strength of the national studies and were not used in our analysis. The state studies represent only 4% of U.S. ATV registrations and all four states are cold weather states that may not reflect winter use in warmer states. State methodologies give results of mixed value. For example, two state studies had low mileage estimates: Michigan had an estimate of 320 mi/yr and Colorado had an estimate of 610 mi/yr, while Utah had an estimate of 1,270 mi/yr which is closer to our estimate. Maine had even more mixed results. Their estimate ranged from 535 mi/yr to 1,646 mi/yr depending on which methodology they used to determine mileage, the direct question or the multiple questions. The Honda survey data had an estimate of 560 mi/yr. The warranty data had an estimate of 1,340 mi/yr. Both of these data sets included only utility ATVs. The CPSC and Industry Panel studies had hour estimates of approximately 250 hr/yr, which depending on the average speed used, can have a mileage range of 1,900 mi/yr (for the average utility ATV speed of 8 mph) to 3,150 mi/yr (for the average sport ATV speed of 13 mph). Therefore, we believe that our estimate of 1,608 miles per year is reasonable and the best estimate considering all of the available data.

There is currently no data set which alone can be characterized as providing the best estimate of ATV annual usage. All of the available data sets have some shortcomings. Looking across all of the studies considered in the analysis yields mileage estimates from 320 mi/yr to

3,150 mi/yr. It is impossible to reconcile all eight data sets and it is not analytically appropriate to average all of the data sets because they aren't all of equal strength or value. The methodology we've developed is the best way to reconcile broadly ranging data of the highest value.

6A.2 Off-Highway Motorcycle Usage

On October 5, 2001, EPA published proposed emission regulations for nonroad land-based recreational vehicles. These regulations covered snowmobiles, off-highway motorcycles, and all-terrain vehicles (ATVs). The Motorcycle Industry Council, Inc. (MIC) submitted comments suggesting that the EPA estimates for off-highway motorcycle (OHMC) usage had been overestimated. They stated that our mileage estimate of 2,400 miles per year was too high and that based on some additional information that they had obtained, a more reasonable estimate was a lifetime average of 600 miles per year. As a result of these comments and the subsequent new information, EPA has revised it's estimate of annual OHMC usage.

Background

On November 20, 2000 EPA published a Final Finding of Contribution and Advance Notice of Proposed Rulemaking (ANPRM) for large nonroad spark-ignition engines and land-based recreational vehicles. We had to develop emission inventories for the various engine and vehicle categories covered by both of these documents. EPA has developed an emissions model named NONROAD, which computes nationwide emission levels for nonroad engines. The model incorporates data on emission rates, usage rates, and vehicle population to determine annual emission levels of various pollutants. For recreational vehicles, and more specifically OHMCs, data on emission rates and usage rates was extremely limited. Because of the lack of data, we initially grouped OHMCs and ATVs together. However, as we performed literature searches and attempted to uncover additional data on OHMC emissions and activity, it became apparent that OHMCs and ATVs were used differently and unique emission rates, usage rates, and populations should be established. We approached members of the OHMC industry to provide us with any data that they had on emission and usage rates. MIC provided survey data on off-highway motorcycle usage. We also found a study done in 1999 by the Oak Ridge National Laboratory (ORNL) titled, "Fuel Used for Off-Road Recreation: A Reassessment of the Fuel Use Model" that provided information on OHMC usage. We examined these two studies to develop our estimate of OHMC usage for the November 2000, ANPRM and the October 2001, NPRM.

Off-Highway Motorcycle Usage as developed for ANPRM and NPRM

For OHMC, there were two sources of information on activity or usage rates that we examined. The first source was information provided by the motorcycle industry. MIC periodically conducts surveys to obtain diverse information on motorcycle facts, such as number of motorcycles per rider, types and makes of bikes, on-road or off-road, bike education, etc. The survey also gathers information on motorcycle usage. MIC used two methods of estimating OHMC usage from the survey results. Method one was based on the results of a single question that asks the respondent how many miles they rode their OHMC in the last year. Method two is based on the compilation of the response from three questions: 1) how many months do you ride per year, 2) how many days do you ride per month, and 3) how many miles do ride per day. The MIC estimate for method one was 222 miles per year and 1,260 miles per year for method two. MIC suggested that method one was the more appropriate estimate because method two may compound any error that exists in the results of each of the three questions. We had concerns with the results of the MIC survey because the values for method one and two were so dramatically different.

The second source of information was the 1999 ORNL study. In their study, ORNL estimated total average fuel usage for off-highway motorcycles. They provided a medium estimate of average fuel usage for OHMCs of 59 gallons per year. Data from California and some older SwRI work on OHMC emission testing suggested that the average fuel economy for OHMCs was approximately 50 miles per gallon (mpg), as tested over the FTP (a relatively non-aggressive driving cycle when compared to some OHMC uses). We determined that this estimate could be too high for actual in-use off-road operation, so we derived from the data an estimate of 40 mpg. By multiplying the average fuel used per year by the average fuel economy, we arrived at an estimate of approximately 2,400 miles per year.

OHMC Usage = (59 gallons/year)(40 miles/gallon) = 2,400 miles/year

We also found another ORNL study published in 1994 where MIC also estimated average fuel usage in their survey with a resulting mean value of 214 gallons per year.[37] If we used our estimate of 40 mpg, 214 gallons per year would yield 8,560 miles. Because of the large discrepancies in the three MIC based values, we chose to use the estimate of 2,400 miles per year.

New Information on Off-Highway Motorcycle Usage

Since the publication of the NPRM in October 2001, several new pieces of information on OHMC usage have become available. These new sources consist of state studies from California[38], Michigan[39], Oregon[40], and Utah[41] on OHMC usage (the California and Oregon studies were used in both of the ORNL studies). These studies present information on the number of miles OHMC's are ridden per year and/or the number of gallons of fuel used per year riding OHMCs. We also received information from the American Motorcycle Association (AMA) on rider surveys which attempt to quantify the number of miles ridden per year by the average OHMC rider.

Finally, we obtained new information on the fuel consumption of OHMCs. The state of California hired the University of California, College of Engineering - Center for Environmental Research and Technology (CE-CERT) to instrument a number of OHMCs that were operated in several California off-road parks and motocross tracks and measure vehicle and engine speed.[42] This work was done to help California better estimate OHMC in-use operation and emissions inventories within California. At this time, California has not completed their analysis of the data, nor have they started to develop any new modeling, so their work is unavailable as a source for OHMC emissions inventories. However, they have shared with us data on fuel consumption from the OHMC testing. We also had updated emission and fuel economy test results for 10 OHMCs tested by EPA over the FTP.

State Studies

All four of the state studies included estimates of average yearly total fuel consumption for OHMCs, but only the Michigan and Utah studies also provided estimates for average yearly mileage for OHMCs. The average yearly total fuel consumption for the four studies ranges from 32 gallons per year for Michigan to 89 gallons per year for Oregon. The average for the four studies is 57 gallons per year. Table 6A.2-1 lists the average yearly total fuel consumption for the four studies. The two states that provided estimates for average yearly mileage were Michigan and Utah. Michigan listed a yearly mileage of 494 miles per year, while Utah had a value more than twice that with 1,067 miles per year.

Table 6A.2-1
Off-Highway Motorcycle Average Gallons of Fuel Consumed and Mileage Ridden Per Year

State Study	Average Gallons Per Year	Average Mileage Per Year
Michigan	32	494
California	44	n/a
Utah	62	1,067
Oregon	89	n/a
Average	57	781

AMA Survey

AMA presented survey results from 1994, 1996, 1998, & 2000 on how many miles AMA members rode OHMCs in each of these years. The data indicates a trend toward increased mileage each year. The survey was based on a mailing to AMA members listing questions as to riding habits. AMA broke the survey results into six bins based on miles ridden in the last 12 months:

- 0 - 499 mi/yr
- 500 - 999 mi/yr
- 1,000 - 1,499 mi/yr
- 1,500 - 1,999 mi/yr
- 2,000 or more
- No answer

They determined the total number of miles ridden by taking the median value of each bin and multiplying it by the number of responses in that bin. They did this for each bin. They then summed the results for all of the bins. The summation was then divided by the total number of responses. For the bin categorizing responses of 2,000 miles or more, rather than using the median, as with the other bins, they capped the mileage at 2,000 miles. This is problematic since 19% of all responses fell into this bin. By capping the values in this bin at 2,000 miles, the estimate for this bin is too low. This would indicate that their estimate for average total OHMC miles ridden per year is also probably too low. They estimated that in 2000, the average AMA member rode 1,158 miles.

New Fuel Economy Estimates

We have tested nine OHMCs at our National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor, Michigan. We also have the fuel economy results from a test done by California on a 1999 Yamaha WR400. All of the tests are over the transient highway motorcycle FTP test cycle. Table 6A.2-2 lists the results for the 4-stroke OHMCs. Table 6A.2-3 lists the results for the 2-stroke OHMCs.

Table 6A.2-2
FTP Fuel Economy for 4-Stroke Off-Highway Motorcycles

Manufacturer	Model	Model Year	Fuel Economy (mpg)
Yamaha	WR250F	2001	39
Yamaha	WR400	1999	55
Husaberg	FE501	2001	53
KTM	400EXC	2001	54
Average			50

Table 6A.2-3
FTP Fuel Economy for 2-Stroke Off-Highway Motorcycles

Manufacturer	Model	Model Year	Fuel Economy (mpg)
KTM	125 SX	2001	21
KTM	125 SX	2001	31
KTM	200 EXC	2001	22
KTM	250 SX	2001	18
KTM	250 EXC	2001	20
KTM	300 EXC	2001	21
Average			22

The CE-CERT data developed for the State of California was based on actual in-use fuel consumption measurements made on numerous OHMCs operated by the owners at several off-road motorcycle parks and a motocross track. The parks consisted of trail riding, desert riding, sand dune riding, and a mixture of all three. These riding scenarios could be considered closer to worst case conditions that may not be reflective of average in-use operation nationally. The results were 24 mpg for the 2-stroke machines and 27 mpg for the 4-stroke machines.

Off-Highway Motorcycle Usage Derivation Methodology for the Final Rule

Based on the new information we have received, there are two approaches we could choose to estimate annual average OHMC usage. The first would be to base the estimate on the mileage estimates presented in the Michigan, Utah, and AMA studies. The second would be to use the same methodology we used for the ANPRM and NPRM, which uses total fuel consumption from four state studies and fuel economy measurements from the California survey and EPA FTP results to estimate mileage.

The first approach appears to be limited, since the AMA study under predicts the annual mileage and since we do not have the raw data, there doesn’t appear to be a method to upgrade the estimate that wouldn’t be somewhat arbitrary. This leaves only the mileage per year estimates from the two state studies. There were two concerns with using the mileage estimates from the two state studies. First of all, many OHMC models are not equipped with odometers, which would make it difficult for participants responding to the state surveys to recall how many miles they actually rode. Secondly, the average gallons per year and miles ridden per year reported result in average fuel economy estimates of 15 and 17 miles per gallon. These values are considerably lower than values from the CE-CERT and EPA testing. This means that either the gallons per year estimates are high or the mileage per year estimates are low. Since we had more sources for total fuel consumption and fuel economy values based on emissions test results and actual in-use operation, it appears to be more appropriate to use the second methodology (which is based on fuel consumption), rather than the first methodology (which is based on mileage) with only two questionable data points.

The equation for estimating average annual OHMC mileage based on fuel consumption is:

OHMC Usage in miles per year = (gallons/year)(miles/gallon)

The gallons per year value is based on the average of the four state studies which is 57 gallons per year. We are not including the ORNL study directly. The ORNL study consisted of data that they had obtained from the California and Oregon studies and the MIC survey. ORNL agrees with us that they thought the MIC survey information was of limited value for the same reasons that we pointed put. To address their concern over using this data, they decided to give each of the three studies a weighted value, with the MIC and Oregon studies having lower weightings than the California study. We decided that it was more prudent to just use the California and Oregon studies in combination with the other two new state studies from Utah and Michigan, rather than include the MIC data.

For the fuel economy we had FTP results from EPA testing and in-use results from CE-CERT. Since there is no way of knowing which of these set of values are the most correct (in-use data was for relatively extreme operation) we chose to take the average of the two data sets. However, before we did this, we decided to determine the overall fuel economy for each data set based on the weighted impact of the two different types of engines, 2-stroke and 4-stroke. The current break-down of 2-stroke and 4-stroke engines in OHMCs is 67% for 2-stroke engines and 33% for 4-stroke engines. Thus, we used the following equation to estimate fuel economy:

Fuel Economy (FE) = (0.67)(2-stroke FE (mpg)) + (0.33)(4-stroke FE (mpg))

For the EPA FTP testing, the average weighted fuel economy results are the following:

FE = (0.67)(22 mpg) + (0.33)(50 mpg) = 31 mpg

For the CE-CERT in-use measurements, the average weighted fuel economy results are the following:

FE = (0.67)(24 mpg) + (0.33)(27 mpg) = 25 mpg

The average of these two data sets is 28 mpg. Combining the value of 28 mpg with the fuel consumption value of 57 gallons per year results in an average of 1,600 miles per year for OHMCs.

OHMC Usage = (57 gallons/year)(28 miles/gallon) = 1,600 miles/year

Chapter 6 References

1. “Evaporative Emission Calculations for Recreational and Large SI Vehicles,” Memorandum from Mike Samulski, U.S. EPA to Docket A-2000-01, September 6, 2002, Document IV-B-38.

2. API Publication No. 4278, “Summary and Analysis of Data from Gasoline Temperature Survey Conducted at Service Stations by American Petroleum Institute,” Prepared by Radian Corporation for American Petroleum Institute, November 11, 1976, Docket A-2000-01, Document II-A-16.

3. Nulman, M., Olejnik, A., Samus, M., Fead, E., Rossi, G., “Fuel Permeation Performance of Polymeric Materials,” SAE Paper 2001-01-1999, 2001, Docket A-2000-01, Document No. IV-A-23.

4. Lockhart, M., Nulman, M, Rossi, G., “Estimating Real Time Diurnal Permeation from Constant Temperature Measurements,” SAE Paper 2001-01-0730, 2001, Docket A-2000-01, Document No. IV-A-21.

5. D. T. Wade, “Factors Influencing Vehicle Evaporative Emissions,” SAE Paper 670126, 1967, Docket A-2000-01, Document II-A-59.

6. Wade et. al., “Mathematical Expressions Relating Evaporative Emissions from Motor Vehicles without Evaporative Loss-Control Devices to Gasoline Volatility,” SAE Paper 72070, 1972, Docket A-2000-01, Document II-A-58.

7. S. Raghuma Reddy, “Prediction of Fuel Vapor Generation from a Vehicle Fuel Tank as a Function of Fuel RVP and Temperature,” SAE Paper 892089, 1989, Docket A-2000-01, Document II-A-61.

8. S. Raghuma Reddy, “Prediction of Fuel Vapor Generation from a Vehicle Fuel Tank as a Function of Fuel RVP and Temperature,” SAE Paper 892089, 1989, Docket A-2000-01, Document II-A-61.

9. “Final Regulatory Impact Analysis: Refueling Emission Regulations for Light Duty Vehicles and Trucks and Heavy Duty Vehicles,” U.S. EPA, January 1994, Docket A-2000-01, Document II-A-79.

10. Pagán, Jaime, “Investigation on Crankcase Emissions from a Heavy-Duty Diesel Engine,” U.S. Environmental Protection Agency, March, 1997, Docket A-2000-01, Document II-A-70.

11.“The Role of Propane in the Fork Lift/Industrial Truck Market: A Study of its Status, Threats, and Opportunities,” Robert E. Myers for the National Propane Gas Association, December 1996, Docket A-2000-01, Document II-A-86.

12.“Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines—Final Report” Jeff J. White, et al, Southwest Research Institute, SwRI 8778, April 1999, p. 45, Docket A-2000-01, Document II-A-08.

13.“Revisions to the June 2000 Release of NONROAD to Reflect New Information and Analysis on Marine and Industrial Engines,” EPA memorandum from Mike Samulski to Docket A-98-01, November 2, 2000, Docket A-2000-01, Document II-B-08.

14.“Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy Duty Engines,” U.S. EPA, December 1979, p. 189, Docket A-2000-01, Document II-A-71.

15. “Transient Adjustment Factors for Large SI Engines,” EPA memorandum from Alan Stout to Docket A-2000-01, September 27, 2001, Docket A-2000-01, Document II-B-29.

16. “Measurement of Evaporative Emissions from Off-Road Equipment,” prepared for South Coast Air Quality Management District by Southwest Research, November 1998, Docket A-2000-01, Document II-A-10.

17. Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Docket A-2000-01, Document II-B-19.

18. “Median Life of Snowmobiles,” note from Phil Carlson, EPA to Ed Klim, ISMA, May 10, 2002, Docket A-2000-01, Document IV-B-28.

19. “Updated Snowmobile Sales Projections from National Economic Research Associates,”, EPA memo from Phil Carlson to Docket A-2000-01, August 1, 2002, Docket A-2000-01, Document IV-B-27.

20. “Updated Population Growth Projections for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 7, 2002, Document IV-B-29.

21. “Updated Emission Factors for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 8, 2002, Document IV-B-26.

22. Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Docket A-2000-01, Document II-B-19.

23. “Estimate for All-Terrain Vehicle Annual Usage,” EPA memo from Linc Wehrly to Docket A-2000-01, September 6, 2002, Document IV-B-35.

24. “Updated Population Growth Projections for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 7, 2002, IV-B-29.

25. “Updated Emission Factors for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 8, 2002, Document IV-B-26.

26. “Estimate for Off-Highway Motorcycle Annual Usage,” EPA memo from Linc Wehrly to Docket A-2000-01, August 26, 2002, Document IV-B-36.

27. “Revised Median Life for Off-Highway Motorcycles,” EPA memo from Phil Carlson to Docket A-2000-01, August 6, 2002, Document IV-B-30.

28. “Updated Population Growth Projections for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 7, 2002, Document IV-B-29.

29. “Updated Emission Factors for Snowmobiles, ATVs, and OHMCs,” EPA memo from Phil Carlson to Docket A-2000-01, August 8, 2002, Document IV-B-26.

30. “Emission Modeling for Recreational Vehicles,” EPA memorandum from Linc Wehrly to Docket A-98-01, November 13, 2000, Docket A-2000-01, Document II-B-19.

31. “1993 statewide Off-Highway Vehicle User Survey Analysis,” Prepared for the California Department of Parks and Recreation, Off-Highway Vehicle Recreation Division by California State University.

32. “ Economic Contribution of Off-Highway Vehicle Use in Colorado,” Prepared for the Colorado Off-Highway Vehicle Coalition by Hazen and Sawyer, July 2001 (submitted as an attachment to the Motorcycle Industry Council’s comments, document IV-D-214).

33. “Gasoline Consumption Attributable to ATVs in Maine,” Margaret Chase Smith Center for Public Policy, The University of Maine, Jonathon Rubin, Suzanne K. Hart, and Charles Morris, June 2001 (submitted as an attachment to the Motorcycle Industry Council’s comments, document IV-D-214).

34. “Michigan Licensed Off-Road Vehicle Use and Users: 1998-1999,” Department of Park, Recreation and Tourism Resources, Michigan State University, October 25, 2000

35. “Off-Highway Vehicle Uses and Owner Preferences in Utah,” Institute for Outdoor Recreation and Tourism, Department of Forestry Resources, Utah State University, July 22, 2001 (submitted as an attachment to the Motorcycle Industry Council’s comments, document IV-D-214).

36. “Off-Highway Motorcycle/All-Terrain Vehicle Activity-Data Collection; and Personal Watercraft Activity-Data Collection; Test Cycle Development and Emissions Test,” Prepared for California Air Resource Board by Thomas Durbin, Matthew R. Smith, Ryan D. Wilson, and Ted Younglove of College of Engineering - Center for Environmental Research and Technology, July 2002.

37. “Fuel Used for Off-Highway Recreation,” Patricia Hu, David Trumble, and An Lu, prepared by Oak Ridge National Laboratory for Federal Highway Administration, July 1994 (ORNL-6794).

38. "A Study To Determine Fuel Tax Attributable To Off-Highway and Street Licensed Vehicles Used For Recreation Off-Highway," prepared for the California Department of Transportation In Cooperation with the Department of Parks and Recreation, by Tyler and Associates, November 1990.

39. "Michigan Licensed Off-Road Vehicle Use and Users: 1998-1999," Department of Park, Recreation and Tourism Resources, Michigan State University, October 25, 2000.

40. "Fuel Used for Off-Highway Recreation," Patricia Hu, David Trumble, and An Lu, prepared by Oak Ridge National Laboratory for Federal Highway Administration, July 1994 (ORNL-6794).

41. "Off-Highway Vehicle Uses and Owner Preferences in Utah," Institute for Outdoor Recreation and Tourism, Department of Forestry Resources, Utah State University, July 22, 2001 (submitted as an attachment to the Motorcycle Industry Council's comments, document IV-D-214).

42. "Off-Highway Motorcycle/All-Terrain Vehicle Activity-Data Collection; and Personal Watercraft Activity-Data Collection; Test Cycle Development and Emissions Test," Prepared for California Air Resource Board by Thomas Durbin, Matthew R. Smith, Ryan D. Wilson, and Ted Younglove of College of Engineering - Center for Environmental Research and Technology, July 2002.

Chapter 7: Cost Per Ton

7.1 Cost Per Ton by Engine Type

7.1.1 Introduction

This chapter presents our estimate of the cost per ton of the various standards contained in this rule. The analysis relies on the costs estimates presented in Chapter 5 and the estimated lifetime emissions reductions using the information presented in Chapter 6. The chapter also presents a summary of the cost per ton of other recent EPA mobile source rulemakings for comparison purposes. Finally, this chapter presents the estimated costs and emission reductions as incurred over the first twenty years after the standards are implemented.

In calculating net present values that were used in our cost-per-ton estimates, we used a discount rate of 7 percent, consistent with the 7 percent rate reflected in the cost-per-ton analyses for other recent mobile source programs. OMB Circular A-94 requires us to generate benefit and cost estimates reflecting a 7 percent rate. Using the 7 percent rate allows us to make direct comparisons of cost-per-ton estimates with estimates for other, recently adopted, mobile source programs.

However, we consider that the cost and cost-per-ton estimates for future proposed mobile source programs could reflect a 3 percent rate. The 3 percent rate is in the 2 to 3 percent range recommended by the Science Advisory Board's Environmental Economics Advisory Committee for use in EPA social benefit-cost analyses, a recommendation incorporated in EPA's new *Guidelines for Preparing Economic Analyses (November 2000).* Therefore, we have also calculated the overall cost-effectiveness of today's rule based on a 3 percent rate to facilitate comparison of the cost-per-ton of this rule with future proposed rules which might use the 3 percent rate. The results using both a 3 percent and 7 percent discount rate are provided in this chapter.

7.1.2 Compression-Ignition Recreational Marine

As described in Chapter 5, several of the anticipated engine technologies will result in improvements in engine performance that go beyond emission control. While the cost estimates described in Chapter 5 do not take into account the observed value of performance improvements, these non-emission benefits should be taken into account in the calculation of cost-effectiveness. We believe that an equal weighting of emission and non-emission benefits is justified for those technologies which clearly have substantial non-emission benefits, namely electronic controls, fuel injection changes, turbocharging, and aftercooling for diesel engines and upgrading to electronic fuel injection for gasoline engines. For some or all of these technologies, a greater value for the non-emission benefits could likely be justified. This has the effect of halving the cost for those technologies in the cost-per-ton calculation. The cost-per-ton values in this chapter are based on this calculation methodology.

Although the rule will also result in PM reductions, we apply the total cost to the ozone forming gases (HC and NOx) presented in Chapter 6 for these calculations. The estimated per vessel costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton as presented in Table 7.1-1 assuming a 7 percent discount rate. Table 7.1-2 presents the cost per tons results assuming a 3 percent discount rate..

Table 7.1-1
Estimated CI Recreational Marine Cost Per Ton of HC + NOx Reduced
(7 percent discount rate)

	Total Cost per Vessel (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vessel Cost ($/ton)
100 kW near-term	$231	0.24	$954
100 kW long-term	$141		$583
400 kW near-term	$396	0.97	$409
400 kW long-term	$175		$181
750 kW near-term	$1,118	1.32	$844
750 kW long-term	$374		$282
Composite near-term	$291	0.44	$669
Composite long-term	$155		$356

Table 7.1-2
Estimated CI Recreational Marine Cost Per Ton of HC + NOx Reduced
(3 percent discount rate)

	Total Cost per Vessel (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vessel Cost ($/ton)
100 kW near-term	$231	0.33	$703
100 kW long-term	$141		$429
400 kW near-term	$396	1.31	$301
400 kW long-term	$175		$133
750 kW near-term	$1,118	1.69	$661
750 kW long-term	$374		$221
Composite near-term	$291	0.59	$495
Composite long-term	$155		$263

7.1.3 Large Industrial SI Equipment

This section provides our estimate of the cost per ton of emissions reduced for large SI engines >19 kW. We have calculated cost per ton on the basis of exhaust HC plus NOx for gasoline, LPG and CNG engines and evaporative HC for gasoline engines. The analysis relies on the costs estimates in presented in Chapter 5 and the estimated net present value of the per vehicle lifetime emissions reductions (tons) presented in Chapter 6.

For the exhaust emission standards, the estimated per vehicle costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton. In addition, we have estimated the cost per ton both with and without estimated fuel/maintenance savings. We have estimated the cost per ton for both the Phase 1 and Phase 2 standards, with the Phase 2 estimates incremental to Phase 1. The results of the cost per ton analysis for exhaust emission controls are presented in Tables 7.1.3-1 through 7.1.3-3 for gasoline, LPG and CNG engines assuming a 7 percent discount rate. The results of the cost-per-ton analysis for exhaust emission controls using a 3 percent discount rate follow in Tables 7.1.3-4 through 7.1.3-6.

Table 7.1-3
Estimated Large SI Gasoline Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced (7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$802	($3,247)	1.6	$496	($1,514)
Phase 1 long-term	$487			$301	($1,708)
Phase 2 near-term	$60	-	0.3	$175	-
Phase 2 long-term	$14			$41	-

Table 7.1-4
Estimated Large SI LPG Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced (7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$552	($4,557)	3.5	$158	($1,146)
Phase 1 long-term	$340			$97	($1,206)
Phase 2 near-term	$53	-	1.0	$56	-
Phase 2 long-term	$14			$15	-

Table 7.1-5
Estimated Large SI CNG Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced (7 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions* (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$552	($1,648)	3.6	$153	($304)
Phase 1 long-term	$340			$94	($363)
Phase 2 near-term	$53	-	0.9	$61	-
Phase 2 long-term	$14			$16	-

* The reductions are calculated on the basis of NMHC+NOx for CNG engines only.

Table 7.1-6
Estimated Large SI Gasoline Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced (3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$802	($3,926)	2.0	$409	($1,573)
Phase 1 long-term	$487			$248	($1,733)
Phase 2 near-term	$60	-	0.4	$143	-
Phase 2 long-term	$14			$33	-

Table 7.1-7
Estimated Large SI LPG Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced
(3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$552	($5,492)	4.2	$131	($1,162)
Phase 1 long-term	$340			$81	($1,212)
Phase 2 near-term	$53	-	1.2	$46	-
Phase 2 long-term	$14			$12	-

Table 7.1-8
Estimated Large SI CNG Engine >19 kW Cost Per Ton of Exhaust HC+NOx Reduced
(3 percent discount rate)

Standard	Total Cost per Vehicle (NPV)	Lifetime Fuel/ Maintenance Cost per Vehicle (NPV)	Lifetime Reductions* (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel/Maintenance Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel/Maintenance Savings ($/ton)
Phase 1 near-term	$552	($2,005)	4.4	$125	($321)
Phase 1 long-term	$340			$77	($369)
Phase 2 near-term	$53	-	1.1	$49	-
Phase 2 long-term	$14			$13	-

* The reductions are calculated on the basis of NMHC+NOx for CNG engines only.

For the evaporative emission standards, the estimated per vehicle costs are presented in

Chapter 5. We have estimated the cost per ton both with and without the estimated fuel savings which occur as evaporative emissions are reduced. The results of the cost per ton analysis for evaporative emission controls for gasoline large SI engines >19 kW are presented in Table 7.1-9 based on both a 7 percent and 3 percent discount rate.

Table 7.1-9
Estimated Large SI Gasoline Engine >19 kW Cost Per Ton of Evaporative HC Reduced

Discount Rate	Total Cost per Vehicle (NPV)	Lifetime Fuel Cost per Vehicle (NPV)	Lifetime Evaporative HC Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
7%	$13	($56)	0.16	$84	($279)
3%	$13	($69)	0.19	$68	($295)

7.1.4 Recreational Vehicle Exhaust Emissions

This section provides our estimate of the cost per ton of exhaust emissions reduced for recreational vehicles. We have calculated cost per ton on the basis of HC plus NOx for off-road motorcycles and ATVs, and both HC and CO for snowmobiles. For snowmobiles, we have spread costs evenly over HC and CO reductions for purposes of calculating cost per ton. If reductions in other pollutants were included, the cost per ton estimates would be lower. The analysis relies on the per vehicle costs estimated in Chapter 5 and the estimated net present value of the per vehicle lifetime emissions reductions (tons) presented in Chapter 6. These cost per ton estimates do not include permeation control which is calculated separately for recreational vehicles, below.

The estimated per vehicle costs presented in Chapter 5 change over time, with reduced costs in the long term. We have estimated both a near-term and long-term cost per ton. In addition, we have estimated cost per ton both with and without estimated fuel savings. For snowmobiles, we have estimated the cost per ton for all three phases of standard incremental to the previous standards. The results of the analysis using the 7 percent discount rate are presented in Tables 7.1-10 through Table 7.1-12. The results using the 3 percent discount rate follow in Tables 7.1-13 through 7.1-15.

Table 7.1-10
Estimated Snowmobile Average Cost Per Ton of HC and CO Reduced
(7 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)		Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)		Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)	
			HC	CO	HC	CO	HC	CO
Phase 1 near-term	$73	($57)	0.40	1.02	$90	$40	$20	$10
Phase 1 long-term	$40				$50	$20	($20)	($10)
Phase 2 near-term	$131	($286)	0.10	n/a	$1,370	n/a	($1,610)	n/a
Phase 2 long-term	$77				$810	n/a	($2,190)	n/a
Phase 3 near-term	$89	($191)	n/a	0.25	n/a	$360	n/a	($410)
Phase 3 long-term	$54				n/a	$220	n/a	($550)

Table 7.1-11
Estimated ATV Average Cost Per Ton of HC + NOx Reduced
(7 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
near-term	$84	($24)	0.21	$400	$290
long-term	$42			$200	$90

Table 7.1-12
Estimated Off-highway Motorcycle Average Cost Per Ton of HC + NOx Reduced*
(7 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
near-term	$155	($48)	0.38	$410	$280
long-term	$95			$250	$120

* non-competition models only

Table 7.1-13
Estimated Snowmobile Average Cost Per Ton of CO Reduced
(3 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)		Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)		Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)	
			HC	CO	HC	CO	HC	CO
Phase 1 near-term	$73	($57)	0.50	1.25	$70	$30	$20	$10
Phase 1 long-term	$40				$40	$20	($20)	($10)
Phase 2 near-term	$131	($286)	0.12	n/a	$1,110	n/a	($1,305)	n/a
Phase 2 long-term	$77				$650	n/a	($1,770)	n/a
Phase 3 near-term	$89	($191)	n/a	0.31	n/a	$290	n/a	($330)
Phase 3 long-term	$54				n/a	$180	n/a	($450)

Table 7.1-14
Estimated ATV Average Cost Per Ton of HC + NOx Reduced
(3 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Phase 1 near-term	$84	($24)	0.26	$330	$240
Phase 1 long-term	$42			$160	$70

Table 7.1-15
Estimated Off-highway Motorcycle Average Cost Per Ton of HC + NOx Reduced*
(3 percent discount rate)

	Total Average Cost per Vehicle	Lifetime Average Fuel Cost per Vehicle (NPV)	Lifetime Average Reductions (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
near-term	$155	($48)	0.46	$340	$230
long-term	$95			$210	$100

* Non-competition models only

7.1.5 Recreational Vehicle Permeation Emissions

This section provides our estimate of the cost per ton of permeation emissions reduced for recreational vehicles. The analysis relies on the per vehicle costs estimated in Chapter 5 and the estimated lifetime emissions reductions (tons) presented in Chapter 6. All costs and emission reductions are discounted to the year of sale of the boats at a rate of 7 percent. Table 7.1-16 presents the cost per ton with and without consideration of the significant fuel savings that will result from evaporative emission control assuming a 7 percent discount rate. The cost per ton results assuming a 3 percent discount rate are presented in Table 7.1-17. As shown in these tables, the fuel savings more than offset the cost of the evaporative emission control technology.

Table 7.1-16
Estimated Cost Per Ton of HC Reduced (7 percent discount rate)

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles					
tank permeation	$2	$5	0.0125	$185	($178)
hose permeation	$4	$7	0.0182	$234	($129)
total	$7	$11	0.0307	$214	($149)
All Terrain Vehicles					
tank permeation	$2	$3	0.0070	$215	($148)
hose permeation	$1	$3	0.0082	$157	($206)
total	$3	$6	0.0152	$184	($179)
Off-Highway Motorcycles					
tank permeation	$1	$1	0.0041	$348	($15)
hose permeation	$2	$3	0.0096	$175	($188)
total	$3	$5	0.0137	$226	($137)

Table 7.1-17
Estimated Cost Per Ton of HC Reduced (3 percent discount rate)

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles					
tank permeation	$2	$5	0.0144	$161	($202)
hose permeation	$4	$8	0.0209	$204	($159)
total	$7	$13	0.0353	$186	($177)
All Terrain Vehicles					
tank permeation	$2	$3	0.0086	$175	($188)
hose permeation	$1	$4	0.0100	$128	($235)
total	$3	$7	0.0186	$150	($213)
Off-Highway Motorcycles					
tank permeation	$1	$2	0.0047	$302	($61)
hose permeation	$2	$4	0.0110	$152	($211)
total	$3	$6	0.0157	$197	($166)

7.2 Cost Per Ton for Other Mobile Source Control Programs

Because the primary purpose of cost-effectiveness is to compare our program to alternative programs, we made a comparison between the cost per ton values presented in this chapter and the cost-effectiveness of other programs. Table 7.2-1 summarizes the cost effectiveness of several recent EPA actions for controlled emissions from mobile sources. These values show that the cost-effectiveness of the standards for this rulemaking fall within the range of these other programs.

Table 7.2-1
Cost-effectiveness of Previously Implemented Mobile Source Programs (Costs Adjusted to 1997 Dollars)

Program	*$/ton*
Tier 2 vehicle/gasoline sulfur	1,340 - 2,260
2007 Highway HD diesel	1,458-1,867
2004 Highway HD diesel	212 - 414
Off-highway diesel engine	425 - 675
Tier 1 vehicle	2,054 - 2,792
NLEV	1,930
Marine SI engines	1,171 - 1,846
On-board diagnostics	2,313
Marine CI engines	24 - 176

The primary advantage of making comparisons to previously implemented programs is that their cost-effectiveness values were based on a rigorous analysis and are generally accepted as representative of the efficiency with which those programs reduce emissions. Unfortunately, previously implemented programs can be poor comparisons because they may not be representative of the cost-effectiveness of potential future programs. In the context of the Agency's rulemaking to revise the ozone and PM NAAQS[ii], the Agency compiled a list of additional known technologies that may be considered in devising new emission reductions strategies.[1] Through this broad review, over 50 technologies were identified to reduce NOx, VOC, or PM. The cost-effectiveness of these technologies averaged approximately $5,000/ton for VOC, $13,000/ton for NOx, and $40,000/ton for PM.

In summary, given the array of controls that will have to be implemented to make progress toward attaining and maintaining the NAAQS, we believe that the weight of the evidence from alternative means of providing substantial NOx + NMHC emission reductions indicates that our program is cost-effective. This is true from the perspective of other mobile source control programs or from the perspective of other stationary source technologies that might be considered.

7.3 20-Year Cost and Benefit Analysis

The following section presents the year-by-year cost and emission benefits associated with the standards for the 20-year period after implementation of the standards. For the categories where we expect a reduction in fuel consumption due to the standards, the fuel savings

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[ii] This rulemaking was remanded by the D.C. Circuit Court on May 14, 1999. However, the analyses completed in support of that rulemaking are still relevant, since they were designed to investigate the cost-effectiveness of a wide variety of potential future emission control strategies.

are presented separately. The overall cost, incorporating the impact of the fuel savings is also presented.

Table 7.3-1 presents the year-by-year cost and emission benefits for the compression-ignition (CI) recreational marine requirements. (The numbers presented in Table 7.3-1 are not discounted.)

Table 7.3-1
Cost and Emission Benefits of the CI Recreational Marine Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	639	0	$7,806,010	$0	$7,806,010
2007	1,310	0	$8,365,319	$0	$8,365,319
2008	2,015	0	$8,573,839	$0	$8,573,839
2009	2,842	0	$9,413,530	$0	$9,413,530
2010	3,705	0	$9,637,035	$0	$9,637,035
2011	4,583	0	$5,213,411	$0	$5,213,411
2012	5,496	0	$5,176,672	$0	$5,176,672
2013	6,424	0	$5,290,764	$0	$5,290,764
2014	7,361	0	$4,958,052	$0	$4,958,052
2015	8,333	0	$5,062,713	$0	$5,062,713
2016	9,313	0	$5,167,682	$0	$5,167,682
2017	10,300	0	$5,272,652	$0	$5,272,652
2018	11,320	0	$5,377,623	$0	$5,377,623
2019	12,345	0	$5,482,592	$0	$5,482,592
2020	13,373	0	$5,587,562	$0	$5,587,562
2021	14,407	0	$5,692,532	$0	$5,692,532
2022	15,416	0	$5,797,503	$0	$5,797,503
2023	16,423	0	$5,902,472	$0	$5,902,472
2024	17,379	0	$6,007,442	$0	$6,007,442
2025	18,190	0	$6,112,413	$0	$6,112,413

Table 7.3-2 presents the sum of the costs and emission benefits over the twenty year period after the CI recreational marine requirements take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3-2
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the CI Recreational Marine Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	181,174	0	$125.9	$0.0	$125.9
Discounted 20-year Value	79,294	0	$75.6	$0.0	$75.6
Annualized Value	7,485	0	$7.1	$0.0	$7.1

Table 7.3-3 presents the year-by-year cost and emission benefits for the large spark-ignition (SI) engine exhaust and evaporative requirements. (The numbers presented in Table 7.3-3 are not discounted.)

Table 7.3-3
Cost and Emission Benefits of the Large SI Engine Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2004	77,259	82,130	$88,806,711	$52,725,475	$36,081,236
2005	133,247	161,404	$91,185,462	$102,980,886	($11,795,424)
2006	187,149	239,617	$75,632,060	$152,926,193	($77,294,133)
2007	265,975	474,426	$84,493,379	$198,943,367	($114,449,988)
2008	329,756	678,940	$86,588,256	$242,829,040	($156,240,784)
2009	391,853	883,333	$68,943,347	$285,094,033	($216,150,686)
2010	451,604	1,076,572	$70,571,930	$325,741,703	($255,169,773)
2011	506,031	1,260,180	$72,200,513	$360,969,773	($288,769,260)
2012	542,932	1,427,950	$68,895,067	$379,398,454	($310,503,387)
2013	576,173	1,589,734	$70,414,812	$395,033,152	($324,618,340)
2014	606,048	1,730,897	$71,934,556	$408,985,187	($337,050,631)
2015	627,504	1,803,389	$73,454,300	$421,230,723	($347,776,423)
2016	646,713	1,866,433	$74,974,044	$432,435,409	($357,461,365)
2017	664,729	1,922,727	$76,493,788	$443,121,586	($366,627,798)
2018	681,633	1,972,496	$78,013,532	$453,291,958	($375,278,426)
2019	697,598	2,017,393	$79,533,276	$462,975,097	($383,441,821)
2020	712,638	2,059,586	$81,053,020	$471,991,726	($390,938,706)
2021	727,377	2,099,624	$82,572,765	$480,919,953	($398,347,188)
2022	741,822	2,137,602	$84,092,509	$489,742,176	($405,649,667)
2023	756,116	2,176,504	$85,612,253	$498,805,313	($413,193,060)

Table 7.3-4 presents the sum of the costs and emission benefits over the twenty year period after the large SI engine exhaust and evaporative requirements are to take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3-4
Annualized Cost and Emission Benefits for the Period 2004-2023 due to the Large SI Engine Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	10,324,157	27,660,937	$1,565.5	$7,060.1	($5,494.7)
Discounted 20-year Value	4,945,366	12,631,259	$892.4	$3,433.5	($2,541.1)
Annualized Value	466,808	1,192,303	$84.2	$324.1	($239.9)

Table 7.3-5 presents the year-by-year cost and emission benefits for the snowmobile exhaust and permeation requirements. (The numbers presented in Table 7.3-5 are not discounted.)

Table 7.3-5
Cost and Emission Benefits of the Snowmobile Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	3,933	9,941	$6,583,529	$391,491	$6,192,038
2007	12,374	31,272	$13,546,439	$1,225,462	$12,320,977
2008	22,502	54,058	$13,183,508	$2,469,788	$10,713,720
2009	32,977	77,582	$13,455,182	$3,747,560	$9,707,622
2010	45,890	105,287	$38,933,137	$9,545,473	$29,387,664
2011	59,319	134,052	$38,685,132	$15,633,653	$23,051,479
2012	76,209	169,882	$51,957,587	$25,065,896	$26,891,691
2013	93,845	207,354	$52,701,157	$34,856,171	$17,844,987
2014	112,031	245,980	$45,309,024	$44,859,909	$449,115
2015	130,397	284,962	$44,402,290	$54,975,510	($10,573,219)
2016	148,455	323,196	$41,860,214	$65,045,977	($23,185,764)
2017	165,914	360,691	$41,738,365	$74,963,244	($33,224,879)
2018	181,480	394,252	$42,211,850	$84,545,886	($42,334,036)
2019	194,065	420,522	$42,677,612	$93,597,148	($50,919,536)
2020	204,737	442,187	$43,138,523	$102,179,264	($59,040,741)
2021	214,492	461,929	$43,138,523	$110,195,147	($67,056,624)
2022	222,824	478,985	$43,138,523	$116,664,922	($73,526,400)
2023	229,775	493,443	$43,138,523	$121,533,783	($78,395,261)
2024	235,195	504,816	$43,138,523	$125,181,189	($82,042,667)
2025	239,208	513,372	$43,138,523	$127,680,885	($84,542,362)

Table 7.3-6 presents the sum of the costs and emission benefits over the twenty year period after the exhaust and permeation requirements for snowmobiles take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3-6
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the Snowmobile Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	2,625,622	5,713,763	$746.1	$1,214.4	($552.9)
Discounted 20-year Value	1,141,218	2,499,999	$379.9	$494.6	($145.8)
Annualized Value	107,723	235,983	$35.9	$46.7	($10.8)

Table 7.3-7 presents the year-by-year cost and emission benefits for the exhaust and permeation requirements for ATVs. (The numbers presented in Table 7.3-7 are not discounted.)

Table 7.3-7
Cost and Emission Benefits of the ATV Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	6,321	4,380	$42,463,856	$933,911	$41,529,945
2007	23,496	14,702	$79,998,942	$4,771,537	$75,227,405
2008	44,313	26,267	$76,517,949	$9,546,220	$66,971,729
2009	69,788	39,269	$70,286,998	$13,556,430	$56,730,568
2010	97,132	53,061	$65,302,237	$17,819,539	$47,482,698
2011	125,655	67,377	$56,379,476	$22,221,930	$34,157,546
2012	154,669	81,890	$52,441,476	$26,654,575	$25,786,901
2013	183,543	96,230	$52,441,476	$31,026,962	$21,414,514
2014	211,466	110,237	$52,441,476	$35,203,428	$17,238,048
2015	238,164	123,603	$52,441,476	$39,163,369	$13,278,107
2016	263,043	136,030	$49,999,146	$42,825,354	$7,173,792
2017	285,924	147,442	$47,556,815	$46,173,993	$1,382,822
2018	304,746	156,446	$47,556,815	$48,949,487	($1,392,672)
2019	316,793	161,571	$47,556,815	$50,819,932	($3,263,117)
2020	324,521	164,444	$47,556,815	$52,105,004	($4,548,189)
2021	329,849	166,533	$47,556,815	$52,985,302	($5,428,487)
2022	333,031	167,857	$47,556,815	$53,516,650	($5,959,835)
2023	335,389	168,858	$47,556,815	$53,912,720	($6,355,905)
2024	337,137	169,554	$47,556,815	$54,215,317	($6,658,502)
2025	338,413	170,055	$47,556,815	$54,442,855	($6,886,040)

Table 7.3-8 presents the sum of the costs and emission benefits over the twenty year period after the exhaust and permeation requirements for ATVs take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3-8
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the ATV Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	4,323,393	2,225,806	$1,078.7	$710.8	$367.9
Discounted 20-year Value	1,951,668	1,014,866	$641.0	$325.3	$315.7
Annualized Value	184,224	95,796	$60.5	$30.7	$29.8

Table 7.3-9 presents the year-by-year cost and emission benefits for the off-highway motorcycle exhaust and permeation requirements. (The numbers presented in Table 7.3-9 are <u>not</u> discounted.

Table 7.3-9
Cost and Emission Benefits of the Off-Highway Motorcycle Requirements

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2006	3,085	2,330	$16,269,072	$633,450	$15,635,622
2007	9,742	7,398	$31,813,960	$2,061,773	$29,752,187
2008	18,028	13,408	$29,592,786	$3,878,230	$25,714,556
2009	27,409	20,236	$26,871,067	$5,903,201	$20,967,866
2010	37,325	27,463	$24,698,975	$8,016,233	$16,682,742
2011	47,542	34,917	$21,818,012	$10,166,886	$11,651,126
2012	57,733	42,364	$21,366,690	$12,282,632	$9,084,058
2013	67,631	49,612	$21,580,357	$14,311,527	$7,268,830
2014	77,400	56,774	$21,796,160	$16,290,860	$5,505,300
2015	86,976	63,810	$22,014,121	$18,207,111	$3,807,010
2016	96,030	70,471	$22,234,263	$19,981,626	$2,252,637
2017	103,553	76,047	$22,456,605	$21,421,145	$1,035,460
2018	108,707	79,882	$22,681,171	$22,409,671	$271,500
2019	112,249	82,490	$22,907,983	$23,107,057	($199,074)
2020	114,994	84,503	$23,137,063	$23,655,679	($518,616)
2021	117,320	86,207	$23,368,434	$24,122,020	($753,586)
2022	119,371	87,712	$23,602,118	$24,532,680	($930,562)
2023	121,137	89,007	$23,838,139	$24,886,440	($1,048,301)
2024	122,719	90,173	$24,076,521	$25,200,670	($1,124,149)
2025	124,218	91,284	$24,317,286	$25,496,728	($1,179,442)

Table 7.3-10 presents the sum of the costs and emission benefits over the twenty year period after the exhaust and permeation requirements for off-highway motorcycles take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-year period (assuming the seven percent discount rate) are also presented.

Table 7.3-10
Annualized Cost and Emission Benefits for the Period 2006-2025 due to the Off-Highway Motorcycle Requirements

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 20-year Value	1,573,169	1,156,088	$470.4	$326.6	$143.9
Discounted 20-year Value	715,044	525,674	$268.9	$149.1	$119.8
Annualized Value	67,495	49,620	$25.4	$14.1	$11.3

Table 7.3-11 presents the year-by-year cost and emission benefits for all of the requirements. (The numbers presented in Table 7.3-11 are <u>not</u> discounted.)

Table 7.3-11
Cost and Emission Benefits of the Requirements for All Equipment Categories

Year	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings	Fuel Savings	Cost w/ Fuel Savings
2004	77,259	82,130	$88,806,711	$52,725,475	$36,081,236
2005	133,247	161,404	$91,185,462	$102,980,886	($11,795,424)
2006	201,127	256,268	$148,754,528	$154,885,046	($6,130,518)
2007	312,897	527,798	$218,218,038	$207,002,139	$11,215,899
2008	416,614	772,673	$214,456,337	$258,723,278	($44,266,941)
2009	524,869	1,020,420	$188,970,125	$308,301,224	($119,331,100)
2010	635,656	1,262,383	$209,143,314	$361,122,948	($151,979,633)
2011	743,130	1,496,526	$194,296,545	$408,992,242	($214,695,697)
2012	837,039	1,722,086	$199,837,493	$443,401,557	($243,564,064)
2013	927,616	1,942,930	$202,428,566	$475,227,812	($272,799,246)
2014	1,014,306	2,143,888	$196,439,267	$505,339,384	($308,900,116)
2015	1,091,374	2,275,764	$197,374,901	$533,576,713	($336,201,812)
2016	1,163,554	2,396,130	$194,235,348	$560,288,366	($366,053,018)
2017	1,230,420	2,506,907	$193,518,225	$585,679,968	($392,161,743)
2018	1,287,886	2,603,076	$195,840,991	$609,197,002	($413,356,011)
2019	1,333,050	2,681,976	$198,158,277	$630,499,234	($432,340,957)
2020	1,370,263	2,750,720	$200,472,982	$649,931,673	($449,458,691)
2021	1,403,445	2,814,293	$202,329,067	$668,222,422	($465,893,354)
2022	1,432,464	2,872,156	$204,187,466	$684,456,428	($480,268,962)
2023	1,458,840	2,927,812	$206,048,201	$699,138,256	($493,090,055)
2024	1,482,773	2,980,012	$207,911,297	$712,465,187	($504,553,890)
2025	1,504,484	3,028,620	$209,776,777	$724,482,067	($514,705,289)

Table 7.3-12 presents the sum of the costs and emission benefits over the twenty-two year period after all of the requirements take effect, on both a non-discounted basis and a discounted basis (assuming a seven percent discount rate). The annualized cost and emission benefits for the twenty-two year period (assuming the seven percent discount rate) are also presented. (A twenty-two period is used in this aggregate analysis to cover the first twenty years of each of the standards which begins in 2004 for large SI engines and concludes in 2006 for the other categories of equipment.)

Table 7.3-12
Annualized Cost and Emission Benefits for the Period 2004-2025 due to the Requirements for All Equipment

	HC+NOx Benefits (tons)	CO Benefits (tons)	Cost w/o Fuel Savings (Million $)	Fuel Savings (Million $)	Cost w/ Fuel Savings (Million $)
Undiscounted 22-year Value	22,106,425	44,300,504	$4,374.0	$11,072.1	($6,698.1)
Discounted 22-year Value	9,073,158	17,971,253	$2,176.7	$4,701.9	($2,525.2)
Annualized Value	789,161	1,561,958	$192.5	$410.1	($217.6)

Chapter 7 References

1.“Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Regional Haze Rule,” Appendix B, “Summary of control measures in the PM, regional haze, and ozone partial attainment analyses,” Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 17, 1997, Docket A-2000-01, Document II-A-77.

Chapter 8: Small Business Flexibility Analysis

This section presents our Small Business Flexibility Analysis (SBFA) which evaluates the impacts of the rule on small businesses. Prior to issuing our proposal, we analyzed the potential impacts of our program on small businesses. As a part of this analysis, we convened two Small Business Advocacy Review (SBAR) Panels, under the requirements of the Regulatory Flexibility Act (RFA), as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), 5 USC 601 *et seq*. Through the two Panel processes, we gathered advice and recommendations from small entity representatives (SERs) who would be affected by the regulation. The two Panel reports have been placed in the rulemaking record.

8.1 Requirements of the Regulatory Flexibility Act

The Regulatory Flexibility Act was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect them. Although we are not required by the Clean Air Act to provide special treatment to small businesses, the Regulatory Flexibility Act requires us to carefully consider the economic impacts that our proposed rules will have on small entities. In general, the Regulatory Flexibility Act calls for determining, to the extent feasible, a rule’s economic impact on small entities, exploring regulatory options for reducing any significant economic impact on a substantial number of such entities, and explaining the ultimate choice of regulatory approach.

For purposes of assessing the impacts of this final rule on small entities, a small entity is defined as: (1) a small business that meet the definition for business based on SBA size standards; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field. This rulemaking will only affect the small businesses.

When proposing rules subject to notice and comment under the Clean Air Act, we are generally required under the Regulatory Flexibility Act to conduct an Initial Regulatory Flexibility Analysis, unless we certify that the requirements of a regulation will not cause a significant impact on a substantial number of small entities. Although we are not required to conduct a Final Regulatory Flexibility Analysis (FRFA), EPA has decided to prepare an assessment of the impacts of the final rule on small entities. This SBFA would meet the requirements of a FRFA, were EPA required to prepare one.

In accordance with section 609 of the RFA, EPA conducted an outreach to affected small entities and convened a Small Business Advocacy Review (SBAR) Panel prior to proposing this rule, to obtain advice and recommendations of representatives of the small entities that potentially would be subject to the rule's requirements. Through the Panel process, we gathered advice and recommendations from small-entity representatives who would be affected by the regulation, and published the results in a Final Panel Report, dated July 17, 2001. EPA had previously convened a separate Panel for marine engines and vessels. This panel also produced a report, dated August 25, 1999. We also prepared an Initial Regulatory Flexibility Analysis (IRFA) in accordance with section 603 of the Regulatory Flexibility Act. The IRFA is found in chapter 8 of the Draft Regulatory Support Document. Both Panel reports and the IRFA have been placed in the docket for this rulemaking (Public Docket A-2000-01, items II-A-85, II-F-22, and III-B-01).

We proposed the majority of the Panel recommendations, and took comments on this and other issues. The information we received during the course of the rulemaking indicated that fewer small entities than we had first estimated would be significantly impacted by the rule. During the SBAR Panel process, we were concerned that ATV and off-highway motorcycle importers would have limited access to certified models for import. We received no comments confirming this concern and believe that the use of cleaner four-stroke engines in these vehicles will continue to increase. As a result, we believe all these small companies should be able to find manufacturers that are able to supply compliant engines for import into the U.S. These importers incur no development costs, and they are not involved in adding emission-control hardware or other variable costs to provide a finished product to market. We also expect that importers would select vehicles for import that have fuel tanks and hoses that comply with the permeation standards. However, even if they were not able to find such vehicles, the few additional dollars per vehicle that it would cost to bring them into compliance with the permeation standards is insignificant in comparison with the normal selling prices for these vehicles. They should therefore expect to buy and sell their products with the normal markup to cover their costs and profit. As noted below, we expect all 21 known small-business importers to face compliance costs of less than one percent of their revenues. Thus, EPA has determined that this final rule will not have a significant economic impact on a substantial number of small entities. Also, as a result of comments received on the proposal, we are finalizing changes that we believe will further reduce the level of impact to small entities directly regulated by the rule. These changes and can be found below in Section 8.6, "Steps Taken to Minimize the Economic Impact on Small Entities."

The key elements of the Small Business Flexibility Analysis include:

- the need for and objectives of the rule;
- the significant issues raised by public comments, a summary of the Agency’s assessment of those issues, and a statement of any changes made to the rule as a result of those comments;
- the types and number of affected small entities to which this rule will apply;
- the projected reporting, record keeping, and other compliance requirements of the regulation, including the classes of small entities that would be affected and the type of professional skills necessary for preparation of the report or record;

- the steps taken to minimize the economic impacts of the regulation on small entities, consistent with the stated objectives of the applicable statutes.

8.2 Need For and Objectives of the Rule

The process of establishing standards for nonroad engines began in 1991 with a study to determine whether emissions of carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOCs) from new and existing nonroad engines, equipment, and vehicles are significant contributors to ozone and CO concentrations in more than one area that has failed to attain the national ambient air quality standards for ozone and CO.[jj] In 1994, EPA finalized its finding that nonroad engines as a whole "are significant contributors to ozone or carbon monoxide concentrations" in more than one ozone or carbon monoxide nonattainment area.[kk]

Upon making this finding, the Clean Air Act (CAA or the Act) requires EPA to establish standards for all classes or categories of new nonroad engines that cause or contribute to air quality nonattainment in more than one ozone or carbon monoxide (CO) nonattainment area. Since the finding in 1994, EPA has been engaged in the process of establishing programs to control emissions from nonroad engines used in many different applications. Nonroad categories already regulated include:

- Land-based compression ignition (CI) engines (e.g., farm and construction equipment),
- Small land-based spark-ignition (SI) engines (e.g., lawn and garden equipment, string trimmers),
- Marine engines (outboards, personal watercraft, CI commercial, CI engines <37kW)
- Locomotive engines

On December 7, 2000, EPA issued an Advance Notice of Proposed Rulemaking (ANPRM), and then issued a Notice of Proposed Rulemaking (NPRM) on September 14, 2001. This final rule continues the process of establishing standards for nonroad engines and vehicles, as required by CAA section 213(a)(3), with new emission standards for recreational marine diesel engines, recreational vehicles, and other nonroad spark-ignition engines over 19 kW.

8.3 Issues Raised by Public Comments

The two SBAR Panels considered a wide range of options and regulatory alternatives for providing small businesses with flexibility in complying with the regulation. As part of the process, the Panels requested and received comment on several ideas for flexibility that were suggested by SERs and Panel members. The major options recommended by the Panel can be

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[jj] "Nonroad Engine and Vehicle Emission Study—Report and Appendices," EPA-21A-201, November 1991 (available in Air docket A-91-24). It is also available through the National Technical Information Service, referenced as document PB 92-126960.

[kk] 59 FR 31306 (July 17, 1994).

found in Section 9 of the Panel Reports.

Many of the flexible approaches recommended by the Panels can be applied to several of the equipment categories that may be affected by the regulation. However, during the consultation process, it became evident that, in a few situations, it could be helpful to small entities if unique provisions were available. Three such provisions are described below.

> (a) Snowmobiles: The Panel recommended that EPA seek comment on a provision allowing small snowmobile manufacturers to request a relaxed standard for one or more engine families, up to 300 engines per year, until the family is retired or modified, if such a standard is justifiable based on the criteria described in the Panel report. Based on comments received, we have adopted this provision, increasing the sales allowance to 600 engines per year.
>
> (b) ATVs and Off-road Motorcycles: The Panel recommended that the hardship provision for ATVs and off-road motorcycles allow for annual review of the relief for up to two years for importers to obtain complying products. We are adopting this provision.
>
> (c) Large SI: The Panel recommended that small entities be granted the flexibility initially to reclassify a small number of their small displacement engines into EPA's small spark-ignition engine program (40 CFR part 90). Small entities would be allowed to use those requirements instead of the requirements we adopt for large entities. We are not adopting this provision, preferring instead to rely on the more flexible approach provided under the hardship provisions. Since there are only two companies affected, we believe this approach best addresses these concerns.

The Panel also crafted recommendations to address SERs' concerns that ATV and off-road motorcycle standards that essentially required manufacturers to switch to four-stroke engines might increase costs to the point that many small importers and manufacturers could experience significant adverse effects. The Panel recommended that EPA request comment in its proposed rule on the effect of the regulation on these small entities, with the specific intent of developing information—including the extent to which sales of their products would likely to be reduced in response to changes in product price attributable to the standards—that could be used to inform a decision in the final rule as to whether EPA should provide additional flexibility beyond that considered by the Panel. We received no comments addressing this concern and therefore believe that the use of four-stroke engines for ATVs and off-highway motorcycles will continue to increase; as a result all these companies should be able to find manufacturers that are able to supply compliant engines into the U.S. market.

In the NPRM for this rule, we proposed only exhaust emission controls for recreational vehicles. However, several commenters raised the issue of control of evaporative emissions related to permeation from fuel tanks and fuel hoses, and indicated that our obligations under section 213 of the Clean Air Act included control of permeation emissions. The commenters pointed to work done by the California Air Resources Board (ARB) on permeation emissions from plastic fuel tanks and rubber fuel line hoses for various types of nonroad equipment, as well as portable plastic fuel containers, as evidence of a new emissions concern. Our own investigation into the hydrocarbon emissions related to permeation of fuel tanks and fuel hoses from recreational land-based and marine applications supports the concerns raised by the commenters. Therefore, on May 1, 2002, we published a notice in the Federal Register reopening the comment period and requesting comment on possible approaches to regulating permeation emissions from recreational vehicles. The notice provided a detailed analysis of possible approaches to regulating permeation emissions and the expected costs and emission reductions from these approaches. The notice also cited sample regulation language that could be used if we decided to finalize such requirements. Commenters had thirty days from May 1, 2002 to provide comments on the notice. We received comments from several affected manufacturers during the comment period, including at least one small entity. These comments have been addressed in the final Summary and Analysis of Comments document, and we have made several changes to the rule in response to suggestions of the commenters.

We received a number of other comments from engine and equipment manufacturers and consumers during the comment period after we issued the NPRM. A number of small engine and equipment manufacturers commented on the financial hardships they would face in complying with the proposed regulations. Most requested that we consider a number of hardship provisions, primarily an exemption from or a delay in the implementation of the proposed standards, or certain flexibilities in the certification process. Due to the wide variety of engines, vehicles, and equipment covered by this rulemaking, we decided that a variety of provisions were needed to address the concerns of the small entities involved. A summary of the comments pertaining to these small entity issues can be found in our Final Summary and Analysis of Comments document contained in the public docket for this rulemaking. Changes to the proposal as a result of SER or other comments are noted below in section 8.6 for each of the sectors affected by this rule.

8.4 Description of Affected Entities

Table 8.4-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 8.4-1
Primary SBA Small Business Categories Potentially Affected by this Regulation

Industry	NAICS[a] Codes	Defined by SBA as a Small Business If:[b]
Motorcycles and motorcycle parts manufacturers	336991	<500 employees
Snowmobile and ATV manufacturers	336999	<500 employees
Independent Commercial Importers of Vehicles and parts	421110	<100 employees
Nonroad SI engines	333618	<1,000 employees
Internal Combustion Engines	333618	<1000 employees
Boat Building and Repairing	336612	<500 employees

a. North American Industry Classification System
b. According to SBA's regulations (13 CFR part 121), businesses with no more than the listed number of employees or dollars in annual receipts are considered "small entities" for purposes of a regulatory flexibility analysis.

8.4.1 Recreational Vehicles (ATVs, off-highway motorcycles, and snowmobiles)

The ATV sector has the broadest assortment of manufacturers. There are seven companies, Bombardier, Honda, Polaris, Kawasaki, Yamaha, Suzuki, and Arctic Cat, representing over 95 percent of total domestic ATV sales. The remaining 5 percent come from one small manufacturer, IPC, and a number of importers who tend to import inexpensive, youth-oriented ATVs from China and other Asian nations.. EPA has identified 21 small companies (as defined in Table 8.4.1, above) that offer off-road motorcycles, ATVs, or both products. Annual unit sales for these companies can range from a few hundred to several thousand units per year.

We expect all 21 known small-business importers to face compliance costs less than one percent of their revenues. These companies incur no development costs and they are not involved in adding emission-control hardware or other variable costs to provide a finished product to market. As a result, they should expect to buy and sell their products with the normal mark-up to cover their costs and profit. During the SBAR Panel process, we were also concerned that importers would have limited access to certified models for import. We received no comments confirming this concern and believe that the supply of four-stroke engines for ATVs and off-highway motorcycles will continue to increase; as a result all these companies should be able to find manufacturers that are able to supply compliant engines into the U.S. market. We also received no comments regarding the permeation standards issue, and believe that the importers will simply purchase compliant models and pass the costs on to the ultimate consumers.

Five large manufacturers, Honda, Kawasaki, Yamaha, Suzuki, and KTM. accounted for approximately 85 percent of all off-highway motorcycle production for sale in the U.S. There are three small business manufacturing off-highway motorcycles in the U.S. Two of these companies make only competition models, so they don't need to certify their products under this regulation. ATK already offers engines that should be meeting the new emission standards, especially under our provisions allowing design-based certification, so we estimate that their compliance costs will be much less than one percent of their revenues.

IPC is the only small business manufacturing ATVs, offering two separate youth ATV models. IPC already uses four-stroke engines. Moreover, the standards are based on emissions per kilometer, which are easier to meet for models with small-displacement engines. We estimate compliance costs of about $50,000 for R&D plus $15,000 for certification, which is much less than 1 percent of IPC's annual revenues.

We do not believe that compliance with the permeation standards will place a significant burden on either the small manufacturers or on the importers. We have estimated the cost of compliance for ATVs and off-highway motorcycles at roughly three dollars per vehicle for the fuel hoses and surface coating for the fuel tank. This estimate includes shipping, and is based on buying the necessary hoses and surface treatment for the fuel tanks from outside suppliers. Thus, no capital outlays are required, and the increase in vehicle cost is insignificant, so that it can easily be passed along to the ultimate consumer. However, to ensure that these requirements do not adversely affect small manufacturers, we are implementing, where they are applicable to permeation, the same flexibility options we proposed for the exhaust emission standards.

Based on available industry information, four major manufacturers, Arctic Cat, Bombardier (also known as Ski-Doo), Polaris, and Yamaha, account for over 99 percent of all domestic snowmobile sales. The remaining one percent comes from very small manufacturers who tend to specialize in unique and high performance designs. There is also one potential manufacturer (Redline), which we have learned is owned by a larger entity (TMAG) and is therefore not a small business, that hopes to produce snowmobiles within the next year.

We are aware of five small businesses that have been producing snowmobiles. Two of these have discontinued production since we completed the SBAR panel. Two of the remaining three manufacturers (Crazy Mountain and Fast, Inc.) specialize in high performance versions of standard recreational snowmobile types (i.e., travel and mountain sleds). The other manufacturer (Fast Trax) produces a unique design, which is a scooter-like snowmobile designed to be ridden standing up. Most of these manufacturers build less than 50 units per year.

Fast, Inc. produces four engine models, one of which is a four-stroke design. The four-stroke engine will need no development or certification work, since we allow design-based certification for this situation. We expect the two-stroke engines to qualify for the special standards that apply to small businesses. As a result, Fast will have only limited development costs to reduce emissions from these engines. We estimate a total of $75,000 in R&D and $15,000 for certification for each of the three engine families. They are projecting sales of around 1,000 units for the time when standards would apply. Since this is a substantial increase over their current volume of 180 per year, we base revenue calculations on projected sales of only 500 per year. The resulting calculation shows a compliance burden less than one percent.

Fast, Inc. was the only recreational vehicle manufacturer to comment on the permeation provisions contained in the May 1 notice. Fast stated that, as a small manufacturer of snowmobiles, they would undergo additional hardship due to this rule, because they do not have the sales volume to warrant installing the barrier treatment equipment for fuel tanks. They also commented that shipping and processing of fuel tanks by an outside vendor could take 3-4 months, and that as a small business it would be unworkable for them to tie up funds for such a long period.

We agree that it is neither necessary nor cost-effective for a small manufacturer to make the capital investment necessary for an in-house treatment facility, given the relatively low cost of the compliance with the requirements and the availability of materials and treatment support by outside vendors. Low permeation fuel hoses are available from vendors today, and we would expect that surface treatment would be applied through an outside company. The $5 to $7 per vehicle incremental cost resulting from the permeation requirements is insignificant compared to the price of one of these high-end sleds, and should not pose a significant cash-flow problem, particularly in view of the likely sales volumes involved. These costs are based on vendor costs, including shipping charges.

Since the costs are low and no capital investment is required, we believe that the permeation control requirements should be relatively easy for small businesses to meet. However, to make sure that these requirements do not adversely affect small entities, we are implementing, where they are applicable to permeation, the same flexibility options we proposed for the recreational vehicle exhaust emission standards . These flexibility options included a 2 year delay of the standards, design-based certification, broader engine families, waiving production line testing, use of assigned deterioration factors, carryover of certification data, ABT, and hardship provisions. These are further described below in section 8.6.. Given the low costs and these flexibilities, there should be no significant economic impact on small entities.

Crazy Mountain produces only about 20 snowmobiles per year in addition to their more extensive business in aftermarket parts and accessories for snowmobiles from other manufacturers. We don’t have revenue information for the whole company, but we expect that total costs of redesigning and certifying their single model will exceed 3 percent of snowmobile revenues. However, with its low production volume, Crazy Mountain could likely qualify for the special standards that apply to small businesses.

Fast Trax provided no response to repeated outreach efforts to determine potential economic effects of the final rule. We expect them to purchase compliant engines, which would result in a compliance burden of less than one percent. Due to the small engine displacements used in current models, we would expect these engines to be certified to the Small SI standards.

8.4.2 Large Spark Ignition Engines

The Panel was aware of one engine manufacturer of Large SI engines that qualifies as a small business. Westerbeke plans to produce engines that meet the standards adopted by CARB in 2004, with the possible exception of one engine family. If EPA adopts long-term standards, this would require manufacturers to do additional calibration and testing work. If EPA adopts new test procedures (including transient operation), there may also be a cost associated with upgrading test facilities. We expect that Westerbeke will face relatively small compliance costs as a result of this rule, since the California-compliant engines will need only a small amount of additional development effort to meet the long-term standards. We estimate that they will need $200,000 each for two engine families, with a potential need to spend an additional $300,000 for upgrading test cells. These costs are less than one percent of their annual revenues.

Since we completed the proposal Wisconsin Motors, a small business, bought the assets of a company that had gone bankrupt. This company did not exist during the SBAR Panel process associated with this rule. Through public comments and other outreach efforts, this company has stated that it faces significant development costs, though much of this effort is required to improve the engine enough to sustain a market presence as other manufacturers continue to make improvements to competitive engines. Under the hardship provisions, we expect them to spread compliance costs over several years to reduce the impact of emission standards. Wisconsin should be able to delay compliance until they are able to retool for production and add developmental efforts to incorporate emission-control technologies. Substantial tooling expenses will be necessary independent of emission standards. We estimate a need for $500,000 for emission-measurement facilities and $500,000 of development costs for each of two engine models. New testing to certify and show compliance on these models comes to about $50,000 total. These costs are about 4 percent of the projected revenues for the time frame when Wisconsin will be certifying their engines. Since this manufacturer is operating in a niche market with customers providing public comments citing the need for these engines, we expect that most of the increased cost of production will be recovered by increased revenues.

8.4.3 Marine Vessels

Marine vessels include the boat, engine, and fuel system. Exhaust emission controls including NTE requirements, as addressed in the two Panel Reports, would affect the engine manufacturers and may affect boat builders.

8.4.3.1 Small Diesel Engine Marinizers

We have determined that there are at least 16 companies that manufacture diesel engines for recreational vessels. Nearly 75 percent of diesel engines sales for recreational vessels in 2000 can be attributed to three large companies. Six of the 16 identified companies are considered small businesses as defined by SBA. Based on sales estimates for 2000, these six companies represent approximately 4 percent of recreational marine diesel engine sales. The remaining companies each comprise between two and seven percent of sales for 2000.

We are thus aware of six small businesses that may produce recreational marine diesel engines. Alaska Diesel and Westerbeke do not offer recreational versions of the marine diesel engines that are different than their commercial products. The regulations allow manufacturers to certify all their products under the commercial standards, even if they may be used in recreational applications. As a result, these companies would likely minimize their costs by certifying all their products to the commercial standards. We therefore believe that they will experience no significant new compliance costs for these engines as a result of this regulation. Daytona has, to the best of our knowledge, discontinued production of their marine product line.

For those companies that will be certifying recreational marine diesel engines, we directly apply the development and certification costs from Chapter 5. For each engine family, we estimate $200,000 of development costs and $30,000 of certification costs. The variable costs considered in Chapter 5 are very small relative to the price of the engines, so we would expect manufacturers to fully recover these costs over time.

American Diesel is a small business for which we were unable to identify gross revenues. However, based on the fact that they reported an employee count of 17, we can reasonably estimate their business volume. They produce a single engine model, so their total estimated fixed costs are $230,000. For compliance costs to fall in the range of 1 to 3 percent of annual revenues, total revenues would need to be between $2.5 and $7.6 million. This is a reasonable estimate compared to other companies producing these engines with a similar number of employees.

Marine Power also sells only a single model. Comparing fixed costs (spread over three years) to their estimated annual revenues of $10 million shows that their compliance burden is 0.8 percent of revenues.

Peninsular Diesel has annual revenues of about $2 million from three employees. They also sell a single engine model. Their estimated compliance burden is 3.8 percent of revenues.

8.4.3.2 Small Recreational Boat Builders

We have less precise information about recreational boat builders than is available about engine manufacturers. We have utilized several sources, including trade associations and

Internet sites when identifying entities that build or sell recreational boats. We have also worked with an independent contractor to assist in the characterization of this segment of the industry. Finally, we received a list of nearly 1,700 boat builders known to the U.S. Coast Guard to produce boats using engines for propulsion. More than 90% of the companies identified so far would be considered small businesses as defined by SBA (NAIC code 336612).

8.4.4 Results for All Small entities

For this regulation as a whole, we expect 32 small businesses to have total compliance costs less than 1 percent of their annual revenues. We estimate that one company will have compliance costs between 1 and 3 percent of revenues. Three companies will likely have compliance costs exceeding 3 percent of revenues, but at least one will likely be able to benefit from the relief provisions outlined below. These estimates include the costs for compliance with the permeation standards.

8.5 Projected Reporting, Recordkeeping, and Other Compliance Requirements of the Regulation

For any emission control program, we be sure that the regulated engines will meet the standards. Historically, EPA programs have included provisions placing manufacturers responsible for providing these assurances. This final rule includes testing, reporting, and record keeping requirements. Testing requirements for some manufacturers include certification (including deterioration testing), and production-line testing. Reporting requirements include test data and technical data on the engines including defect reporting. Manufacturers keep records of this information.

8.6 Steps to Minimize Significant Economic Impact on Small Entities

EPA conducted outreach to small entities and convened two Small Business Advocacy Review Panels to obtain advice and recommendations of representatives of the small entities that potentially would be subject to the rule's requirements. The first panel covered only marine engines and vessels. That Panel published its report on August 29, 1999, and where appropriate, its recommendations have been incorporated into this analysis. In a subsequent Federal Register notice dated May 2, 2002 (67 FR 21613), EPA sought comment on applying permeation control standards for fuel tanks and fuel hoses used on recreational vehicles. These provisions would generally apply to those controls as well.

On May 3, 2001, EPA’s Small Business Advocacy Chairperson convened a second Panel covering all engine/vehicle categories in this rulemaking, under Section 609(b) of the Regulatory Flexibility Act (RFA) as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA). In addition to the Chair, the Panel consisted of the Director of the Assessment and Standards Division (ASD) within EPA's Office of Transportation and Air Quality, the Chief Counsel for Advocacy of the Small Business Administration, and the Deputy Administrator of the Office of Information and Regulatory Affairs within the Office of Management and Budget. As part of the SBAR process, the Panel met with small entity representatives (SERs) to discuss the potential emission standards and, in addition to the oral comments from SERs, the Panel solicited written input. In the months preceding the Panel process, EPA conducted outreach with small entities from each of the five sectors as described above. On May 18, 2001, the Panel distributed an outreach package to the SERs. On May 30 and 31, 2001, the Panel met with SERs to hear their comments on preliminary alternatives for regulatory flexibility and related information. The Panel also received written comments from the SERs in response to the discussions at this meeting and the outreach materials. The Panel asked SERs to evaluate how they would be affected under a variety of regulatory approaches, and to provide advice and recommendations regarding early ideas for alternatives that would provide flexibility to address their compliance burden.

SERs representing companies in each of the sectors addressed by the Panel raised concerns about the potential costs of complying with the rules under development. For the most part, their concerns were focused on two issues: (1) the difficulty (and added cost) that they would face in complying with certification requirements associated with the standards EPA is developing, and (2) the cost of meeting the standards themselves. SERs observed that these costs would include the opportunity cost of deploying resources for research and development, expenditures for tooling/retooling, and the added cost of new engine designs or other parts that would need to be added to equipment in order to meet EPA emission standards. In addition, in each category, the SERs noted that small manufacturers (and in the case of one category, small importers) have fewer resources and are therefore less well equipped to undertake these new activities and expenditures. Furthermore, because their product lines tend to be smaller, any additional fixed costs must be recovered over a smaller number of units. Thus, absent any provisions to address these issues, new emission standards are likely to impose much more significant adverse effects on small entities than on their larger competitors.

The Panel discussed each of the issues raised in the outreach meetings and in written comments by the SERs. The Panel agreed that EPA should consider the issues raised by the SERs and that it would be appropriate for EPA to propose and/or request comment on various alternative approaches to address these concerns. The Panel’s key discussions centered around the need for and most appropriate types of regulatory compliance alternatives for small businesses. The Panel considered a variety of provisions to reduce the burden of complying with new emission standards and related requirements. Some of these provisions would apply to all companies (e.g., averaging, banking, and trading), while others would be targeted at the unique circumstances faced by small businesses. A complete discussion of the regulatory alternatives recommended by the Panel can be found in the Final Panel Report. Summaries of the Panel’s recommended alternatives for each of the sectors subject to this action can be found in their respective sections of the preamble. The vast majority of the Panel recommendations were adopted by the Agency, and are being finalized as part of this rule, either as first-tier or second-tier flexibilities.

First-tier flexibilities provide the greatest flexibility for many small entities. These provisions are likely to be most valuable because they either provide more time for compliance (e.g., additional lead time and hardship provisions) or allow for certification of engines based on particular engine designs or certification to other EPA programs. We are adopting these provisions essentially as proposed.

Second-tier flexibilities have the potential to reduce near-term and even long-term costs once a small entity has a product it is preparing to certify. These are important in that the costs of testing multiple engine families, testing a fraction of the production line, and developing deterioration factors can be significant. Small businesses may also meet an emission standard on average or generate credits for producing engines that emit at levels below the standard; these credits can then be sold to other manufacturers for compliance or banked for use in future model years. We are adopting these provisions essentially as proposed.

8.6.1 General Provisions

The most universal of the first-tier flexibilities are the hardship provisions. These apply to all the categories of vehicles and engines covered by this rulemaking. The Panel recommended that we propose two types of hardship provisions. The first type allows small businesses to petition EPA for additional lead time (e.g., up to 3 years) to comply with the standards. To qualify, a small manufacturer must make the case that it has taken all possible business, technical, and economic steps to comply, but that the burden of compliance costs will have a significant impact on the company’s solvency. A manufacturer must provide a compliance plan detailing when and how it will achieve compliance with the standards. Hardship relief may include requirements for reducing emission on an interim basis and/or purchasing and using emission credits. The length of the hardship relief decided during review of the hardship application may be up to one year, with the potential to extend the relief as needed. The second hardship program allows companies to apply for hardship relief if circumstances outside their control cause the failure to comply (i.e., supply contract broken by parts supplier) and if the failure to sell the subject engines will have a major impact on the company’s solvency. We would, however, not grant hardship relief if contract problems with a specific company prevent compliance for a second time.

Since equipment manufacturers who don’t manufacture their own engines depend on engine manufacturers to supply certified engines, there was a concern that these engines would not be received in time to produce complying equipment by the date emission standards take effect. We have heard of certified engines being available too late for equipment manufacturers to redesign their equipment for changing engine size or performance characteristics. To address this concern, equipment manufacturers may request up to one extra year before using certified engines if they are not at fault and will face serious economic hardship without an extension.

A second-tier of flexibility, the averaging, banking and trading (ABT) program is also almost universal in its applicability. Averaging programs allow a manufacturer to certify one or more engine families at emission levels above the applicable emission standards, provided that the increased emissions are offset by one or more engine families certified below the applicable standards. Adding an emission-credit program containing banking and trading provisions, allow manufacturers to generate emission credits for certifying below the standards, and bank them for future use in their own averaging program or sell them to another entity.

ABT programs are being finalized for all categories of vehicles and engines covered by this rule, except for Large SI engines. However, a simplified ABT variation, which we are calling “family banking,” will allow Large SI manufactures to certify an engine family early, and then to delay certification of a comparable engine family to the Phase 1 standards. ABT provisions are not limited to small entities, but provide another flexibility for reducing the burden on these entities.

8.6.2 Nonroad recreational vehicles

As described above, the report of the Small Business Advocacy Review Panel addresses the concerns of small-volume manufacturers of recreational vehicles. To identify representatives of small businesses for this process, we used the definitions provided by the Small Business Administration for producers and importers of motorcycles, ATVs, and snowmobiles (fewer than 500 employees for manufacturers, 100 for importers). Eleven small businesses agreed to serve as small-entity representatives. These companies represented a cross-section of off-highway motorcycle, ATV, and snowmobile manufacturers, as well as importers of off-highway motorcycles and ATVs. We proposed to adopt the provisions recommended by the panel and received comments on the proposals. We are now finalizing the provisions below essentially as proposed, with the modifications noted below.

As noted above, permeation standards were not part of the original NPRM for this rule, which incorporated recommendations from the SBAR Panel process. When we reopened the comment period on May 1, 2002 to request comment on possible approaches to regulating permeation emissions from recreational vehicles, we did not specifically discuss small business issues. However, it was our intent that the proposed flexibilities for exhaust emissions should carry over to permeation controls for all three vehicle categories, to the extent that they are applicable, and we are finalizing these flexibilities for the permeation standards as well as for the exhaust standards. Thus, we are effectively extending the work of the SBAR panel to cover the permeation requirements in this final rule by including the flexibilities described below.

The following Panel recommendations apply to nonroad motorcycles, ATVs and snowmobiles. The Panel recommended that EPA restrict the flexibilities described below for off-road motorcycle and ATV engines to those produced or imported by small entities with combined annual sales of less than 5,000 units per model year. Because of the differences, both in numbers and production, between small snowmobile manufacturers and small ATV/off-road motorcycle manufacturers, the Panel recommended no maximum production limits for snowmobiles.

Additional lead time. The Panel recommended that EPA propose at least a two-year delay, but seek comment on whether a longer time period is appropriate given the costs of compliance for small businesses and the relationship between importers and their suppliers. This would provide additional time for small-volume manufacturers to revise their manufacturing process, and would allow importers to change their supply chain to acquire complying products. The Panel recommended that EPA request comment on the appropriate length for a delay (lead-time). We are finalizing a two year delay beyond the date that larger businesses must comply with the standards for the Phase 1, and (in the case of snowmobiles) Phase 2 and Phase 3 standards.

Design-based certification. The Panel recommended that EPA propose to permit small entities to use design certification. The Panel also recommended that EPA work with the small-entity representatives and other members of the industry to develop appropriate criteria for such design-based certification. We are finalizing this recommendation. Small-volume manufacturers may use design-based certification, which allows us to issue a certificate to a small business for the emission-performance standard based on a demonstration that engines or vehicles meet design criteria rather than by emission testing. The intent is to demonstrate that an engine using a design similar to or superior than that being used by larger manufacturers to meet the emission standards will ensure compliance with the standards. The demonstration must be based in part on emission test data from engines of a similar design. Under a design-based certification program, a manufacturer provides evidence in the application for certification that an engine or vehicle meets the applicable standards for its useful life based on its design (e.g., the use a four-stroke engine, advanced fuel injection, or any other particular technology or calibration). Design criteria might include specifications for engine type, calibrations (spark timing, air /fuel ratio, etc.), and other emission-critical features, including, if appropriate, catalysts (size, efficiency, precious metal loading). Manufacturers submit adequate engineering and other information about their individual designs showing that they will meet emission standards for the useful life.

Broaden engine families. The Panel recommended that EPA request comment on engine family flexibility, in addition to conducting design-based certification emissions testing. Under this provision, small businesses may define their engine families more broadly, putting all their models into one engine family (or more, as needed) for certification purposes. Manufacturers could then certify their engines using the “worst-case” configuration within the family. A small manufacturer who might need to conduct certification emission testing, rather than pursuing design-based certification, would likely find broadened engine families useful

Production-line testing (PLT) waiver. The Panel recommended that EPA propose to provide small manufacturers and small importers a waiver from manufacturer production line testing. The Panel also recommended that EPA request comment on whether limits or the scope of this waiver are appropriate. Under PLT, manufacturers must test a small sampling of production engines to ensure that production engines meet emission standards. We are waiving production-line testing requirements for small manufacturers. This waiver will eliminate production-line testing requirements for small businesses.

Use of assigned deterioration factors (DFs) for certification. The Panel recommended that EPA propose to provide small business with the option to use assigned deterioration factors. Small manufacturers may use DFs assigned by EPA. Rather than performing a durability demonstration for each family for certification, manufacturers may elect to use deterioration factors determined by us to demonstrate emission levels at the end of the useful life, thus reducing the development and testing burden. This might also be a very useful and cost-beneficial option for a small manufacturer opting to perform certification emission testing instead of design-based certification.

Using emission standards and certification from other EPA programs. A wide array of engines certified to other EPA programs may be used in recreational vehicles. For example, there is a large variety of engines certified to EPA lawn and garden standards (Small SI). The Panel recommended that EPA propose to provide small business with this flexibility through the fifth year of the program and request comment on which of the already established standards and programs are believed to be a useful certification option for the small businesses. We are accepting that recommendation. Manufacturers of recreational vehicles may use engines certified to any other EPA standards for five years. Under this approach, engines certified to the Small SI standards may be used in recreational vehicles, even though the recreational vehicle application may not be the primary intended application for the engine. These engines would then meet the Small SI standards and related provisions rather than those adopted in this document for recreational vehicles. Small businesses using these engines will not have to recertify them, as long as they do not alter the engines in a way that might cause it to exceed the emission standards it was originally certified to meet. Naturally, a small manufacturer may also use a comparable certified engine produced by a large manufacturer, as long as the small manufacturer did not change the engine in a way that might cause it to exceed the applicable emission standards. This provides a reasonable degree of emission control. For example, if a manufacturer changed a certified engine only by replacing the stock exhaust pipes with pipes of similar configuration or the stock muffler and air intake box with a muffler and air box of similar air flow, the engine would still be eligible for this flexibility option, subject to our review.

Averaging, banking, and trading (ABT). The Panel recommended that EPA propose to provide small business with the same ABT program flexibilities that would apply for large manufacturers and request comment on how the provisions could be enhanced for small business to make them more useful. For the overall program, we are adopting corporate-average emission standards with opportunities for banking and trading of emission credits. At first we expect the averaging provisions to be most helpful to manufacturers with broad product lines. Small manufacturers and small importers with only a few models might not have as much opportunity to take advantage of these flexibilities. However, we received comment from one small manufacturer supporting these types of provisions as a critical component of the program. Therefore, we are adopting corporate-average emission standards with opportunities for banking and trading of emission credits for small manufacturers.

8.6.2.1 Off-highway motorcycles and ATVs

In addition to ABT, EPA is finalizing other provisions that are not limited to small entities, but which could prove helpful to small businesses. Small entities could benefit from harmonization of the ATV standards with California emission standards since only one model, rather than two, would need to be certified to allow the product to be sold in all 50 states. Similarly, the 2 gram and the optional 4 gram HC +NOx emission standards for off-highway motorcycles could make it less costly for small entities to comply with the standards, in addition to their primary purposes of preventing product shortages and encouraging certification of competition bikes. The optional 4 gram HC + NOx standard in fact was suggested in the comments submitted by a small manufacturer. Finally, small ATV producers could benefit from the option of complying with engine-based emission standards using the SAE J1088 test procedure for three years. This flexibility could allow small entities to phase in major equipment purchases such as chassis dynamometers necessary to be able to run the Federal Test Procedure.

As stated earlier, we are applying the flexibilities outlined above in section 8.6.2 to engines produced or imported by small entities with combined off-highway motorcycle and ATV annual sales of fewer than 5,000 units. The SBAR Panel recommended these provisions to address the potentially significant adverse effects on small entities of an emission standard that may require conversion to four-stroke engines. The 5,000-unit threshold is intended to provide these flexibilities to those segments of the market where the need is likely to be greatest, and to ensure that the flexibilities do not result in significant adverse environmental effects during the period of additional lead-time recommended below. For example, some importers with access to large supplies of vehicles from major overseas manufacturers could substantially increase their market share by selling less expensive noncomplying products. In addition, we are limiting some or all of these flexibilities to companies that are in existence or have product sales at the time we proposed emission standards to avoid creating arbitrary opportunities in the import sector, and to guard against the possibility of corporate reorganization, entry into the market, or other action for the sole purpose of circumventing emission standards.

8.6.2.2 Snowmobiles

As in the case of off-highway motorcycles and ATVs, small snowmobile manufacturers may benefit from provisions set for both large and small manufacturers. Small entities could benefit from the pull ahead standards provision, whereby a manufacturer could certify to the Phase 2 standards and bypass the Phase 1 standards. There are special snowmobile ABT provisions that could also be helpful to small entities. The early credit provision, where manufacturers could generate credits by marketing clean snowmobiles earlier than 2006, and the elimination of FEL limits for Phase 1 are the prime examples. However, Even with these and the broad flexibilities for all recreational vehicles described above in section 8.6.2, there may be a situation where a small snowmobile manufacturer cannot comply. There are only a few small snowmobile manufacturers, who sell only a few hundred sleds a year, which represents less than 0.5 percent of total annual production. Therefore, the per-unit cost of regulation may be significantly higher for these small entities because they produce very low volumes. Additionally, these companies do not have the design and engineering resources to tackle compliance with emission standard requirements at the same time as large manufacturers and tend to have limited ability to invest the capital necessary to conduct emission testing related to research, development, and certification. Finally, some of the requirements of the snowmobile program may be infeasible or highly impractical because some small-volume manufacturers may have typically produced engines with unique designs or calibrations to serve niche markets (such as mountain riding). The new snowmobile emission standards may thus impose significant economic hardship on these few manufacturers whose market presence is small. We therefore believe significant additional flexibility for these small snowmobile manufacturers is necessary and appropriate, as described below.

Additional lead time. The Panel recommended that EPA propose to delay the standards for small snowmobile manufacturers by two years from the date when other manufacturers would be required to comply. The Panel also recommended that EPA propose that emission standards for small snowmobile manufacturers be phased in over an additional two years (four years to fully implement the standard). We are adopting these recommendations. The two-year delay noted above in the general provisions in section 8.6.1 also applies to the timing of the standards for snowmobiles. In addition, for small snowmobile manufacturers, the emission standards phase in over an additional two years at a rate of 50 percent, then 100 percent. Phase 1 thus phases in at 50/100 percent in 2008/2009, Phase 2 phases in at 50/100 percent in 2012/2013, and Phase 3 phases in at 50/100 percent in 2014/2015.

Unique snowmobile engines. The Panel recommended that EPA seek comment on an additional provision, which would allow a small snowmobile manufacturer to petition EPA for relaxed standards for one or more engine families. The Panel also recommended that EPA allow a provision for EPA to set an alternative standard at a level between the prescribed standard and the baseline level until the engine family is retired or modified in such a way as to increase emission and for the provision to be extended for up to 300 engines per year per manufacturer would assure it is sufficiently available for those manufacturers for whom the need is greatest. Finally, the Panel recommended that EPA seek comment on initial and deadline dates for the submission of such petitions. We received no comments in this area, but for clarity have decided to require at least nine months lead time by the petitioner.

In response to these recommendations and comments, we are adopting an additional provision to allow a small snowmobile manufacturer to petition us for relaxed standards for one or more engine families. The manufacturer must justify that the engine has unique design characteristics, calibration, or operating characteristics that make it atypical and infeasible or highly impractical to meet the emission-reduction requirements, considering technology, cost, and other factors. At our discretion, we may then set an alternative standard at a level between the prescribed standard and the baseline level, which would likely apply until the family is retired or modified in a way that might alter emissions. These engines will be excluded from averaging calculations. We proposed that this provision be limited to 300 snowmobiles per year. However, we received comment that this limit is too restrictive to be of much assistance to small businesses. Based on this comment we are adopting a limit for this provision of 600 snowmobiles per year.

8.6.3 Nonroad industrial engines

As is the case for nonroad recreational vehicles, some of the provisions not specifically targeted at small entities may ease the burden of compliance for them. For example, comments from equipment manufacturers, including small entities, have made it clear that some nonroad applications involve operation in severe environments that require the use of air-cooled engines, which rely substantially on enrichment to provide additional cooling relative to water-cooled engines. Severe-duty applications include concrete saws and concrete pumps, which are exposed to high levels of concrete dust and highly abrasive particles. At the richer air-fuel ratios, catalysts are able to reduce NOx emissions but oxidation of CO emissions is much less effective. As a result, we are adopting less stringent emission standards for these “severe-duty” engines. Manufacturers may request approval in identifying additional severe-duty applications subject to these less stringent standards based on the current use of air-cooled engines or some other engineering arguments showing that air-cooled engines are necessary for these applications. This arrangement generally prevents these higher-emitting engines from gaining a competitive advantage in markets that don’t already use air-cooled engines.

The SBAR Panel recommended that EPA propose several possible provisions to address concerns that the new EPA standards could potentially place small businesses at a competitive disadvantage to larger entities in the industry. Except as noted, we have adopted the specific Panel recommendations listed below.

Using Certification and Emissions Standards from Other EPA Programs. The Panel made several recommendations for this provision. First, the Panel recommended that EPA temporarily expand this arrangement to allow small numbers of constant-speed engines up to 2.5 liters (up to 30kW) to be certified to the Small SI standards. Second, the Panel further recommended that EPA seek comment on the appropriateness of limiting the sales level of 300. Third, the Panel recommended that EPA request comment on the anticipated cap of 30 kW on the special treatment provisions outlined above, or whether a higher cap on power rating is appropriate. Finally, the Panel recommended that EPA propose to allow small-volume manufacturers producing engines up to 30kW to certify to the small SI standards during the first 3 model years of the program. Thereafter, the standards and test procedures which could apply to other companies at the start of the program would apply to small businesses. We are not adopting this provision and are instead relying on the hardship provisions in the final rule, which will allow us to accomplish the objective of the proposed provision with more flexibility.

Delay of Emission Standards. The Panel recommended that EPA propose to delay the applicability of the long-term standards to small-volume manufacturers for three years beyond the date at which they would generally apply to accommodate the possibility that small companies need to undertake further design work to adequately optimize their designs and to allow them to recover the costs associated with the near-term emission standards. We are also folding this provision into the scope of the hardship provision, but believe it would be appropriate to allow up to four years delay, depending on need.

Production Line Testing. The Panel made several recommendations for this provision. First, the Panel recommended that EPA adopt provisions allowing more flexibility than is available under the California Large SI program or other EPA programs generally to address the concern that production-line testing is another area where small-volume manufacturers typically face a difficult testing burden. Second, the Panel recommended that EPA allow small-volume manufacturers to have a reduced testing rate if they have consistently good test results from testing production-line engines. Finally, the Panel recommended that EPA allow small-volume manufacturers to use alternative low-cost testing options to show that production-line engines meet emission standards.

Deterioration Factors. The Panel recommended that EPA allow small-volume manufacturers to develop a deterioration factor based on available emission measurements and good engineering judgement. We are adopting an approach that gives manufacturers wide discretion to establish deterioration factors for Large SI engines. The general expectation is that manufacturers will rely on emission measurements from engines have operated for an extended period, either in field service or in the laboratory. The manufacturer should do testing as needed to be confident that their engines will meet emission standards under the in-use testing program. However, we intend to rely on manufacturers' technical judgment and related data (instead of results from in-use testing) to appropriately estimate deterioration factors to protect themselves from the risk of noncompliance.

Hardship Provision. The Panel recommended that EPA propose two types of hardship provisions for Large SI engines. First the Panel recommended that EPA allow small businesses to petition EPA for additional lead time (e.g., up to 3 years) to comply with the standards. Second, the Panel recommended that EPA allow small businesses to apply for hardship relief if circumstances outside their control cause the failure to comply (i.e., supply contract broken by parts supplier) and if the failure to sell the subject engines would have a major impact on the company's solvency. We are adopting hardship provisions to address the particular concerns of small-volume manufacturers, which generally have limited capital and engineering resources. These hardship provisions are generally described in Section 8.6.1. For Large SI engines, we are adopting a longer available extension of the deadline, up to three years, for meeting emission standards for companies that qualify for special treatment under the hardship provisions. We will, however, not extend the deadline for compliance beyond the three-year period. This approach considers the fact that, unlike most other engine categories, qualifying small businesses are more likely to be manufacturers designing their own products. Other types of engines more often involve importers, which are limited more by available engine suppliers than design or development schedules.

8.6.4 Recreational marine diesel engines

Prior to the proposal, we conducted a Small Business Advocacy Review Panel. The panel process gathers input from small entities potentially affected by the new regulations. To identify small businesses representatives for this process, we used the Small Business Administration definitions for engine manufacturers and boat builders. We then contacted companies manufacturing internal-combustion engines employing fewer than 1,000 people to be small-entity representatives for the Panel. Companies selling or installing such engines in boats and employing fewer than 500 people were also considered small businesses for the Panel. Based on this information, we asked 16 small businesses to serve as small-entity representatives. These companies represented a cross-section of both gasoline and diesel engine marinizers, as well as boat builders. With input from small-entity representatives, the Panel drafted a report with findings and recommendations on how to reduce the potential small-business burden resulting from this rule. The Panel’s recommendation’s were proposed by EPA and are now being finalized essentially as proposed. Commenters generally supported these provisions. The following sections describe these flexibilities.

8.6.4.1 Engine Dressers

The manufacturers involved include engine dressers, small-volume engine marinizers, and small-volume boat builders. Many recreational marine diesel engine manufacturers modify new, land-based engines for installation on a marine vessel. Some of the companies that modify engines for installation in boats make no changes that might affect emissions. Their modifications may consist only of adding mounting hardware and a generator or reduction gears for propulsion. They may involve installing a new marine cooling system that meets original manufacturer specifications and duplicates the cooling characteristics of the land-based engine, but with a different cooling medium (i.e., sea water). In many ways, these manufacturers are similar to nonroad equipment manufacturers who purchase certified land-based nonroad engines to make auxiliary engines. This simplified approach of producing an engine can more accurately be described as dressing an engine for a particular application.

To clarify the responsibilities of engine dressers under this rule, we will exempt them from the requirement to certify engines to emission standards, as long as they meet the following seven conditions.

> (1) The engine being dressed (the "base" engine) must be a highway, land-based nonroad, or locomotive engine, certified pursuant to 40 CFR part 86, 40 CFR part 89, or 40 CFR part 92, respectively, or a marine diesel engine certified pursuant to this part.
>
> (2) The base engine's emissions, for all pollutants, must meet the otherwise applicable recreational marine emission limits. In other words, starting in 2005, a dressed nonroad Tier 1 engine will not qualify for this exemption, because the more stringent standards for recreational marine diesel engines go into effect at that time.
>
> (3) The dressing process must not involve any modifications that can change engine emissions. We do not consider changes to the fuel system to be engine dressing, because this equipment is integral to the combustion characteristics of an engine. However, we are expanding the small-volume engine dresser definition to include water-cooled turbochargers where the goal is to match the performance of the non-water-cooled turbocharger on the original certified configuration. We believe this would provide more opportunities for diesel marinizers to be excluded from certification testing if they operate as dressers
>
> (4) All components added to the engine, including cooling systems, must comply with the specifications provided by the engine manufacturer.
>
> (5) The original emissions-related label must remain clearly visible on the engine.
>
> (6) The engine dresser must notify purchasers that the marine engine is a dressed highway, nonroad, or locomotive engine and is exempt from the requirements of 40 CFR part 94.
>
> (7) The engine dresser must report annually to us the models that are exempt pursuant to this provision and such other information as we deem necessary to ensure appropriate use of the exemption.

Any engine dresser not meeting all these conditions will be considered an engine manufacturer and will accordingly need to certify that new engines comply with this rule's provisions and label the engine, showing that it is available for use as a marine engine. An engine dresser violating the above criteria might also be liable under anti-tampering provisions for any change made to the land-based engine that affects emissions.

8.6.4.2 Small Diesel Engine Marinizers

The other small entities can be categorized as sterndrive and inboard engine marinizers, compression-ignition recreational marine engine marinizers, and boat builders that use these engines. We are providing additional flexibilities listed below for small-volume engine marinizers. The purpose of these flexibilities is to reduce the burden on companies who cannot distribute their fixed costs over a large number of engines. For this reason, we are defining a small-volume engine manufacturer based on annual U.S. sales of engines, and are providing the additional flexibilities on this basis, rather than on business size in terms of the number of employees, revenue, or other such measures. The production count we will use includes all engines (automotive, other nonroad, etc.), not just recreational marine engines. We consider recreational marine diesel engine manufacturers to be small volume for purposes of this provision if they produce fewer than 1,000 internal combustion engines per year. Based on our characterization of the industry, there is a natural break in production volumes just above the 500 engine sales mark. The next smallest manufacturers make tens of thousands of engines. We chose 1,000 engines as a limit because it groups together all the marinizers most needing relief, while still allowing for reasonable sales growth.

<ins>Delay Standards for Five Years.</ins> The Panel recommended that EPA delay the standards for five years for small businesses. We are concerned about the loss of emission control from part of the fleet during this time, but we recognize the special needs of small-volume marinizers and believe the added time may be necessary for these companies to comply with emission standards. This additional time will allow small-volume marinizers to obtain and implement proven, cost-effective emission-control technology. We are adopting the five-year delay; the standards will take effect from 2011 to 2014 for small-volume marinizers, depending on engine size. Marinizers may apply this five-year delay to all or just a portion of their production. Thus they may still sell engines that meet the standards where possible on some product lines, while delaying the introduction of emission-control technology on other product lines. This option provides more time for small marinizers to redesign their products, allowing time to learn from the technology development of the rest of the industry.

<ins>Design-Based Certification</ins> The Panel recommended that EPA allow manufacturers to certify by design and to be able to generate credits under this approach. The Panel also recommended that EPA provide adequately detailed design specifications and associated emission levels for several technology options that could be used to certify. Although we proposed this approach, we were unable to specify any technology options for diesel engines that could be used for a design-based certification. We requested comment on such designs and received no comment. Therefore, we are not finalizing a design-based certification option. However, as noted above, we are finalizing the engine dresser provisions and expanding these provisions to include water-cooled turbocharging. This will essentially allow some engines to be exempt from the standards based on design.

Broadly Defined Product Certification Families The Panel recommended that EPA take comment on the need for broadly defined emission families and how these families should be defined. We have established engine criteria for distinguishing between engine families which could result in a number of engine families for a manufacturer depending on the make-up of their product line.   We are allowing small-volume marinizers to put all of their models into one engine family (or more as necessary) for certification purposes. Marinizers would then certify using the "worst-case" configuration. This approach is consistent with the option offered to post-manufacture marinizers under the commercial marine regulations. This approach has the advantage of minimizing certification testing, because the marinizer can use a single engine in the first year to certify their whole product line. As with large companies, the small-volume manufacturers could then carry-over certification data from year to year until they change their engine designs in a way that might significantly affect emissions.

Minimize compliance requirements. The Panel suggested we eliminate the compliance burden on small entities to the extent possible. As a result, we proposed to eliminate production-line and deterioration testing requirements for small-volume marinizers. We will assign a deterioration factor for use in calculating end-of-life emission factors for certification. The advantage of this approach is to minimize compliance testing.

Streamlined certification. The Panel recommended that EPA propose to specifically include NTE in a design-based approach. As noted above, we have concerns regarding a design-based approach. However, we will allow small-volume marinizers to certify to the not-to-exceed (NTE) requirements using a streamlined approach. We believe small-volume marinizers can make a satisfactory showing that they meet NTE standards with limited test data. Once these manufacturers test engines over the five-mode certification duty cycle (E5), they can use those or other test points to extrapolate the results to the rest of the NTE zone. For example, an engineering analysis may consider engine timing and fueling rate to determine how much the engine's emissions may change at points not included in the E5 cycle. For this streamlined NTE approach, keeping all four test modes of the E5 cycle within the NTE standards will be enough for small-volume marinizers to certify compliance with NTE requirements, as long as there are no significant changes in timing or fueling rate between modes.

Hardship provisions. The Panel recommended that EPA propose two types of hardship programs for marine engine manufacturers, boat builders and fuel tank manufacturers. First, that EPA should allow small businesses to petition EPA for additional lead time to comply with the standards. Second, that EPA should allow small businesses to apply for hardship relief if circumstances outside their control cause the failure to comply (i.e. supply contract broken by parts supplier) and if the failure to sell the subject fuel tanks or boats would have a major impact on the company's solvency. The Panel also recommended that EPA work with small manufacturers to develop these criteria and how they would be used.

We are adopting two hardship provisions for small-volume marinizers, who may apply for this relief on an annual basis. These are essentially the same provisions noted in section 8.6.1. First, small marinizers may petition us for additional time to comply with the standards. The marinizer must show that it has taken all possible steps to comply but the burden of compliance costs will have a major impact on the company's solvency. Also, if a certified base engine is available, the marinizer must generally use this engine. We believe this provision will protect small-volume marinizers from undue hardship due to certification burden. Also, some emission reduction can be gained if a certified base engine becomes available.

Second, small-volume marinizers may also apply for hardship relief if circumstances outside their control caused the failure to comply (such as a supply contract broken by parts supplier) and if failure to sell the subject engines will have a major impact on the company's solvency. We consider this relief mechanism to be an option of last resort. We believe this provision will protect small-volume marinizers from circumstances outside their control. We, however, intend to not grant hardship relief if contract problems with a specific company prevent compliance for a second time.

Although the panel did not specify a time limit for these hardship provisions, and we are not finalizing any such time limits, we envision these hardship provisions as transitional in nature. We would expect their use to be limited to the early years of the program, in a similar time frame as we are establishing for the recreational vehicle hardship provisions discussed above.

8.6.4.3 Small Recreational Boat Builders

The SBAR Panel Report also recommended approaches for reducing the burden on small-volume boat builders. The recommendations were based on the concerns that even though boat builders are not required to certify their own engines to the emission standards, they are required to use certified engines, and may need to redesign engine compartments on some boats if engine designs were to change significantly. EPA proposed the flexibilities recommended by the Panel and are finalizing them as proposed.

We are adopting four options for small-volume vessel manufacturers using recreational marine diesel engines. These options are intended to reduce the compliance burden on small companies which are not able to distribute their fixed costs over a large number of vessels. As proposed, we are therefore defining a small-volume boat builder as one that produces fewer than 100 boats for sale in the U.S. in one year and has fewer than 500 employees. The production count includes all engine-powered recreational boats. These options may be used at the manufacturer's discretion. The options for small-volume boat builders are discussed below.

<u>Percent-of-production delay.</u> Manufacturers with a written request from a small-volume boat builder and prior approval from us may produce a limited number of uncertified recreational marine diesel engines. From 2006 through 2010, small-volume boat builders may purchase uncertified engines to sell in boats in an amount equal to 80 percent of engine sales for one year.

For example, if the small boat builder sells 100 engines per year, a total of 80 uncertified engines may be sold over the five-year period. This will give small boat builders an option to delay using new engine designs for a portion of business. Engines produced under this flexibility must be labeled accordingly so that customs inspectors know which uncertified engines can be imported. We continue to believe this approach is appropriate and are finalizing it as proposed.

Small-volume allowance. This allowance is similar to the percent-of-production allowance, but is designed for boat builders with very small production volumes. The only difference with the above allowance is that the 80-percent allowance described above may be exceeded, as long as sales do not exceed either 10 engines per year or 20 engines over five years (2006 to 2010). This applies only to engines less than or equal to 2.5 liters per cylinder.

Existing inventory and replacement engine allowance. Small-volume boat builders may sell their existing inventory after the implementation date of the new standards. However, no purposeful stockpiling of uncertified engines is permitted. This provision is intended to allow small boat builders the ability to turn over engine designs.

Hardship relief provision. Small boat builders may apply for hardship relief if circumstances outside their control caused the problem (for example, if a supply contract were broken by the engine supplier) and if failure to sell the subject vessels will have a major impact on the company’s solvency. This relief allows the boat builder to use an uncertified engine and is considered a mechanism of last resort. These hardship provisions are consistent with those currently in place for post-manufacture marinizers of commercial marine diesel engines.

8.7 Conclusion

EPA has conducted a substantial outreach program designed to gather information as to the effect of this final rule on small entities. This process has included two Small Business Advocacy Review Panels, which sought out small entities that would be affected by the rulemaking and obtained advice and recommendations from them as to ways in which to minimize the compliance burden placed upon them. We have also published an Advance Notice of Proposed Rulemaking and a Notice of Proposed Rulemaking which requested comments from the affected entities as well as from other interested parties in the public at large. Further, we have reopened the comment period to take comments on the permeation issue raised during the initial comment period, and have included permeation in the analysis of the effects of this rule on small entities. We have met with a number of stakeholders, including state and environmental organizations, engine manufacturers, and equipment manufacturers. From the information we have gathered during this process, as well as information provided by contractor studies, we have found that only 3 small entities are likely to be impacted by more than 3 percent of their sales, and estimate that the degree of impact is likely to be further reduced by the flexibilities that are being finalized in this rulemaking. EPA has thus determined that this final rule will not have a significant economic impact on a substantial number of small entities.

Chapter 9: Economic Impact Analysis

This chapter presents the economic impacts on the markets of the various vehicle categories affected by the emissions control program. Each category of vehicles is modeled separately. However the structure of the economic model used to estimate impacts is essentially the same. The first section of this chapter provides a summary of the economic impact results for each of the categories of vehicles affected by the rule. Next, we provide a general description of the economic theory used to estimate market impacts. We then discuss the concept of fuel efficiency gains resulting from the emissions control program and how they have been incorporated into the economic analysis. Also addressed is the potential for product attribute changes that may result due to the regulation. This is followed by a description of the methodology used to develop the economic model and the supply and demand elasticity estimates.

The remainder of the chapter takes each vehicle category in turn and describes the baseline market characterization, the per vehicle control costs of the regulation, the future years in which the costs are expected to be incurred, and the economic impact results generated from the model (excluding fuel efficiency gains). We compare the future year streams of engineering costs to the estimated economic welfare losses for each vehicle category for which the standards apply. Economic welfare loss is equal to the sum of the loss in consumer and producer surplus measures, excluding fuel efficiency gains. Last, we calculate a future year stream of social costs/gains by adding fuel cost savings to economic welfare losses and compare this stream to the stream of engineering costs of the rule (including fuel efficiency gains).

For each vehicle market, the economic model relies upon the most current year of data available (either the year 2000 or 2001) and examines the effect of the emissions control program as if the standards took effect in this year. The per engine control costs change over time as different phases of the standard are implemented and the learning curve is applied (see Chapter 5 for details concerning the learning curve). It is important to note that the per engine control costs reflect the variable cost and annual portion of capital cost associated with the regulations. To examine the effect of these cost changes, we calculate estimated impacts using baseline year price and output. This allows us to generate relative changes in prices and market quantities and compute losses in consumer and producer surplus. Price and quantity data from a baseline year are used rather than future year projections of prices and quantities because price projections for the future time stream are not available for the various vehicle markets, though quantity projections are.

As stated above, a future stream of welfare (or surplus) losses (excluding fuel cost savings) is calculated by summing of the losses of consumer and producer surplus. This stream of surplus losses, developed from baseline year price and quantity data, is compared to a hypothetical future stream of engineering costs that are calculated by multiplying the annual regulatory cost per vehicle in each year by the baseline year quantity. We calculate hypothetical engineering costs holding quantity constant so that we can make a valid comparison between the loss in surplus and engineering costs. The purpose of this comparison is to generate a surplus loss stream that accounts for projected changes in quantity.

Through our comparison, we develop an annual ratio of surplus loss to engineering costs, which is used to project the annual loss in surplus without fuel efficiency for the future year time stream (this projection is made by multiplying the annual ratio of surplus loss to engineering costs by the annual engineering costs shown in Chapter 7 for each vehicle category). The future stream of surplus losses differs from baseline estimates due to the projected growth in vehicle sales expected through the year 2030. Last, we calculate the future stream of annual social costs/gains by adding fuel cost savings to the projected loss in surplus and compare this stream of social costs/gains to the engineering costs accounting for fuel efficiency.

9.1 Summary of Economic Impact Results

An economic impact analysis of the emissions control program has been carried out to estimate its effects on the recreational diesel marine vessel, Large SI, snowmobile, ATV, and off-highway motorcycle markets. A summary of the economic impact results is presented in this section to show the relative changes in price and quantity and the future year streams of consumer and producer surplus losses (which exclude fuel cost savings), engineering costs, and social costs/gains (which include fuel cost savings) in each vehicle market. The net present value of the stream of surplus loss, fuel savings, and social costs/gains for each vehicle category is also presented. Discussions of the economic theory, methodology, and full estimation of the economic impacts are presented in the sections that follow. The results presented here for each vehicle category summarizes the full results provided in Section 9.6 through 9.10.

As mentioned above, the relative changes in price and quantity have been estimated for each vehicle category using the per vehicle costs as they change over future years. We calculate these economic impacts assuming baseline market price and quantity is the same as it was in the most current year for which data were available (year 2000 or 2001, depending on the vehicle category).

9.1.1 Summary Results for Marine

The focus of the diesel recreational marine vessel analysis is the market for diesel inboard cruisers. Based on discussions with industry representatives, inboard cruisers are the main type of recreational marine vessel equipped with diesel engines. Using a year 2001 baseline average market price of $341,945 (taken from data provided by the National Marine Manufacturers Association) and market quantity of 8,435 inboard cruisers (taken from EPA projections based on data from the National Marine Manufacturers Association), the future year stream of economic impacts were estimated for the changes in per marine vessel costs. These results are presented in Table 9.1-1.

As the table shows, the price and quantity changes are all less than one-quarter of a percent and by the year 2012, the relative price increase and quantity decrease are less than one-tenth of a percent. These impacts are considered minimal. Projected surplus losses are equal to over 99 percent of engineering costs for the diesel inboard cruiser market. The surplus losses are highest in the year 2010 (approximately $9.6 million), which coincides with the implementation of the second phase of the emissions control program for two of the three engine power classes affected by the rule. They fall to their lowest level (approximately $4.9 million) in the year 2014. They then steadily increase up through the year 2030. This trend of increased surplus losses occurs because a larger population of engines are projected further out into the future, hence a larger number of engines need to be controlled. Note that beyond the year 2010, loss in surplus of the rule for recreational diesel marine vessels are in the $5 to $7 million range. For the recreational diesel marine engine market, no fuel cost savings are projected. Therefore, the annual stream of surplus losses equals the social costs of the regulation for this vehicle category.

Table 9.1-1
Summary Economic Impact Results for the Diesel Inboard Cruiser Market

Year	Cost/unit ($)	Change in Price (%)*	Change in Quantity (%)*	Surplus Losses ($$10^3$)**	Engineering Costs ($$10^3$)	Social Costs ($$10^3$)***
2006	$808	0.12%	-0.18%	$7,795.3	$7,806.0	$7,795.3
2007	$844	0.13%	-0.19%	$8,350.3	$8,365.3	$8,350.3
2008	$844	0.13%	-0.19%	$8,558.2	$8,573.8	$8,558.2
2009	$905	0.14%	-0.20%	$9,398.8	$9,413.5	$9,398.8
2010	$905	0.14%	-0.20%	$9,621.7	$9,637.0	$9,621.7
2011	$478	0.07%	-0.10%	$5,203.9	$5,213.4	$5,203.9
2012	$464	0.07%	-0.10%	$5,165.6	$5,176.7	$5,165.6
2013	$464	0.07%	-0.10%	$5,279.4	$5,290.8	$5,279.4
2014	$426	0.06%	-0.09%	$4,952.0	$4,958.1	$4,952.0
2015	$426	0.06%	-0.09%	$5,056.6	$5,062.7	$5,056.6
2016	$426	0.06%	-0.09%	$5,161.4	$5,167.7	$5,161.4
2017	$426	0.06%	-0.09%	$5,266.2	$5,272.7	$5,266.2
2018	$426	0.06%	-0.09%	$5,371.2	$5,377.6	$5,371.2
2019	$426	0.06%	-0.09%	$5,476.0	$5,482.6	$5,476.0
2020	$426	0.06%	-0.09%	$5,580.8	$5,587.6	$5,580.8
2021	$426	0.06%	-0.09%	$5,685.5	$5,692.5	$5,685.5
2022	$426	0.06%	-0.09%	$5,790.3	$5,797.5	$5,790.3
2023	$426	0.06%	-0.09%	$5,895.3	$5,902.5	$5,895.3
2024	$426	0.06%	-0.09%	$6,000.1	$6,007.4	$6,000.1
2025	$426	0.06%	-0.09%	$6,104.9	$6,112.4	$6,104.9
2026	$426	0.06%	-0.09%	$6,209.7	$6,217.2	$6,209.7
2027	$426	0.06%	-0.09%	$6,314.3	$6,322.0	$6,314.3
2028	$426	0.06%	-0.09%	$6,419.0	$6,426.9	$6,419.0
2029	$426	0.06%	-0.09%	$6,523.6	$6,531.7	$6,523.6
2030	$426	0.06%	-0.09%	$6,628.4	$6,636.5	$6,628.4

*Percent change in price and quantity are based upon baseline market conditions for 2001

** Surplus Loss is equal to the sum of the loss in consumer surplus and producer surplus. This estimate reflects projected growth in vehicles occurring subsequent to the baseline year of 2001.

***Social Costs are equal to the surplus losses net fuel cost savings. For this vehicle category, there are no fuel cost savings; the future stream of surplus losses is therefore equal to the future stream of social costs. Cost estimates are based on 2001 dollars.

9.1.2 Summary Results for Large SI

As explained in Section 9.7, we performed an economic impact analysis for only the forklift segment of the Large SI market. A summary of the estimated changes in price and quantity, and the sum of consumer and producer surplus losses for forklifts is contained in Table 9.1-2. To estimate the total social costs/gains for Large SI, we use the engineering costs to approximate the sum of consumer and producer surplus losses for Large SI engines other than forklifts. This approach slightly overestimates the surplus losses for the category since engineering costs are higher than surplus losses.

The baseline year for the economic analysis of the forklift market is 2000. In this year, the forklift price is taken to be $26,380 (the price of a representative Class 5 forklift equipped with a Large SI engine) and the market output is equal to 65,000 forklifts (taken from the Power Systems Research (PSR) database). Based on these data, the relative changes in market price and output are calculated, as are the annual future year streams of surplus losses, engineering costs, and social costs/gains. Results are presented in Table 9.1-2.

Table 9.1-2
Summary Economic Impact Results for the Forklift Market

Year	Cost/unit ($)	Change in Price (%)*	Change in Quantity (%)*	Surplus Losses ($$10^3$)**	Engineering Costs ($$10^3$)	Social Costs/Gains ($$10^3$)***
2004	$610	0.75%	-1.12%	$43,823.1	$44,403.4	$6,724.8
2005	$610	0.75%	-1.12%	$44,996.9	$45,592.7	($29,708.1)
2006	$493	0.60%	-0.90%	$37,410.6	$37,816.0	($75,354.6)
2007	$537	0.66%	-0.98%	$41,745.3	$42,246.7	($108,221.4)
2008	$537	0.66%	-0.98%	$42,780.3	$43,294.1	($143,423.9)
2009	$418	0.51%	-0.77%	$34,194.5	$34,471.7	($187,187.5)
2010	$418	0.51%	-0.77%	$35,002.2	$35,286.0	($220,411.8)
2011	$418	0.51%	-0.77%	$35,809.9	$36,100.3	($248,987.1)
2012	$390	0.48%	-0.72%	$34,185.7	$34,447,5	($263,690.9)
2013	$390	0.48%	-0.72%	$34,939.8	$35,207.4	($273,632.9)
2014	$390	0.48%	-0.72%	$34,693.9	$35,967.3	($282,531.5)
2015	$390	0.48%	-0.72%	$36,448.0	$36,727.2	($290,434.8)
2016	$390	0.48%	-0.72%	$37,202.1	$37,487.0	($297,344.7)
2017	$390	0.48%	-0.72%	$37,956.2	$38,246.9	($303,835.7)
2018	$390	0.48%	-0.72%	$38,710.3	$39,006.8	($309,915.5)
2019	$390	0.48%	-0.72%	$39,464.3	$39,766.6	($315,594.1)
2020	$390	0.48%	-0.72%	$40,218.4	$40,526.5	($320,692.6)
2021	$390	0.48%	-0.72%	$40,972.5	$41,286.4	($325,792.0)

2022	$390	0.48%	-0.72%	$41,726.6	$42,046.3	($330,892.1)
2023	$390	0.48%	-0.72%	$42,480.7	$42,806.1	($336,421.4)
2024	$390	0.48%	-0.72%	$43,234.8	$43,566.0	($342,011.8)
2025	$390	0.48%	-0.72%	$43,988.9	$44,325.9	($347,604.0)
2026	$390	0.48%	-0.72%	$44,743.0	$45,085.7	($352,536.0)
2027	$390	0.48%	-0.72%	$45,497.1	$45,845.6	($357,472.3)
2028	$390	0.48%	-0.72%	$46,251.2	$46,605.5	($362,412.8)
2029	$390	0.48%	-0.72%	$47,005.3	$47,365.4	($367,356.6)
2030	$390	0.48%	-0.72%	$47,759.4	$48,125.2	($372,304.0)

*Percent change in price and quantity are based upon baseline market conditions for 2000
** Surplus Loss is equal to the sum of the loss in consumer surplus and producer surplus. This estimate reflects projected growth in vehicles occurring subsequent to the baseline year of 2000.
***Social Costs/Gains are equal to the surplus losses net fuel cost savings. ( ) represents a negative cost (social gain). Cost estimates are based upon 2000$.

The relative changes in price and quantity are slightly larger than they were for the inboard diesel cruiser market, but they are still considered minimal. The price and quantity changes resulting from the per forklift costs are less than 1 percent, with the exception of the quantity change during the two years of the rule’s implementation. By the year 2014, the relative increase in market price is estimated to equal about one-half of one percent and the reduction in quantity is equal to approximately three-quarters of one percent. As the table shows, the annual surplus losses are approximately equal to 98 to 99 percent of engineering costs. Over the future year time stream presented, surplus losses range from a low of $34.2 million in 2009 to a high of $47.8 million in 2030.

An examination of the social costs/gains shows that the gains continually increase in the future. This growth in social gains arises from the increasing fuel savings over time. The initial growth in fuel savings can be attributed to the gradual turnover to new forklifts in the marketplace. After this turnover, the growth in fuel savings can be credited to an increase in the sales of forklifts. With a larger population of forklifts projected, the fuel savings are expected to be larger. Hence the rule, as it affects the forklift market, is expected to result in larger social gains as new forklifts enter the market and as more forklifts are purchased and operated in the future. In 2030, the social gains of the rule for this vehicle category are just over $370 million. Note that the figures discussed here and presented in the above table are not discounted.

Finally, to estimate the social costs/gains for the Large SI category as a whole, we can use engineering costs as an estimate for the sum of consumer and producer surplus losses. These estimates are contained in Table 9.1-3.

Table 9.1-3
Surplus Losses, Fuel Efficiency Gains, and Social Gains/Costs for Large SI Engines in 2030[a]

Vehicle Category	Surplus Losses in 2030 ($\$10^6$)	Fuel Efficiency Gains in 2030 ($\$10^6$)	Social Gains/Costs in 2030[b] ($\$10^6$)
Forklifts	$47.8	$420.1	$372.3
Other Large SI	$48.1	$138.4	$90.3
All Large SI	$95.9	$558.5	$462.6

[a] Figures are in 2000 dollars.

[b] Figures in this column exclude estimated social benefits.

[c] Figure is engineering costs; see text for explanation.

[d] Net Present Value is calculated over the 2002 to 2030 time frame using a 3 percent discount rate.

9.1.3 Summary Results for Snowmobiles

The baseline year for the economic analysis of the snowmobile market is 2001. In this year, the average snowmobile price is $6,360 and the market output is 140,629. These data are provided by the International Snowmobile Manufacturing Association (ISMA).[1] Based on these data, the relative changes in market price and output are calculated, as are the annual future year streams of surplus losses, engineering costs, and social costs or gains. Results are presented on Table 9.1-4.

Table 9.1-4
Summary Economic Impact Results for the Snowmobile Market

Year	Cost/unit ($)	Change in Price (%)*	Change in Quantity (%)*	Surplus Losses ($\$10^3$)**	Engineering Costs ($\$10^3$)	Social Costs/Gains ($\$10^3$)***
2006	$35	0.28%	-0.56%	$6,546.9	$6,583.5	$6,155.4
2007	$69	0.56%	-1.11%	$13,397.7	$13,546.4	$12,172.3
2008	$65	0.52%	-1.05%	$13,047.2	$13,183.5	$10,577.4
2009	$65	0.52%	-1.05%	$13,316.0	$13,455.2	$9,568.5
2010	$185	1.49%	-2.98%	$37,787.2	$38,933.1	$28,241.7
2011	$181	1.46%	-2.92%	$37,571.1	$38,685.1	$21,937.4
2012	$239	1.92%	-3.85%	$49,981.9	$51,957.6	$24,916.0
2013	$239	1.92%	-3.85%	$50,697.2	$52,701.2	$15,841.0
2014	$202	1.63%	-3.25%	$43,852.8	$45.309.0	($1,007.1)
2015	$196	1.58%	-3.16%	$43,017.6	$44,402.3	($11,957.9)
2016	$182	1.47%	-2.93%	$40,648.1	$41,860.2	($24,397.9)

2017	$180	1.45%	-2.9%	$40,543.0	$41,738.4	($34,420.2)
2018	$180	1.45%	-2.9%	$41,003.0	$42,211.9	($43,542.9)
2019	$180	1.45%	-2.9%	$41,455.4	$42,677.6	($52,141.8)
2020	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($60,276.2)
2021	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($68,292.1)
2022	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($74,761.8)
2023	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($79,630.7)
2024	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($83,278.1)
2025	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($85,777.8)
2026	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($87,804.8)
2027	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($89,549.9)
2028	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($91,022.3)
2029	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($92,224.9)
2030	$180	1.45%	-2.9%	$41,903.1	$43,138.5	($93,165.9)

*Percent change in price and quantity are based upon baseline market conditions for 2001.
** Surplus Loss is equal to the sum of the loss in consumer surplus and producer surplus. This estimate reflects projected growth in vehicles occurring subsequent to the baseline year of 2001.
***Social Costs/Gains are equal to the surplus losses net fuel cost savings.
( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

The relative increases in price expected to occur due to the rule range from 0.28 percent to 1.92 percent and reach a steady state level of 1.45 percent in 2015. The peak occurs in 2012 when the Phase III standards are implemented and the impacts decline with the recognition of learning curve effects. Estimated quantity changes follow a similar trend ranging from decreases of 0.56 percent to 3.85 percent in 2010 then reaching a steady state of 2.9 percent in 2017. It is important to note that these price quantity changes are based upon baseline 2001 snowmobile market conditions. As the table shows, the annual surplus losses are approximately equal to 96 to 99 percent of engineering costs. Over the future year time stream presented, surplus losses range from a low of $6.5 million in 2006 to a high of $50.7 million in 2012. These surplus losses account for projected growth in snowmobiles sales during the period.

An examination of the social costs and gains of the snowmobile regulation shows losses occur through 2013. Social gains begin in 2014 and continually increase in the future. This growth in social gains arises from the increasing fuel savings over time. The growth in fuel savings can be attributed to the gradual turnover of the snowmobile fleet to new fuel efficient technologies and to projected increases in the sales of snowmobiles. With a larger population of snowmobiles projected, the fuel savings are expected to be larger. Hence the rule, as it affects the snowmobile market, is expected to result in larger social gains as new snowmobiles enter the market and as more snowmobiles are purchased and operated in the future. In 2030, the social gains of the rule for this vehicle category are anticipated to be just over $93.0 million. Note that the figures discussed here and presented in the above table are not discounted and reflect 2001$.

9.1.4 Summary Results for ATVs

The baseline year for the economic analysis of the ATV market is 2001. In this year, the average ATV price is estimated to be $5,123 and the market output is equal to 880,000, this data was provided by MIC. Based on these data, the relative changes in market price and output are calculated, as are the annual future year streams of surplus losses, engineering costs, and social costs/gains. Results are presented in Table 9.1-5.

Table 9.1-5
Summary Economic Impact Results for the ATV Market

Year	Cost/unit ($)	Change in Price (%)*	Change in Quantity (%)*	Surplus Losses ($$10^3$)**	Engineering Costs ($$10^3$)	Social Costs/Gains ($$10^3$)***
2006	$43	0.28%	-0.56%	$42,186.6	$42,463.9	$41,252.7
2007	$82	0.53%	-1.07%	$80,258.8	$80,270.6	$76,563.7
2008	$78	0.51%	-1.02%	$75,611.8	$76,518.0	$68,657.0
2009	$71	0.46%	-0.92%	$69,529.4	$70,287.0	$58,605.5
2010	$66	0.43%	-0.86%	$64,681.3	$65,302.2	$49,541.9
2011	$57	0.37%	-0.74%	$55,891.6	$56,379.5	$36,400.4
2012	$53	0.34%	-0.69%	$52,019.5	$52,441.5	$28,143.4
2013	$53	0.34%	-0.69%	$52,019.5	$52,441.5	$23,830.7
2014	$53	0.34%	-0.69%	$52,019.5	$52,441.5	$19,705.2
2015	$53	0.34%	-0.69%	$52,019.5	$52,441.5	$15,801.2
2016	$51	0.33%	-0.66%	$49,612.0	$49,999.1	$9,780.7
2017	$48	0.31%	-0.62%	$47,210.3	$47,556.8	$4,086.6
2018	$48	0.31%	-0.62%	$47,210.3	$47,556.8	$1,360.2
2019	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($456.0)
2020	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($1,630.4)
2021	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($2,429.8)
2022	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($2,924.0)
2023	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($3,298.2)
2024	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($3,580.7)
2025	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($3,790.0)
2026	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($3,942.6)
2027	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($4,054.2)
2028	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($4,132.9)
2029	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($4,189.3)
2030	$48	0.31%	-0.62%	$47,210.3	$47,556.8	($4,227.9)

*Percent change in price and quantity are based upon baseline market conditions for 2001
** Surplus Loss is equal to the sum of the loss in consumer surplus and producer surplus. This estimate reflects projected growth in vehicles occurring subsequent to the baseline year of 2001.
***Social Costs/Gains are equal to the surplus losses net fuel cost savings. ( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

The relative changes in price and quantity resulting from the ATV regulations are considered minimal. The anticipated price change increases resulting from the per ATV costs are 0.53 percent or less. The quantity change decreases resulting from the engine modification costs are 1 percent or less. As the table shows, the annual surplus losses are approximately equal to 98 to 99 percent of engineering costs. Over the future year time stream presented, surplus losses range from a low of $42.2 million in 2006 to a high of $80.3 million in 2007 and reach a steady state of $47.2 million in 2017.

An examination of the social costs/gains shows that the losses decrease beginning in 2008 and become gains in 2019 with gains continually increasing in the future through 2030. This growth in social gains arises from the increasing fuel savings over time. The initial growth in fuel savings can be attributed to the gradual conversion of ATVs to new fuel saving technologies in the marketplace. After this turnover, the growth in fuel savings can be credited to an increase in the sales of ATVs. With a larger population of ATVs projected, the fuel savings are expected to be larger. Hence the rule, as it affects the ATV market, is expected to result in larger social gains as new ATVs enter the market and as more ATVs are purchased and operated in the future. In 2030, the social gains of the rule for this vehicle category are just over $4.2 million. Note that the figures discussed here and presented in the above table are not discounted and reflect 2001$.

9.1.5 Summary Results for Off-Highway Motorcycles

The baseline year for the economic analysis of the off-highway motorcycle market is 2001. In this year, the average off-highway motorcycle price is estimated to be $2,253 and the market sales are equal to195,250 off-highway motorcycles. These data were provided by MIC. Based on these data, the relative changes in market price and output are calculated, as are the annual future year streams of surplus losses, engineering costs, and social costs/gains. Results are presented in Table 9.1-6.

Table 9.1-6
Summary Economic Impact Results for the Off-Highway Motorcycle Market

Year	Cost/unit ($)	Change in Price (%)*	Change in Quantity (%)*	Surplus Losses ($$10^3$)**	Engineering Costs ($$10^3$)	Social Costs/Gains ($$10^3$)***
2006	$79	1.11%	-2.23%	$15,840.8	$16,269.1	$15,207.4
2007	$155	2.18%	-4.37%	$30,551.2	$32,215.0	$28,489.4

2008	$143	2.01%	-4.03%	$28,424.3	$29,846.5	$24,658.7
2009	$128	1.80%	-3.61%	$25,970.3	$27,127.3	$20,302.3
2010	$117	1.65%	-3.30%	$23,984.8	$24,957.7	$16,332.2
2011	$102	1.44%	-2.87%	$21,328.9	$22,079.4	$11,658.7
2012	$99	1.39%	-2.79%	$20,895.5	$21,630.7	$9,242.8
2013	$99	1.39%	-2.79%	$21,104.4	$21,847.0	$7,551.0
2014	$99	1.39%	-2.79%	$21,315.5	$22,065.4	$5,910.8
2015	$99	1.39%	-2.79%	$21,528.6	$22,508.9	$4,332.7
2016	$99	1.39%	-2.79%	$21,743.9	$22,734.0	$2,893.5
2017	$99	1.39%	-2.79%	$21,961.4	$22,961.4	$1,757.2
2018	$99	1.39%	-2.79%	$22,181.0	$22,961.4	$1,039.5
2019	$99	1.39%	-2.79%	$22,402.8	$23,191.0	$609.1
2020	$99	1.39%	-2.79%	$22,626.8	$23,422.9	$325.0
2021	$99	1.39%	-2.79%	$22,853.1	$23,657.1	$119.2
2022	$99	1.39%	-2.79%	$23,081.6	$23,893.7	($35.0)
2023	$99	1.39%	-2.79%	$23,312.4	$24,132.6	($133.4)
2024	$99	1.39%	-2.79%	$23,545.6	$24,374.0	($195.4)
2025	$99	1.39%	-2.79%	$23,781.6	$24,617.7	($240.6)
2026	$99	1.39%	-2.79%	$24,018.0	$24,863.9	($256.0)
2027	$99	1.39%	-2.79%	$24,259.0	$25,112.2	($252.0)
2028	$99	1.39%	-2.79%	$24,501.6	$25,363.7	($244.9)
2029	$99	1.39%	-2.79%	$24,746.6	$25,617.3	($214.4)
2030	$99	1.39%	-2.79%	$24,994.1	$25,873.5	($170.7)

*Percent change in price and quantity are based upon baseline market conditions for 2001

** Surplus Loss is equal to the sum of the loss in consumer surplus and producer surplus. This estimate reflects projected growth in vehicles occurring subsequent to the baseline year of 2001.

***Social Costs/Gains are equal to the surplus losses net fuel cost savings. ( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

The anticipated price change increases resulting from the engine modification costs range from 1.11 percent to 2.18 percent and reach a steady state of 1.39 percent in 2012. The quantity change decreases resulting from the per off-highway motorcycle costs range from 2.23 percent to 4.37 percent and reach a steady state of 2.79 percent in 2012. As the table shows, the annual surplus losses are approximately equal to 98 to 99 percent of engineering costs. Over the future year time stream presented, surplus losses range from a low of $15.8 million in 2006 to a high of $30.6 million in 2007.

An examination of the social costs/gains shows that the social costs reach a peak in 2007 and diminish annually through 2021. In 2020, annual social gains occur for this rule and annual gains occur through 2030. This diminishing social cost and increasing social gain arise from the increasing fuel savings over time. The initial growth in fuel savings can be attributed to the gradual conversion of off-highway motorcycles new fuel saving technologies in the marketplace. Hence the rule, as it affects the off-highway motorcycle market, is expected to result in larger social gains as new off-highway motorcycles enter the market and as more off-highway motorcycles are purchased and operated in the future. In 2030, the social gains of the rule for this vehicle category are $170,700. Note that the figures discussed here and presented in the above table are not discounted and reflect 2001$.

9.1.6 Net Present Value of Surplus Loss, Fuel Cost Savings, and Social Costs/Gains

For each of the vehicle categories, the net present value of the future streams of surplus losses, fuel savings, and social costs/gains have been calculated. The net present values of these future streams are calculated using a 3 percent discount rate and are calculated over the 2002 to 2030 time frame. We also show this information using a 7 percent discount rate. Table 9.1-7 presents the net present values and the surplus loss, fuel savings, and social costs/gains for the year 2030 for each of the vehicle categories.

Table 9.1-7
Year 2030 and Net Present Values of Surplus Losses, Fuel Cost Savings, and Social Costs/Gains ($million)[A]

Vehicle Category	Surplus Loss in 2030	NPV of Surplus Loss[B]	NPV of Surplus Loss[C]	Fuel Cost Savings in 2030	NPV of Fuel Cost Savings[B]	NPV of Fuel Cost Savings[C]	Social Costs/Gains in 2030[D]	NPV of Social Costs/Gains[B,D]	NPV of Social Costs/Gain[C,D]
CI Marine	$6.6	$99.6	$59.0	$0.0	$0.0	$0.0	$6.6	$99.6	$59.0
Forklifts	$47.8	$692.2	$415.8	$420.1	$4,883.4	$2,644.2	($372.3)	($4,191.2)	($2,228.4)
Other Large SI[E]	$48.1	$698.4	$419.7	$138.4	$1,494.4	$804.8	($90.3)	($796.0)	($385.1)
Snowmobiles	$41.9	$553.1	$296.9	$135.0	$999.6	$459.7	($93.1)	($446.5)	($162.8)
ATVs	$47.2	$829.2	$491.9	$51.4	$510.5	$253.0	($4.2)	$318.7	$238.9
Off-Highway Motorcycles	$25.0	$358.9	$206.2	$25.2	$242.4	$120.6	($0.2)	$116.5	$85.6
Total	$216.6	$3,231.4	$1,889.5	$770.1	$8,130.3	$4,282.3	($553.5)	($4,898.9)	($2,392.8)

[A] Figures are in year 2000 and 2001 dollars, depending on the vehicle category. ( ) represents a negative cost (social gain).
[B] Net Present Values are calculated using a discount rate of 3 percent over the 2002 - 2030 time period.
[C] Net Present Values are calculated using a discount rate of 7 percent over the 2002 - 2030 time period.
[D] Figures in this column do not include human health and environmental benefits of the regulations.
[E] Figures in this row are engineering cost estimates. See Section 9.7.6.

9.2 Economic Theory

Economic theory is based on the examination of choice behavior. As market conditions change, producers and consumers alter their production and purchasing decisions. In essence, this approach models the expected reallocation of society's resources in response to a regulation. The behavioral approach explicitly models the changes in market prices and production. These changes can be used to compute other impact variables, such as changes in producer and consumer surplus, changes in employment, and total changes in economic welfare. EPA relies heavily on this approach to develop impacts for the economic analysis. In order to develop a methodological approach to examine the economic impacts of the emissions standards applied to diesel recreational marine vessels, forklifts, and recreational vehicles, certain issues such as the model scope and length of run for the analysis must be considered. These concepts are discussed in detail here and can also be found in the OAQPS Economic Analysis Resource Document[2].

9.2.1 Partial vs. General Equilibrium Model Scope

A partial equilibrium market model examines the effect of a regulatory action on a single market, ignoring all other possible market interactions. Such an approach is justified in cases where a regulation's effect is expected to be concentrated in one market sector (i.e., the effect of the regulation in indirectly affected markets is relatively small). Other times this approach is used because of the difficulties of acquiring data for indirectly affected markets.

A general equilibrium market model tracks the effects of a regulation in all sectors of the economy. In this case, all inter-sectoral linkages are accounted for and examined. It is often difficult to examine every effect of a regulation on every market. Many market models therefore examine the most important linkages between sectors of the economy. These are generally referred to as "general" equilibrium models or multi-market partial equilibrium models.

For the analysis of the recreational vehicles emission standards, we rely upon a partial equilibrium market model to examine the economic impacts on the markets of each affected vehicle category. This choice was made because most of the economic impacts are expected to be incurred in the directly affected market and because of data availability issues.

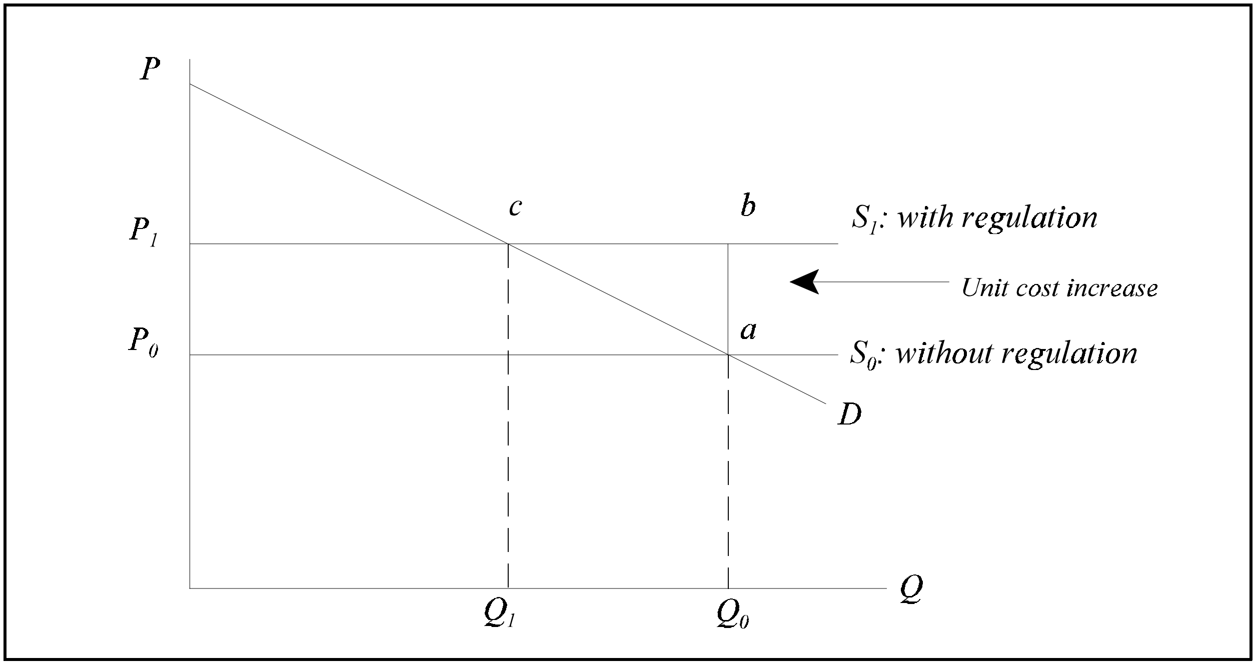
9.2.2 Length-of-Run Considerations

In developing the partial equilibrium model for this analysis, the choices available to producers must be considered. The choices are largely dependent upon the time horizon for which the analysis is performed. Three benchmark time horizons are presented here: the very short run, the long run, and the intermediate run. For this analysis, we focus on the partial quilibrium intermediate run analysis. Though these horizons refer to different lengths of time, they will likely differ depending upon the market in question. What defines these time horizons is the set of options or degree of flexibility producers have to respond to changing market conditions.

In the very short run, all factors of production are assumed to be fixed, thus leaving the directly affected entity with no means to respond. Within a short time horizon, regulated producers are unable to adjust inputs or outputs due to contractual, institutional, or other factors. In this scenario, the impacts of the regulation fall entirely on the regulated entities. Producers in this case incur the entire regulatory burden as a one-to-one reduction in their profit. This is often referred to as the “full-cost absorption” scenario.

In the long run, all factors of production are variable and producers can be expected to adjust their production plans in response to changes in cost resulting from a regulation. Entry and exit of firms into the industry is feasible. Figure 9.2-1 illustrates one example of a typical, if somewhat simplified, long-run supply function. In this example, the supply curve is horizontal, indicating that the marginal and average costs of production are constant with respect to output. This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market. Industry long run supply curves may exhibit constant, increasing, or decreasing returns to scale even in perfectly competitive markets. In many industries expansion of production in the long run may bid input prices up leading to increasing returns to scale. Constant returns to scale are assumed for illustrative purposes.

Figure 9.2-1
Full-Cost Pass Through of Regulatory Costs

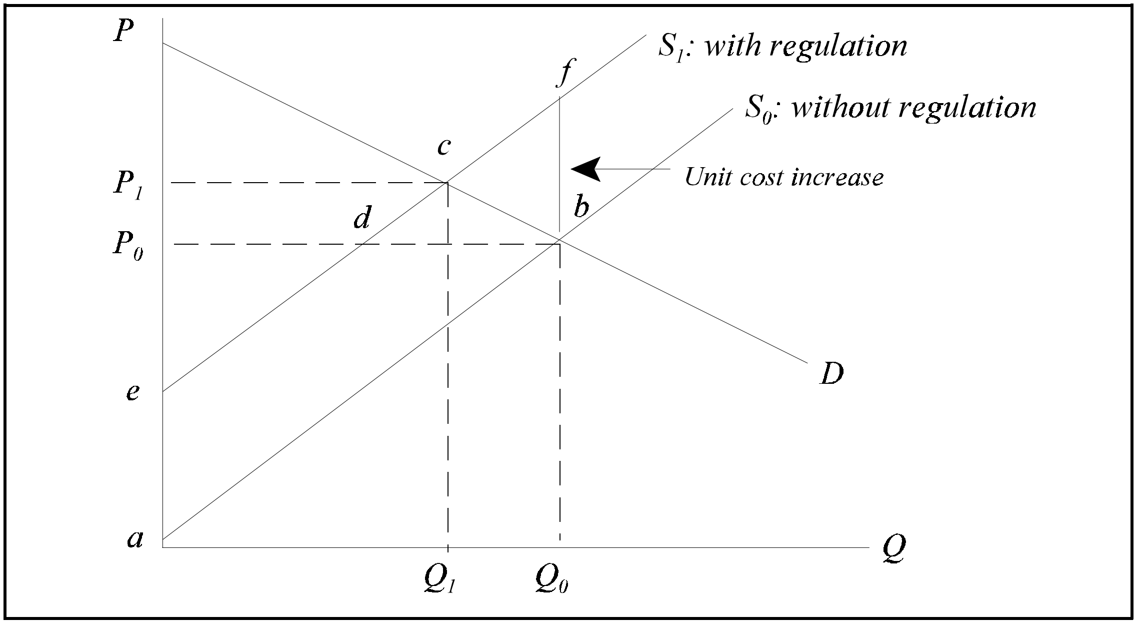


Market demand is represented by the standard downward-sloping curve. A constant cost industry is assumed; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward parallel shift in the market supply curve represents the regulation's effect on production costs. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P_0 to P_1). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q_0 to Q_1). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P_0acP_1). In the nomenclature of EIAs, this long-run scenario is typically referred to as "full-cost pass-through."

The "intermediate" run can best be defined by what it is not. It is not the very short run and it is not the long run. In the intermediate-run, some factors are fixed; some are variable. The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost function (which occupies the same locus of points as the supply curve) that rises with the output rate, as shown in Figure 9.2-2.

Again, the regulation causes an inward shift in the supply function due to the increase in production costs. The lack of resource mobility may cause profit (producer surplus) losses for producers in the face of regulation. However, unlike the full-cost absorption scenario, producers are able to pass through the associated costs to consumers to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P_0 to P_1) that is less than the per-unit increase in costs (fb), so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In this case, the change in consumer surplus is equal to P_0cbP_1. Producer surplus is equal to an increase in revenues on units it had previously sold prior to the cost increase (P_1cdP_0) and a loss due to the costs per unit they now face (area edba). The producer surplus is therefore equal to area edba - P_1cdP_0. The combined consumer and producer surplus loss is equal to P_1cdP_0 - P_1cbP_0 - edba. This is represented by area ecba and is referred to throughout this analysis as the surplus loss.

Figure 9.2-2
Partial-Cost Pass-Through of Regulatory Costs



As mentioned earlier, the economic analysis for each vehicle category focuses on an intermediate run approach. This is justified as the supply curve for each vehicle category shifts inwards by the total annualized cost per vehicle, not simply variable costs. Though this rule goes into effect over a number of years, there is a loss in economic welfare that is distributed across producers and consumers as the rule goes into effect. The analysis presented here chooses to focus on this loss in surplus and how it affects producers and consumers. Even if we were to take a long-run approach, the industry supply curve for each vehicle category may not be horizontal, (and thus represent a constant-cost industry). In fact, in many industries an increasing-cost industry might be the norm as the prices of factors of production are bid upwards as these industries expand.

9.3 Fuel Efficiency Gains

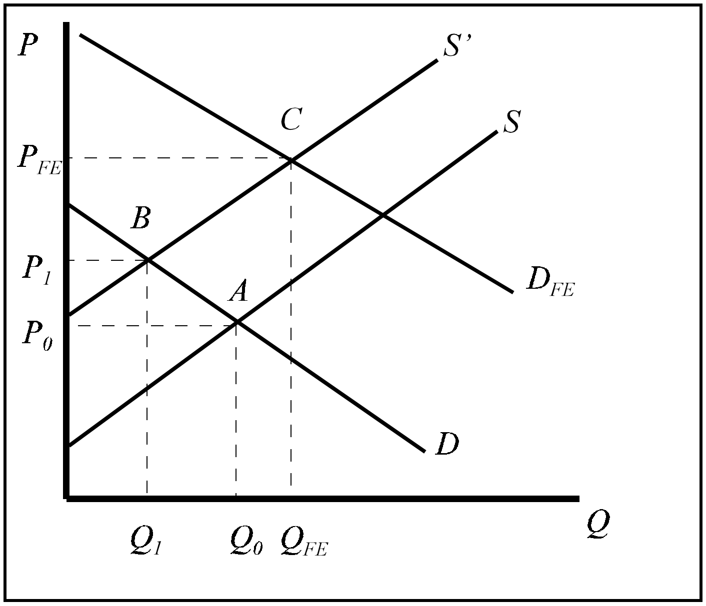
The main purpose of the emissions control program is to reduce emissions. However the changes made to the engines in forklifts, snowmobiles, ATVs, and off-highway motorcycles are also expected to result in fuel cost savings over the lifetime operation of these vehicles. Though the prices of these vehicles are expected to increase due to the regulatory costs imposed, consumers will spend less on fuel to operate the vehicles than they would have had the emissions control program not been implemented. This reduced spending on fuel is a benefit to consumers. This section qualitatively discusses the market impacts and welfare gains that may result from the savings in fuel costs.

When recreational vehicle and large SI engine producers are required to meet the emissions standard, they face an increase in the cost of production. This production cost increase causes an inward shift of the supply curve equal to the regulatory cost per vehicle, shown in Figure 9.2-2. As discussed earlier in Section 9.2.2, this leads to a loss in economic welfare equal to the sum of the loss in producer surplus and consumer surplus. What is not accounted for in Figure 9.2-2, however, is how fuel cost savings might affect the market equilibrium and what surplus gain is reaped from the improved fuel efficiency. Consumers may or may not incorporate the fuel efficiency gains into their valuation of a particular vehicle and the extent to which they do affects the market equilibrium quantity and price, surplus changes, and social costs.

If consumers value the improvement in fuel efficiency of a particular recreational vehicle, their demand curve for this product will shift out. The degree to which demand shifts reflects the magnitude of the potential fuel cost savings, the costs of being informed about the savings, and consumer time preferences. It may be the case that consumers are unaware of the fuel cost savings, that they don't perceive them to be as large as they are, or that they heavily discount their value. In those cases, there may be little or no shift in demand. Larger shifts in demand are expected if consumers face low information costs and/or have a low discount rate for the future savings in fuel costs.

For demonstration purposes, we can examine the hypothetical market for snowmobiles depicted in Figures 9.3-1 through 9.3-3 to see how market equilibrium price and quantity (point A) may change in response to the emissions control program and the fuel cost savings it generates. It is important to note that this discussion applies to all vehicle categories affected by the rule and the snowmobile market is used for explanatory purposes. This entails an examination of the changes in both supply and demand. Looking at Figure 9.3-1, assume that the net present value (NPV) of fuel cost savings per vehicle exceeds the regulatory control costs per snowmobile. As described above, the increase in the costs of producing snowmobiles results in a parallel shift inward of the supply curve. This leads to a higher price (P_1) and lower quantity (Q_1) sold, resulting in a new equilibrium point B. Now however, snowmobiles can operate using less fuel due to the technology advancements that are adopted to reduce emissions. This change in attribute may result in an outwards shift of the demand curve. If consumers fully value the fuel cost savings, demand will shift out to D_{FE}. The new equilibrium price (P_{FE}) and quantity (Q_{FE}) is represented by point C, which exceeds the market equilibrium price (P_0) and quantity (Q_0) before the emissions control program was adopted (point A). If producers were certain that consumers would fully value the fuel efficiency attribute, this change in technology may have occurred without the implementation of the regulation. If consumers and producers view the world in this manner, this scenario appears to be a market failure. What appears to be a win-win situation for consumers and producers does not occur in the market place absent regulation. The risk of producing new technology engines is borne by the producer as it is the producer that incurs the increased production costs. In contrast, fuel efficiency gains are experienced by the consumer to the extent the consumer is willing to pay the higher initial purchase price to gain fuel efficiency over the useful life of the vehicle. Producers offering the new technologies only gain from the new technology investment to the extent consumer’s demand increases (demand curve shifts outward) sufficiently to offset the increased cost of production. Thus investment in the new fuel efficient technologies does represent a business risk for the producer and issues such as risk aversion may enter into the decision to introduce these newer, cleaner, and fuel efficient technologies into the marketplace absent regulatory requirements. As is depicted by the next two scenarios, perfect information does not exist regarding consumers preferences for fuel efficiency. Thus absent regulation, producers are making expenditures with uncertain potential for returns.

Figure 9.3-1
New Equilibrium with Full Consumer Valuation of Fuel Efficiency



If consumers do not fully value the fuel cost savings resulting from the regulation, demand may not shift out to D_{FE}, but instead shift to D'. As Figure 9.3-2 shows, market equilibrium is now represented by point D where new equilibrium market price (P_2) exceeds the original market price (P_0). However, the new equilibrium quantity (Q_2) is lower than the original equilibrium quantity (Q_0). In such a scenario, consumers do value the attribute somewhat and are willing to pay an increased price for the fuel efficient vehicles. However the price consumers are willing to pay does not fully compensate the producers for the cost of making the vehicle modification. In this scenario, it is likely that producers will be unwilling to make the engine technology improvements absent regulation.

Another possibility is that demand may not shift at all if consumers do not perceive the fuel cost savings associated with the new technology. In this case, Figure 9.3-3 represents the market outcome. In this final scenario consumers do not value fuel efficiency for these vehicles and, there is no profit motivation for producer to implement the technology changes absent regulation.

Figure 9.3-2
New Equilibrium With Partial Consumer Valuation of Fuel Efficiency

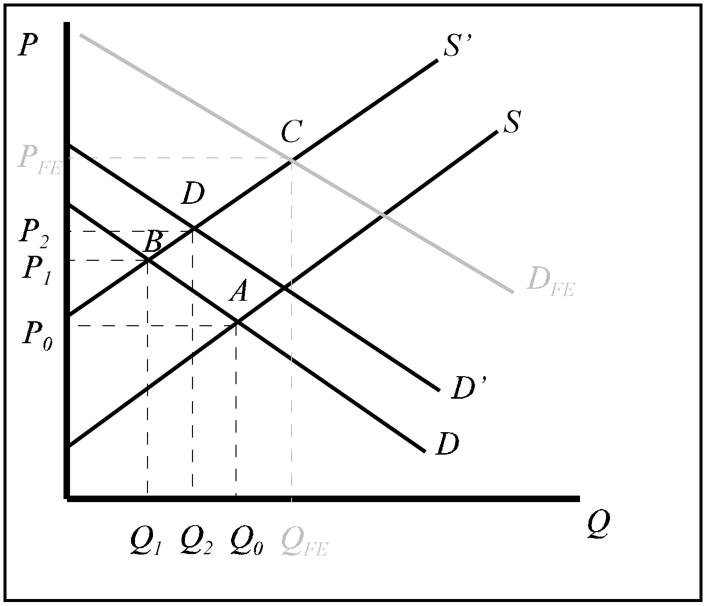
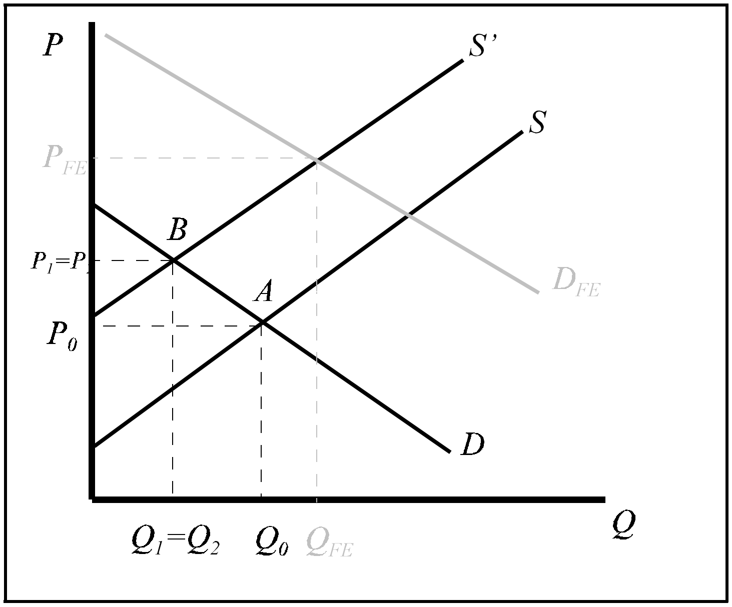


Figure 9.3-3
New Equilibrium with
No Consumer Valuation of Fuel Efficiency



It is important to recognize that the new price and quantity in the market for snowmobiles is determined by both a shift in supply as the cost of producing snowmobiles increases and a shift in demand to account for consumers' valuation of fuel cost savings. The potential gains to producers from making engine technology changes that increase fuel efficiency are uncertain and provide an explanation as to why these changes have not occurred in some recreational vehicle markets absent regulation.

Another effect not depicted in the graphs above occurs in the fuel or gasoline market where consumers now demand a smaller quantity of fuel to operate the fuel efficient vehicles. Since consumers will now require less fuel to operate snowmobiles than would be required absent the regulation, there is an inward shift in demand for gasoline. This shift in demand will likely be so small as to not affect the price of fuel since consumers of large SI engine equipment and recreational vehicles are a small segment of the total gasoline market. However, consumers experience a gain equal to the NPV of the change in the quantity of fuel consumed multiplied by the price of fuel over the lifetime of the vehicle. This is taken to equal the fuel cost savings for each vehicle category as calculated and presented in Chapter 7. This gain occurs independently of consumer preferences for fuel efficient vehicles. Specifically, if a consumer chooses to purchase a more fuel efficient vehicle, the consumer will experience the gain of increased fuel cost savings while using the product regardless of his or her preference for the fuel efficient attributes of the vehicle.

For this analysis, we are uncertain of the size of the outward shift in demand. We therefore do not project the price and quantity changes that occur taking fuel savings into account. However, we do account for the fuel cost savings by subtracting it from the surplus losses of the rule for each vehicle category over the future year time stream to generate a more accurate assessment of the social costs/gains of the regulation. The annual fuel efficiency gains are projected for each vehicle category in the future as described in Chapter 7 and appropriately consider the fleet of fuel efficient vehicles operating annually through 2030 and expected vehicle usage. The fuel efficiency gains represent the fuel cost savings consumers will experience over the useful life of the more fuel efficient vehicle. We calculate these results for each vehicle category analyzed. Surplus losses without fuel savings and total social costs/gains with fuel savings are presented in the following analysis.

9.4 Potential Product Attribute Changes

It is anticipated that the air emission standards for recreational vehicles will be met by utilizing newer, cleaner, and quieter engine technologies. Anticipated engine technology changes are perhaps most significant for the snowmobile industry. While the ATV and off-highway motorcycle industries have utilized 4-stroke engine technology extensively absent regulation, the snowmobile manufacturers have been slow to introduce this technology. Current models of ATVs are comprised by approximately 80 percent 4-stroke technologies, while the 4-stroke technology represents approximately 55 percent of off-highway motorcycles sales. In contrast, only nine 4-stroke snowmobile models are currently available in the marketplace, and the sales of these vehicles are estimated to account for a small percentage of annual total snowmobile sales. An issue has been raised as to whether the technology changes envisioned to meet the emission standards for recreational vehicles will create attribute changes in vehicles sold. Since the engine technology changes contemplated may be the most significant for snowmobiles, this issue is addressed specifically for this industry in the economic analysis. The relevant question to be addressed from an economic perspective is will snowmobiles post-regulation be perceived from the consumer's perspective as the same product as snowmobiles pre-regulation? Further, will any product attribute changes be adversely or positively viewed by consumers impacting snowmobile demand post-regulation?

Particular product attribute changes alleged to negatively impact snowmobile sales relate specifically to potential performance changes. Modifications to engines may impact the versatility, reliability, or compactness of snowmobiles. Assertions have arisen that consumers of snowmobiles demand high power-to-weight ratio machines and that the new engine technologies contemplated will impair this product attribute. The issue of whether the increased costs per engine will make entry level machines too costly for the entry level or marginal consumer have also been claimed.

Potential product attribute changes are relevant to evaluate the economic impacts of the rule. The economic analysis conducted for this rule postulates that the post-regulation demand for snowmobiles will be identical to the pre-regulation demand for snowmobiles. Consumers will simply respond to the increased cost of an engine and based upon this increased price will likely reduce the quantity of snowmobiles purchased (a movement along a demand curve as opposed to a shift). If however, consumers view these product attribute changes as significant, demand for the product may increase or decrease (demand shift inward or outward). For positive attributes demand may increase (demand shifts outward). Under this scenario, consumers will be willing to pay a higher price for the product because they value the enhanced or new product attribute. If consumers view the product changes negatively, the opposite reaction occurs and demand decreases (demand shifts inward). With decreased demand, consumers will pay a lesser price for the product due to their perceptions that the attribute change negatively affects the value of the product to them. If consumers view the attribute changes positively, the economic analysis overstates market impacts. However, if consumers view the attribute changes negatively, the economic analysis understates the market impacts of the rule. Thus it is important to account for potential product attribute changes in order to provide a reasonable estimation of the potential economic consequences of the rule.

The technology changes envisioned for snowmobiles will enhance the fuel efficiency of snowmobiles. The issue of consumer potential reactions to fuel efficiency gains, a possible positive product attribute change are discussed in Section 9.3. The 4-stroke and direct fuel injection (dfi) technologies also offer the positive attribute of “cleaner and quieter” vehicles. The health and environmental benefits analysis of the rule presented in Chapter 10 assesses the public’s willingness to pay for the human health and environmental benefits of these “cleaner and quieter” technologies. A separate, but somewhat related question is whether snowmobile consumers are willing to pay for these product attributes. It is the latter issue that is relevant for the study of attributes.

The National Park Service (NPS) banned the use of snowmobiles for Yellowstone and Grand Teton National Parks in January 2001. This ban on snowmobile use was based upon the belief that snowmobile usage “adversely affects air quality, wildlife, natural soundscapes, and the enjoyment of other visitors” to the parks.[3] Both the “clean and quiet” aspects of snowmobile attributes are reflected in the NPS ruling. The NPS service is now reviewing their ban and may reverse the ban and allow snowmobiles in the parks with restrictions. It is possible that these actions may impact consumer’s demand for “clean and quiet” engine technologies versus the older technologies. The outcome of the NPS activities on sales of snowmobiles and the mix of technologies consumers will demand is an uncertainty in the economic analysis conducted for this market and the evaluation of consumer’s valuation of product attributes.

The EPA has conducted a product attribute analysis for snowmobiles to address the issue of potential product attribute changes that may occur as a result of this regulation. Specifically, the EPA has looked at the products currently available in the marketplace and those attributes associated with the machines sold. Special emphasis is made to address those attributes that may change with the regulation.

9.4.1 Technology Changes for Snowmobiles

The technology changes anticipated for the snowmobile industry to meet the standards are addressed in Chapter 4 of this report. These standards do not dictate the use of a particular technology, but the engineering analysis evaluates currently available technologies that will meet the emission standards. With the Phase 2 standards for snowmobiles, 50 percent reductions in HC and CO emissions are mandated. While snowmobile manufacturers may meet these standards in a variety of ways, the EPA estimates 20 percent of the market will use 4-stroke technology, 50 percent direct fuel injection technology, 20 percent modified 2-stroke engines with pulse air, and 10 percent will use unmodified 2-stroke technologies. This technology mix is used to calculate the engineering costs of the rule. It is relevant to note that the standards allow for fleet emissions averaging. Thus particular manufacturers may choose the vehicles most suited to the new technologies to meet the standards. Technologies chosen to meet the standards are also the choice of the manufacturer. This means a manufacturer fearing the loss of consumers for entry level machines may opt not to convert those machines to the newer technologies.

Currently all four manufacturers of snowmobiles produce machines with the 4-stroke technology. In its 2003 product line, Yamaha has introduced a new 4-stroke high performance model.[4] This machine represents a total redesign for the company's highest performance machine. The Yamaha RX-1 is reported to have a horsepower rating of 145 making it one of the most powerful snowmobiles available in the market. The redesigned machine offers a high power-to-weight ratio that compares favorably to high performance 2 stroke competitor models. Yamaha has redesigned the chassis and suspension of its 4-stroke model to achieve the goal of high power to weight performance. Not only is the cleaner and quieter technology compatible with the high performance and maneuverability, this combination has already been introduced into the market with positive reviews.[5] For several snowmobile manufacturers, the 4-stroke technology is offered in more moderately priced, low to middle power range vehicles. For example, the two 4-stroke machines offered for sale by Arctic Cat have estimated horsepower of approximately 53. Thus, different manufacturers within the market place are introducing the newer technologies using dissimilar marketing strategies. A relevant issue from the economic impact perspective is whether snowmobile manufacturers currently in the market are in the same competitive position to introduce these new technologies. This issue is discussed in Section 9.8 of this report.

9.4.2 Statistical Analysis of Snowmobile Product Attributes

In order to address the issue of potential product attribute changes, a statistical analysis of product attributes for all snowmobiles in the 2003 model line is conducted. One technique frequently used to value product attributes is the hedonic model. This model is used extensively in the economic literature to measure consumer's willingness to pay for particular product attributes. The hedonic model assumes that there is a continuous function relating the market price of a good to its constituent attributes. The assumption is made that snowmobile consumers select a snowmobile based upon the marginal value they place on individual snowmobile attributes and the price of those attributes. By analyzing the prices of products currently available in the market, one may gain knowledge of those product attributes consumers value and perhaps gain some insight as to consumer's view of potential changes in those product attributes.

An important limitation of the analysis must be addressed. The hedonic model estimated reflects a market equilibrium relationship between price and product attributes for a single model year. The equilibrium exists because producers of snowmobiles equate the marginal cost of producing attributes to consumer's willingness to pay for available attributes. The hedonic model adjusts until the marginal cost equals the marginal willingness to pay and equilibrium is achieved. However, the regulations considered will impose a non-marginal change in the product characteristics; therefore one cannot equate the value to consumers directly from this model. Thus the statistical hedonic models estimated cannot be used predictively to evaluate potential market impacts of the regulation (potential shifts in market demand). Additional modeling is required to conduct this type of estimation. Rather, these statistical models provide insight into implicit attribute prices for current product attributes. As stated previously in 9.3, the market model used to assess market impacts for these regulations assumes that no shifts in demand will occur as a result of this regulation.

9.4.2.1 Relevant Product Attributes

An assumption is made that different snowmobiles model prices may be represented by accounting for individual product attributes. Thus, the price of a particular snowmobile model is assumed to be a function of these characteristics. The goal of the hedonic analysis is to determine those product attributes that account for the product price and to analyze those attributes likely to change with regulation.

In order to complete the snowmobile hedonic analysis, an accounting of current product characteristics and those likely to change with regulation is conducted. Product specifications may be separated into the following categories: engine, chassis, dimensions, features, and other attributes. Engine specifications likely to contribute positively to the price of a snowmobile include engine type, engine size (displacement cc), number of cylinders, cooling system, ignition, transmission, breaking system and carburetion. Chassis characteristics involve elements that affect the maneuverability and handling of the vehicle such as suspension and shocks. The length, width, height, weight and fuel capacity are examples of dimension attributes of snowmobiles. Snowmobiles features include a variety of items such as electric start, reverse, seating capacity, color and other enhancements to the vehicles. Finally the brand of snowmobile may have some influence upon product price. Each of the previously listed product attributes potentially influence the price of a vehicle. Those directly measured in the study are chosen based upon the availability of data and the ability to measure these attributes. The characteristics hypothesized to influence price for purpose of this study include engine type, engine displacement cc, the cooling system type, carburetion type, vehicle dimensions (length, width), fuel capacity (impacts the range a vehicle may travel on a tank of gas), seating, electric start, reverse, and color. Color is essentially eliminated as an issue relevant for study by using Manufacturers Suggested Retail Price (MSRP) values for the basic paint vehicles. Other product attributes not evaluated in the study are either unavailable from publicly available sources (snowmobile manufacturers websites), available for a subset of the companies, or difficult to evaluate given the information provided. For example, transmission changes may occur when using new technologies, but transmission types are difficult to measure in a quantitative or qualitative manner as all snowmobiles have automatic transmissions.

Of these attributes, engine type, engine displacement, carburetion, cooling system, and vehicle dimensions (length, width, and fuel tank size) may change with the regulation. Each of these attributes potentially impact the performance of the vehicle. Engine displacement is a measure of the power of the vehicle. In general for 2-stroke engines the greater the engine size the greater the power. In contrast, the relationship between engine displacement and power in the 4-stroke engine is less direct, and this phenomenon may introduce measurement error when looking at a data set that combines 2-stroke and 4-stroke vehicles. While horsepower (hp) may be a better measure of this attribute, hp data are not readily available for all vehicle models. Ideally weight would be the better measure than vehicle length and width to test power-to-weight influence upon price. However, weight data are available for only a subset of snowmobiles offered for sales. Thus width and length proxy for the weight of the vehicle. Consumer's taste and preferences for engine power appear to be changing over time with the demand for greater power machines increasing. According to PSR data, the average engine displacement sized snowmobile produced rose significantly between 1995 and 2000.[6]

The issue of fuel efficiency and consumers willingness to pay for increased fuel efficiency is addressed in part with the fuel tank size variable. Gasoline mileage (miles per gallon) and range (length in hours of a ride with a single tank of gas) information are not available for any snowmobile models on any of the company websites. The absence of any information concerning fuel efficiency is somewhat surprising and may perhaps indicate that snowmobile sellers do not perceive that consumers of snowmobiles have great interest in the relative fuel efficiency of different products. Thus informational problems exist currently for consumers to be able to assess the fuel efficiency of products on the market. However, those products with 4-stroke and dfi technologies are reported to have fuel savings of up to 30% over comparable vehicles with older technologies.[7] Due to the absence of published fuel efficiency data, engine testing data provided by ISMA and from publications are used to construct a statistical relationship between mileage and engine size.[8] All data in the sample are based upon the 2-stroke engine technology. Based upon the sample engine test data, the statistical relationship estimated follows:

Hypothesized relationship: Gallons per hour = f (engine displacement cc)

Fitted Equation: Gallons per hour = -1.56615 + .00920 engine displacement cc

This equation is used to estimate gallons per mile for each of the vehicles in the data set. The gallons per hour are then converted to miles per gallon to estimate mileage for each vehicle type. This information is used along with fuel tank size to estimate the range of each vehicle. The descriptive statistics for data used in the model, parameter estimates, and relevant statistical model information are displayed on Table 9.4-1. The fitted model estimates gallons per hour for 2-stroke vehicles only. It is assumed that 4-stroke vehicles and those equipped with dfi have fuel efficiency gains over comparable 2-stroke vehicles of 25 percent. The mileage and range estimates constructed appear to systematically underestimate the mileage experienced by the typical snowmobile and the range for many of the vehicles appears to be understated suggesting measurement error in these estimates. While these data are used in the analysis, potential measurement errors in the data exist.

As indicated in the fitted equation, mileage is a function of engine size and as the engine size increases fuel consumption increases. The implications of this relationship are quite interesting. If consumers positively value power and power is inversely related to fuel efficiency, product prices may indicate consumers negatively value fuel efficiency. This is an inaccurate conclusion. We assume consumers are rational and value fuel efficiency. A more accurate description of this phenomenon is consumers value power and are willing to pay higher prices for larger engine sizes with greater power. Fuel efficiency declines within 2-stroke models with larger engines.

The prices consumers pay for the attributes of power (measured as engine size displacement) and fuel efficiency (mileage) are jointly determined. The modeling approach taken evaluates the implicit price of the attribute engine size. It is likely that consumers currently have a lower implicit price for engine displacement than would occur if this engine displacement also included greater fuel efficiency. Thus it is important to recognize these attributes are inextricably linked when consumers make purchase choices. The new technologies of dfi and 4-stroke engines do, however, represent the potential to gain fuel efficiencies for a given level of engine power, all other factors held constant.

Table 9.4-1
Statistical Model of Snowmobile Gas Mileage

Data Descriptive Statistics[9]	**Mean**	**Standard Deviation**
Sample Size = 15		
Variable description:		
Engine Size (displacement cc)	540.9	173.2
Gallons per hour	3.41	1.73
Statistical Model Specification: Gallons per hours = f (engine displacement) Gallons per hour = $\beta_1 + \beta_2$ (engine displacement) + ϵ		
Model Results: Gallons per hour = -1.56615 + .00920 engine displacement cc		
Statistical Information	Parameter Estimate	
Variable:		Standard Errors
Intercept	-1.56615	0.60571*
Engine displacement	0.00920	0.00107**
F-Value	73.95	Pr > F < 0.0001
Adjusted R Square	0.839	

* Statistically significant at the 2% significance level.
** Statistically significant at the 1% significance level

9.4.2.2 Data for Hedonic Analysis

The websites of Polaris, Arctic Cat, Bombardier, and Yamaha include listings of the 2003 models available for sale.[10, 11, 12, 13] The specifications for each snowmobile model are listed on these websites and these data are used as the data set for the study. Data are presented for the one hundred and forty four models offered for sale in the 2003 product lines of these manufacturers. Children's snowmobiles are excluded from the study, because the technologies used in this application differ greatly from the typical snowmobile available for sale.

The price of a snowmobile is the dependent variable in the statistical estimation and price must be measured to complete the hedonic analysis. MSRP are used to measure the price of vehicles offered for sale. While the actual price paid for a snowmobile typically is a negotiated price between the buyer and seller, only MSRP are published and readily available for models currently offered for sale. Descriptive Statistics for snowmobile prices and product attributes are shown on Table 9.4-2.

Table 9.4-2
Snowmobile Price and Product Attribute Descriptive Statistics - All Vehicles [14]
(Sample Size = 144)

Product Attributes	Measurement	Mean Value	Standard Deviation
Engine Type	2-stroke versus 4-stroke	Dummy Variable 0 = 2-stroke 1 = 4-stroke (9 4-stroke)	N/A
Engine Size	cubic centimeters	642	144
Cooling System	air cooled or liquid cooled	Dummy Variable 0 = air cooled 1 = liquid cooled (114 liquid cooled)	N/A
Length	inches	116.6	6.7
Width	inches	46.6	1.9
Fuel Tank Size	gallons	11.3	1
Seating Capacity	1 or 2 person vehicle	Dummy Variable 0 = 2 person 1 = 1 person (106 1-person)	N/A
Electric Start	standard equipment or optional	Dummy Variable 0 = option 1 = standard (55 standard)	N/A
Reverse	standard equipment or optional	Dummy Variable 0 = optional 1 = standard (81 standard)	N/A
Electronic Fuel Injection (efi)	Included or not included	Dummy Variable 0 = no efi 1 = efi (27 efi)	N/A
Direct Fuel Injection (dfi)	Included or not included	Dummy Variable 0 = no dfi 1 = dfi (6 dfi)	N/A
Brand Name	Polaris, Arctic Cat, Bombardier, or Yamaha	Dummy Variables 1 = particular brand	N/A

Mileage	Miles per gallon	6.2	2.7
Range	Miles traveled on a tank of gas	69.3	26.3
Dependent Variable: Snowmobile price	Manufacturers suggested retail price	$7,291	$1,411

Since the 4-stroke engine represents a significant technical departure from the 2-stroke engines, alternative models are estimated for the 2-stroke and 4-stroke models exclusively. The descriptive statistics for those variables subject to quantitative estimates for the 4-stroke and 2-stroke models are shown on Tables 9.4-3 and 9.4-4, respectively. In general, qualitative variables measured by dummy variables are measured as depicted for all vehicles. Some features that are measured using dummy variables are not applicable for the 4-stroke technology. For example, all 4-stroke engines are liquid cooled and have electric start as standard features. Dfi technology is available exclusively on 2-stroke models. Horsepower data are available for all nine 4-stroke models.

Table 9.4-3
Snowmobile Price and Product Attribute Descriptive Statistics[15]
Four-Stroke Models Only (Sample Size =9)

Product Attributes	Measurement	Mean Value	Standard Deviation
Engine Size	cubic centimeters	872	150.7
HP	number	88.6	44
Length	inches	116.6	8.5
Width	inches	47.3	1.4
Fuel Tank Size	gallons	11.1	1.1
Brand Name	Polaris, Arctic Cat, Bombardier, or Yamaha	Dummy Variables 1 = particular brand	N/A
Mileage	Miles per gallon	4.9	1.3
Range	Miles traveled on a tank of gas	55.4	20.7
Dependent Variable: Snowmobile price	Manufacturers suggested retail price	$8,316	$687

Table 9.4-4. Snowmobile Price and Product Attribute Descriptive Statistics[16]
Two-Stroke Models Only (Sample Size = 135)

Product Attributes	Measurement	Mean Value	Standard Deviation
Engine Size	cubic centimeters	626.4	130.7
Length	inches	116.5	6.5
Width	inches	46.6	1.9
Fuel Tank Size	gallons	11.2	0.9
Brand Name	Polaris, Arctic Cat, Bombardier, or Yamaha	Dummy Variables 1 = particular brand	N/A
Mileage	Miles per gallon	6.3	2.8
Range	Miles traveled on a tank of gas	69.9	26.3
Dependent Variable: Snowmobile price	Manufacturers suggested retail price	$7,213	$1,423

9.4.2.3 Statistical Model Results

This section presents the results of statistical estimations including results of statistical tests. The statistical package, SAS 8.2 for Windows was used to generate all statistical results. Various model specifications were estimated including log-log, log-linear and linear models. Generally, the log-log model specification provided the best statistical fit. In this model, all variables are transformed to natural logs except the dummy variables. Numerous model variations were estimated. In nearly all model specifications, the variables electric start, electronic fuel injection, brand name, length, fuel tank size, and electric start are consistently not statistically significant. Since the range and mileage variables are a function of the engine size, these variables are highly correlated. For this reason, model runs were conducted with engine size, range or mileage exclusively. The 4-stroke parameter is correlated with engine size variable. When the model is specified using both of the parameters, the 4-stroke variable appears to have a negative coefficient and to be statistically significant. When the model is estimated with the 4-stroke variable and excludes engine size, the parameter estimates are not significantly different from zero. Thus the fitted model excludes 4-stroke technology from the estimation. It is possible that a dummy variable is not an adequate method of capturing the attributes associated with the technology. Given this results a hedonic models of 2-stroke and 4-stoke models only are estimated. The estimated hedonic function for the full model using engine size follows:

$$\log MSRP = 8.2419 + 0.5821 \log(\text{engine displacement cc}) + 0.8561 \log(\text{width}) + 0.2397\ \text{cooling} - 0.0685\ \text{seat} + 0.0495\ \text{reverse} + 0.1066\ \text{dfi}.$$

All parameter estimates are significant at a 1 percent significance level. Relevant statistical model results are shown on Table 9.4-5.

Table 9.4-5
Full Model Statistical Results Using Engine Displacement

Variable	Parameter Estimate	Standard Error*
Intercept	8.2419	0.6987
log (engine displacement cc)	0.5821	0.0362
log (width)	0.8561	0.1713
cool	0.2397	0.0223
seat	-0.0685	0.0159
reverse	0.0495	0.0143
dfi	0.1066	0.0343
F Value Adjusted R-Square	157.28* 0.8677	

* All parameter estimates are statistically significant at a 1% significance level.

The model is re-estimated using the same specifications and variables shown in Table 9.4-5, but replacing engine size with a mileage variable and in a subsequent run with the range variable. The models and parameter estimates remain statistically significant. The mileage variable and range variable have negative signs as previously postulated and are statistically significant in each of the runs.

Based upon the statistical results, one may conclude that the relative prices (as measured by MSRP) are higher for vehicles with larger engine sizes, greater width, liquid cooling systems, reverse, and dfi. Alternatively, one-seating capacity machines are priced generally lower than two-seat machines. In the alternative model specifications, the mileage and range variables have negative signs and are statistically significant. This result may be interpreted to mean that consumers value power even when greater power translates into less fuel efficiency.

The full data set is split into a 4-stroke data set and a 2-stroke data set to assess the model differences with these two technologies. The model estimation results for the 2-stroke technology are as follows:

$$\text{Log (MSRP)} = 7.5689 + 0.6461 \log(\text{engine displacement cc}) + 0.7847 \log(\text{width}) + 0.2260\ \text{cool} + 0.0626\ \text{reverse} - 0.0722\ \text{reverse} + 0.0906\ \text{dfi}$$

Statistical results are shown in Table 9.4-6. In general, the results of this run differ little from the full model. This is not surprising since 135 observations of the full data set are represented in the 2-stroke model specification. Thus the conclusions for the full model apply to the two-stroke technology.

Table 9.4-6
Two-Stroke Model Statistical Results Using Engine Displacement

Variable	Parameter Estimate	Standard Error*
Intercept	7.5689	0.6984
log (engine displacement cc)	0.6461	0.0386
log (width)	0.7847	0.1683
cool	0.226	0.0218
reverse	0.0626	0.0143
seat	-0.0722	0.0143
dfi	0.0906	0.0333
F Value Adjusted R-Square	165.49* 0.8805	

* All parameter estimates are statistically significant at a 1% significance level.

Only nine 4-stroke models are currently available for sale. Thus the sample size is quite small. In general, only engine size or horsepower are statistically significant. Horsepower provides a stronger statistical relationship to MSRP and the model results are shown below:

$$\log(\text{MSRP}) = 8.3330 + 0.1577 \log(\text{hp})$$

Model results are shown in Table 9.4-7.

Table 9.4-7
Four-Stroke Model Statistical Results Using Engine Horsepower

Variable	Parameter Estimate	Standard Error *
Intercept	8.333	0.1064
log (horsepower)	0.1577	0.0242
F Value	42.53*	
Adjusted R-Square	0.8941	

* All parameter estimates are statistically significant at a 1% significance level.

The model results tend to provide confirmation that higher powered (greater hp) four-stroke machines are higher priced that than lower powered 4-stroke machines.

In general, the statistical results from all model runs tend to indicate that higher MSRP exist in the current snowmobile market for power (larger engine size or hp), wider machines, liquid cooling, reverse, and dfi product attributes. One-seat machines, all other factors held constant, are lower priced than two-seat machines. The statistical results also indicate prices are higher for vehicles equipped with the dfi technology.

The statistical results indicate that fuel efficiency is inversely related with engine size. Since prices are relatively higher for more powerful machines, this translates to lower fuel efficiency. This phenomenon is related to the two-stroke technology. This does not likely reflect a negative view of fuel efficiency so much as a positive view of greater power. While consumers of 4-stroke models also are willing to pay higher prices for greater power, greater fuel efficiency is an intrinsic attribute of the 4-stroke technology. The model results are not satisfying with regard to the 4-stroke technology. This is likely due to the fact that the dummy variable does not adequately capture the attributes associated with the 4-stroke technology and may also be due to the relatively small number of models with this technology.

9.4.3 Anecdotal Pricing Information For Snowmobiles

The statistical analysis is unsuccessful at identifying product price differentials for the 4-stroke technology versus 2-stroke. For this reason, a model by model comparison is conducted of the 4-stroke snowmobile models that are similar except for engine type. The MSRP differential typically ranges from $500 to $600 for the 4-stroke model when compared to the 2-stroke comparable model.[17] The prices consumers actually pay for these comparison vehicles are ultimately dependent upon a negotiated price rather than MSRP.

9.4.4 Uncertainties and Limitations of the Attribute Study

The statistical uncertainties of the attribute study are presented in the discussions of the models estimated. In additional to the statistical uncertainties, other uncertainties exist. The outcome of NPS issues with snowmobile usage in national parks is an uncertainty that cannot be adequately addressed in the analysis. To the extent that NPS actions, spur demand for "cleaner and quieter" snowmobiles, demand for the new technologies may increase. However, the overall impact of a ban on snowmobile usage in the parks is a recognized uncertainty of the economic impact analysis conducted for this rule.

The hedonic model estimated reflects a market equilibrium relationship between price and attributes for a single model year. The equilibrium exists because producers of snowmobiles equate the marginal cost of producing attributes to consumer's willingness to pay for available attributes. The hedonic model adjusts until the marginal cost equals the marginal willingness to pay and equilibrium is achieved. However, the regulations considered will impose a non-marginal change in the product characteristics; therefore one cannot equate the value to consumers directly from this model. Additional modeling is required to conduct this type of estimation.

9.4.5 Conclusions

Two questions are posed at the beginning of this analysis regarding potential product attribute changes. Those questions are: will snowmobiles post-regulation be perceived from the consumer's perspective as the same product as snowmobiles pre-regulation and will product attribute changes be adversely or positively viewed by consumers impacting snowmobile demand post-regulation? The answer to the first question is that the technology changes envisioned by the rule do alter the attributes of snowmobiles such that the typical consumers of snowmobiles post-regulation will view these products as different from the pre-regulation snowmobile. Two qualifiers to this conclusion exists. The first is that these technologies are already available in the market place. The regulation will simply encourage the proliferation of these new technologies throughout the snowmobile market. The second is a mix of technologies will exist that include older technologies. Thus consumers of the older technology machines will not likely perceive product changes post regulation.

With regard to the second question, consumer demand may change as a result of these altered product attributes. However, quantification of any demand changes is not possible with the data evaluated. The negative aspects of product changes alleged by some involve potential degradation of the power-to-weight ratio for high performance machines. Yamaha's introduction of its new high performance 4-stroke machine is evidence that the "clean and quiet" technologies can coexist with high power-to-weight ratios. Thus consumers will be able to obtain "clean and quiet" high powered snowmobiles. The question then becomes are consumers willing to pay higher prices for the new attributes of cleaner, quieter, greater fuel efficiency, and other performance attributes of snowmobiles equipped with dfi or 4-stroke engines. The statistical analysis provides evidence that MSRP is higher for vehicles equipped with dfi, all other factors held constant. A comparison of the suggested MSRP of comparable 4-stroke and 2-stroke vehicles reflects higher prices for the 4-stroke engine vehicles currently offered in the market of approximately \$500 to \$600. Thus snowmobile manufacturer's recommend higher prices for the newer technologies. This recommendation reflects the belief that certain consumers will value the bundle of product attributes of the new cleaner quieter machines and be willing to pay a premium for these attributes. The actual price differences paid for new versus old technology vehicles is determined by those prices negotiated in the market. Further, the increased price may reflect an increased cost of production and not necessarily translate into additional profits for the manufacturer.

With regard to the issue of whether entry level consumers will leave the market, fleet emissions averaging will allow producers to use older less costly technologies on entry level machines to avoid sales losses for this segment of the market.

9.5 Methodology

For the economic impact analysis of the effects of the emissions control program, we rely upon a national-level partial equilibrium market model. Inputs to this model include baseline market price, market output (domestic and imported quantities), and estimates of price elasticity of supply and demand. Price elasticities measure the responsiveness of quantity demanded and supplied to changes in price. This section describes the conceptual model used to generate the economic impacts and it provides the methodology and data inputs used to develop estimates of supply and demand price elasticities for each vehicle category.

9.5.1 Conceptual Model

The regulatory compliance costs provide an exogenous shock to the model with the per unit total compliance costs (*c*) resulting in a shift of the domestic supply curve (S_0 to S_1 in Figure 9.2-2 above). This shift, expressed as the cost increase per vehicle, is based on the cost information presented in Chapter 5 (generally, the regulatory cost per engine is taken to equal the cost per vehicle). The model equations that respond to this exogenous shock are described below.

The change in domestic supply (dq^D) due to the imposition of the regulation will depend upon the typical supply response to a price increase and the change in the "net" price of a given vehicle (i.e., $dP - c$) so that

$$dq^D = \xi^D \left[\frac{q^D}{P}\right](dP - c) \qquad \textbf{(Eq. 9-1)}$$

where ξ^D is the domestic supply elasticity. Supply elasticities have been estimated for each of the vehicle categories affected by the emissions standards and a description of the estimation procedure used is provided below.

International trade is included through the specification of an equation to characterize imports to the U.S. Thus, the change in imports from these foreign countries is included through the following equation:

$$dq^I = \xi^I \left[\frac{q^I}{P} \right] (dP - c) \qquad \textbf{(Eq. 9-2)}$$

where ξ^I is the import supply elasticity. Data to estimate import supply elasticities for the various vehicle categories were not available. For the economic impact analysis, the value of the import supply elasticity is assumed to equal the value of the domestic supply elasticity.

Next, the change in market supply must equal the change in the quantity of individual suppliers both domestic and foreign, i.e.,

$$dQ = dq^D + dq^I \qquad \textbf{(Eq. 9-3)}$$

where dq^D is the change in domestic supply and dq^I is the change in imports.

Lastly, the market demand condition must hold, i.e.,

$$dQ = \eta \left[\frac{Q}{P} \right] dP \qquad \textbf{(Eq. 9-4)}$$

where η is the market demand elasticity. The economic model relies upon demand elasticities that have been estimated or found in the economics literature for the various vehicle categories. Estimation procedures for demand elasticity are discussed below.

Equations 9-1 through 9-4 form four linear equations with four unknowns (dq^D, dq^I, dQ, and dP) that can be solved using linear algebra, i.e.,

$$\mathbf{b} = \mathbf{A}^{-1}\mathbf{c}'$$

where **b** is the vector containing the four unknowns (dq^D, dq^I, dQ, and dP), $\mathbf{A}^{-1}$ is the inverse of A, a 4x4 matrix, and **c** is the vector (c, c, 0, 0). Using this model, we develop our national-level economic impacts resulting from the rule. The full system of equations (**Ab = c**) is as follows:

$$\begin{bmatrix} -\left(\frac{1}{\varepsilon^d}\right)\left(\frac{P}{q^d}\right) & 0 & 0 & 1 \\ 0 & -\left(\frac{1}{\varepsilon^d}\right)\left(\frac{P}{q^i}\right) & 0 & 1 \\ -1 & -1 & 1 & 0 \\ 0 & 0 & -1 & \eta\frac{Q}{P} \end{bmatrix} \begin{bmatrix} dq^d \\ dq^i \\ dQ \\ dP \end{bmatrix} = \begin{bmatrix} c \\ c \\ 0 \\ 0 \end{bmatrix} \qquad \textbf{(Eq. 9-5)}$$

9.5.2 Price Elasticity Estimation

As discussed above, demand and supply elasticities are crucial components of the partial equilibrium model used to quantify the economic impacts of the emission standards. The price elasticity of demand is a measure of the sensitivity of buyers of a product to a change in price of the product. The price elasticity of demand represents the percentage change in the quantity demanded resulting from each 1 percent change in the price of the product. The price elasticity of supply is a measure of the responsiveness of producers to changes in the price of a product. The price elasticity of supply indicates the percentage change in the quantity supplied of a product resulting from each 1 percent change in the price of the product.

This section presents the analytical approach employed to estimate the demand and supply price elasticities used in the partial equilibrium analysis for each vehicle category. As discussed below, demand and supply elasticity estimates used in the market model are either estimated, assumed, or retrieved from previous studies that have carried out these estimations. In the case of recreational diesel marine vessels, a demand elasticity measure was available from a previous study, but the supply elasticity was estimated. For forklifts, both supply and demand elasticities were estimated. Because of data limitations, EPA's estimates of demand elasticity for the forklift model are not considered robust. Two estimates were generated; one was not significant while the other was significant but not of reasonable size. The economic impact analysis therefore relies upon an assumed price elasticity of demand for forklifts based on the results generated for this vehicle category. A sensitivity analysis is included in an appendix to show the economic impacts of the rule on the forklift market when the large estimate of demand elasticity is used. For the snowmobile, ATV, and OHM markets, attempts were made at econometric estimation of the price elasticity of demand. These attempts were unsuccessful as was a search to find these data in the literature. In lieu of estimates specific to the snowmobile, ATV and the OHM markets, an estimate of the price elasticity of demand for recreational boats obtained from a study are used to estimated market impacts. This value is assumed to be a reasonable estimate of the price elasticity of demand for the snowmobile, ATV and OHM markets. The uncertainties involved in this estimate are acknowledged. A sensitivity analysis is included in the Appendix to Chapter 9 to recognize the uncertainties associated with this estimate. The price elasticity of supply is estimated for the snowmobile and OHM markets. Attempts to estimate this value for the ATV market were unsuccessful. The price elasticity of supply estimate generated for the OHM market is assumed to be a reasonable estimate of this value for the ATV market. Sensitivity analyses are presented in the appendix to this chapter to evaluate the uncertainties involved in these estimates. A summary of the price elasticity of demand and supply used in the study for each vehicle type are summarized in Table 9-5.0 shown below.

Table 9-5.0 Summary of Price Elasticity of Demand and Supply
Used in the Market Analyses

Market	Price Elasticity of Demand	Price Elasticity of Supply
Inboard Cruisers	-1.41	1.62
Forklifts	-1.52	0.72
Snowmobiles	-2.03	2.12
ATVs	-2.03	1.04
Off-highway motorcycles	-2.03	0.92

[1] Raboy, David. G. 1987. *Results of an Economic Analysis of Proposed Excise Taxes on Boats*. Washington, D.C: Patton, Boggs, and Blow. Prepared for the National Marine Manufacturing Association. Docket A-2000-01, Document IV-A-129.

[2] Assumed value.

[3] Econometrically estimated.

[4] Assumed value based upon the price elasticity of demand estimate for recreational boats in the Raboy study listed above.

[5] Assumed value based upon the price elasticity of supply estimate for off-highway motorcycles.

9.5.2.1 Price Elasticity Estimation for Marine

Demand Elasticity

The economic model developed for the CI recreational marine vessel market concentrates solely on the inboard cruiser market. This is the segment of the recreational marine vessel market which relies upon diesel engines more than any other. Fortunately, a previously estimated price elasticity of demand for the inboard cruiser market is available[18]. For this reason, demand elasticity was not estimated. The previously estimated value that is used in the economic model is -1.44.

Supply Elasticity

Published sources of the price elasticity of inboard marine cruisers were not readily available. Therefore, an econometric analysis of the price elasticity of supply for boat manufacturing was conducted, assuming that this estimate is representative of the supply elasticity for the inboard cruiser market. The approach used to estimate the supply elasticity makes use of the production function. The methodology of deriving a supply elasticity from an estimated production function will be briefly discussed with the industry production function defined as follows:

$$Q^S = f(L, K, M, t) \qquad \textbf{(Eq. 9-6)}$$

where:

Q^S = output or production
L = the labor input, or number of labor hours,
K = real capital stock,
M = the material inputs, and
t = a time variable to reflect technology changes.

In a competitive market, market forces constrain firms to produce at the cost minimizing output level. Cost minimization allows for the duality mapping of a firm's technology (summarized by the firm's production function) to the firm's economic behavior (summarized by the firm's cost function). The total cost function for a boat producer is as follows:

$$TC = h(C, K, t, Q^S) \qquad \textbf{(Eq. 9-7)}$$

where:

TC = the total cost of production, and
C = the cost of production (including cost of materials and labor).

All other variables have been previously defined.

This methodology assumes that capital stock is fixed, or a sunk cost of production. The assumption of a fixed capital stock may be viewed as a short-run modeling assumption. This assumption is consistent with the objective of modeling the adjustment of supply to price changes after implementation of controls. Firms will make economic decisions that consider those costs of production that are discretionary or avoidable. These avoidable costs include production costs, such as the costs associated with labor and materials. In contrast, costs associated with existing capital are not avoidable or discretionary. Differentiating the total cost function with respect to Q^S derives the following marginal cost function:

$$MC = h'(C, K, t, Q^S) \qquad \textbf{(Eq. 9-8)}$$

where MC is the marginal cost of production and all other variables have been previously defined.

Profit maximizing competitive firms will choose to produce the quantity of output that equates market price, P, to the marginal cost of production. Setting the price equal to the preceding marginal cost function and solving for Q^S yields the following implied supply function:

$$Q^S = (P, P_L, P_M, K, t) \qquad \textbf{(Eq. 9-9)}$$

where:

P = the price of recreational marine vessels,
P_L = the price of labor, and
P_M = the price of materials input.

All other variables have been previously defined.

An explicit functional form of the production function may be assumed to facilitate estimation of the model. For this analysis, the Cobb-Douglas, or multiplicative form, of the production function is postulated. The Cobb-Douglas production function has the convenient property of yielding constant elasticity measures. The functional form of the production function becomes:

$$Q_t = AK_t^{\alpha_K} t^{\lambda} L_t^{\alpha_L} M_t^{\alpha_M} \qquad \textbf{(Eq. 9-10)}$$

where:

Q_t = output or production in year t,
K_t = the real capital stock in year t,
L_t = the quantity of labor hours used in year t,
M_t = the material inputs in year t, and
$A, \alpha_K, \alpha_L, \alpha_M, \lambda$ = parameters to be estimated by the model.

This equation can be written in linear form by taking the natural logarithms of both sides of the equation. Linear regression techniques may then be applied. Using the approach described, the implied supply function may be derived as:

$$\ln Q = \beta_0 + \gamma \ln P + \beta_1 \ln K + \beta_2 \ln P_L + \beta_3 \ln P_M + \beta_4 \ln t \qquad \textbf{(Eq. 9-11)}$$

where:

P_L = the factor price of the labor input,
P_M = the factor price of the material input, and
K = fixed real capital.

The β_i and γ coefficients are functions of the α_i, the coefficients of the production function. The supply elasticity, γ, is equal to the following:

$$\gamma = \frac{\alpha_L + \alpha_M}{1 - \alpha_L - \alpha_M} \qquad \textbf{(Eq. 9-12)}$$

It is necessary to place some restrictions on the estimated coefficients of the production function in order to have well-defined supply function coefficients. The sum of the coefficients for labor and materials should be less than one. Coefficient values for α_L and α_M that equal to one result in a price elasticity of supply that is undefined, and values greater than one result in negative supply elasticity measures. For these reasons, the production function is estimated with the restriction that the sum of the coefficients for the inputs equal one. This is analogous to assuming that the boat manufacturing industry exhibits constant returns to scale, or is a long-run constant cost industry. This assumption seems reasonable on an *a priori* basis and is not inconsistent with the data.

The estimated model reflects the production function for boats, using annual time series data for the years from 1958 through 1999. The following model was estimated econometrically, using real values of capital stock, production wages, and material inputs:

$$\ln Q_t = \ln A + \alpha_K \ln K_t + \lambda \ln t + \alpha_L \ln L_t + \alpha_M \ln M_t \qquad \textbf{(Eq. 9-13)}$$

where each of the variables and coefficients have been previously defined.

The data inputs used to estimate the supply elasticity are enumerated in Table 9.5-1. This table contains a list of the variables included in the model and the units of measure. The data for the price elasticity of supply estimation model includes: the value of domestic shipments in millions of dollars; the price index for the value of domestic shipments (the value of domestic shipments deflated by the price index represents the quantity variable which is the dependent variable in the analysis); a technology time variable; production wages in millions of dollars; the implicit GDP deflator (used to deflate production wages), the material inputs in millions of dollars; the price index for value of materials; investment in millions of dollars; the price index for investment; and real net capital stock in millions of dollars.

Table 9.5-1
Data Inputs for the Estimation of Supply Elasticity for the Boat Building Industry[19,2021,22,23,24]

Variable	Unit of Measure
1. Value of Shipments for the Boat Building Industry (SIC 3732)	millions of $
2. Price Index of Shipments for the Boat Building Industry (SIC 3732)	index
3. Time trend	-
4. Production Worker Wages	millions of $
5. Implicit GDP Deflator	index
6. Cost of Material Inputs	millions of $
7. Price Index of Material Inputs	index
8. Investment	millions of $
9. Price Index of Investment	index
10. Real Capital Stock	millions of 1987$

Data to estimate the production function exclusively for inboard cruisers were largely unavailable; therefore, data for SIC code 3732 (Boat Building) is utilized for each of the variables previously enumerated with the exception of the time variable. All data for the supply elasticity estimation were retrieved from the National Bureau of Economic Research-Center for Economic Studies (NBER-CES) Productivity Database and the U.S. Census Bureau’s Annual Survey of Manufactures (ASM), with the exception of the technology time trend, the implicit GDP deflator, the price index for investment for SIC 3732 for the years 1997 through 1999, the price indices of shipments and material inputs for SIC 3732 for the years 1998 and 1999, and real capital stock for the years 1998 and 1999 (these data for real capital stock were not available). These variables (except the time trend and real capital stock for 1998 and 1999), were retrieved from the Bureau of Economic Analysis (BEA).

More specifically, the price index of shipments for 1998 and 1999 was retrieved from the BEA’s Shipments of Manufacturing Industries. Note that since a price index of material inputs for SIC 3732 was not available beyond 1997, we relied upon a general price index for intermediate materials from BEA’s Survey of Current Business. A price index for investment for SIC 3732 was also not available beyond 1996, so a general price index for capital equipment was used for the years 1997 - 1999 from the same source. Last, real capital stock for the years 1998 and 1999 was calculated using the following formula:

$$\text{real cap stock}_i = \text{real cap stock}_{i-1} + \text{real investment}_i - \text{depreciation rate*real cap stock}_{i-1} \qquad \textbf{(Eq. 9-14)}$$

where i = 1998, 1999. The depreciation rate for capital for SIC 3732 was taken as the average depreciation rate over the last 10 years for which investment and capital stock data were available (1987 - 1996).

The capital stock variable was the most difficult variable to quantify for use in the econometric model. Ideally, this variable should represent the economic value of the capital stock actually used by each facility to produce boats for each year of the study. The most reasonable data for this variable would be the number of machine hours actually used to produce boats each year. These data are unavailable. In lieu of machine hours data, the dollar value of net capital stock in constant 1987 prices, or real net capital stock, is used as a proxy for this variable. However, these data are imperfect because they represent accounting valuations of capital stock rather than economic valuations. This aberration is not easily remedied, but is generally considered unavoidable in most studies of this kind.

SAS Release 8.2 for Windows was used to develop econometric estimates of the price elasticity of supply for the boat manufacturing industry. A restricted least squares estimator was used to estimate the coefficients of the production function model. A log-linear specification was estimated with the sum of the α_i restricted to unity. This procedure is consistent with the assumption of constant returns to scale. The model was further adjusted to correct for first-order serial correlation using the Yule-Walker estimation method. The results of the estimated model are presented in Table 9.5-2 with p-values listed in parentheses below each coefficient estimate.

Table 9.5-2
Estimated Supply Model Coefficients for the Boat Building Industry

Variables	Estimated Coefficients
ln(Time) *(t)*	0.3445* (<.0001)
ln(Real Capital Stock) (K_t)	0.3888* (<.0001)
ln(Real Production Wages) (L_t)	0.7604* (<.0001)
ln(Real Material Inputs) (M_t)	-0.1492* (<.0001)

* statistically significant

The coefficients for real capital and real production wages have the anticipated signs and are significant at a high level of confidence. The real material inputs coefficient does not have the anticipated sign but does test significantly different from zero. Using the estimated coefficients and the formula for supply elasticity shown above, the price elasticity of supply for boat manufacturing is derived to be 1.57. The calculation of statistical significance for this elasticity measure is not a straightforward calculation since the estimated function is non-linear. No attempt has been made to assess the statistical significance of the estimated elasticity. The corrections for serial correlation and the restricted model results yield inaccurate standard measures of goodness of fit (R^2). However, the model that is unrestricted and unadjusted for serial correlation has an R^2 of 0.99.

The estimated price elasticity of supply for the boat manufacturing industry reflects that the industry in the United States will increase production of boats by 1.57 percent for every 1.0 percent increase in the price of this product. The preceding methodology does not directly estimate the supply elasticity of inboard cruisers due to a lack of necessary data. The assumption implicit in the use of this estimate of price elasticity of supply is that the supply elasticity of inboard cruisers will not differ significantly from the price elasticity of supply for all products classified under SIC code 3732.

9.5.2.2 Price Elasticity Estimation for Forklifts

Demand Elasticity

Forklifts are used as intermediate products to produce final goods. The demand for large SI engine forklifts is therefore derived from the demand for these final products. Information is provided in Section 2.2 concerning the end uses of forklifts. According to this information, forklifts are used primarily as an input in the manufacturing and wholesale trade sectors. One primary use for forklifts is to lift and transport materials and merchandise in warehouse or retail trade settings. Forklifts are therefore used in the production of a wide variety of goods manufactured by these sectors of the economy.

The assumption was made that firms using forklifts as inputs into their productive processes seek to maximize profits. The profit function for these firms may be written as follows:

$$\underset{Q,I}{MAX}\ \pi = P_{FP} \times f(Q, I) - (P \times Q) - (P_{OI} \times I) \qquad \textbf{(Eq. 9-15)}$$

where:

π = profit,
P_{FP} = the price of the final product or end-use product,
$f(Q, I)$ = the production function of the firm producing the final product,
P = the price of the forklifts,
Q = the quantity input use of forklifts
P_{OI} = a vector of prices of other inputs used to produce the final product, and
I = a vector of other inputs used to produce the final product.

The solution to the profit function maximization results in a system of derived demand equations for forklifts. The derived demand equations are of the following form:

$$Q \bullet g(P, P_{FP}, P_{OI}) \qquad \textbf{(Eq. 9-16)}$$

A multiplicative functional form of the derived demand equations are assumed because of the useful properties associated with this functional form. The functional form of the derived demand function is expressed in the following formula:

$$Q = AP^{\beta} P_{FP}^{\beta_{FP}} \quad \textbf{(Eq. 9-17)}$$

where:

A = a constant

β = the price elasticity of demand for forklifts, and

β_{FP} = the final product price elasticity with respect to the use of forklifts.

All other variables have been previously defined and β, β_{FP}, and A are parameters to be estimated by the model. In the above equation, β represents the own-price elasticity of demand. The price of other inputs (represented by P_{OI}) has been omitted from the estimated model, because data relevant to these inputs were unavailable. The implication of this omission is that the use of forklifts in production is fixed by technology.

The market price and quantity sold of forklifts are simultaneously determined by the demand and supply equations. For this reason, it is advantageous to apply a systems estimator to obtain unbiased and consistent estimates of the coefficients for the demand equations.[25] Two-stage least squares (2SLS) is the estimation procedure used in this analysis to estimate the demand equation for forklifts. Two-stage least squares uses the information available from the specification of an equation system to obtain a unique estimate for each structural parameter. The first stage of the 2SLS procedure involves regressing the observed price of forklifts against the supply and demand “shifter” variables that are exogenous to the system. These are referred to as instruments. This first stage produces fitted (or predicted) values for the forklift price variable that are, by definition, uncorrelated with the error term by construction and thus do not incur endogeneity bias. These fitted values for price are then used in the second stage equation (see Eq. 9-17). By converting the above equation to natural logarithms, the coefficient on the forklift price variable (β) yields an estimate of constant elasticity of supply.

The exogenous supply-side variables used to estimate the demand function include: the real capital stock variable for SIC code 3537 (the industry that manufactures forklifts), a technology time trend (t), and the price indices for the cost of labor and the cost of materials for SIC code 3537. A price index for the cost of labor was generated by dividing real production worker wages (derived by dividing nominal production worker wages by the implicit GDP deflator) by production worker hours. The demand-side variables include: real GDP and the price indices of manufacturing and wholesale trade. Generally, the price of final products are used as demand-side variables, but because forklifts are used as an input to the production of a wide variety of goods, we rely upon price indices of the manufacturing and wholesale trade sectors.

Data relevant to the econometric modeling of the price elasticity of demand for forklifts are listed in Table 9.5-3. Consistent time series data for the period 1970 through 1999 were obtained. The annual domestic quantity of forklift shipments was retrieved from the Industrial Truck Association Membership Handbook. Price data for forklifts over this time period were not available, so the price index of shipments for SIC code 3537 was retrieved from both the NBER-CES Productivity Database and BEA's Shipments of Manufacturing Industries instead. The following variables were also retrieved from the NBER-CES Productivity Database and the Census Bureau's ASM: production worker wages, production worker hours, real capital stock (except for the years 1998 and 1999), investment, the price index of investment (except for the years 1997 through 1999), and the price indices of shipments and material inputs (except for the years 1998 and 1999).

Other variables, including the price indices for the manufacturing and wholesale trade industries, the implicit GDP deflator, real GDP, the price index of investment for SIC code 3537 for the years 1997 to 1999, and the price indices of shipments and material inputs for the years 1998 and 1999 were retrieved from the Bureau of Economic Analysis. Note that since a price index of material inputs for SIC 3537 was not available beyond 1997, we relied upon a general price index for intermediate materials from BEA's Survey of Current Business. A price index for investment for SIC 3537 was also not available beyond 1996, so a general price index for capital equipment was used for the years 1997 - 1999 from the same source. Real capital stock for the years 1998 and 1999 was derived for SIC 3537 (see Equation 9-13 for the equation used to calculate real capital stock for these years).

Table 9.5-3
Data Inputs for the Estimation of
Demand Equations for the Forklift Industry[26,27,28,29,30,31,32]

Variable	Unit of Measure
1. Time Trend	-
2. Price Index of Shipments for the Industrial Truck, Tractor, Trailer, and Stacker Mainery Industry (SIC 3537)	index
3. Quantity of Forklift Shipments	units
4. Price Index for the Manufacturing Industry	index
5. Price Index for the Wholesale Trade Industry	index
6. Price Index of Material Inputs	index
7. Production Worker Wages	millions of $
8. Implicit GDP Deflator	index
9. Production Worker Hours	thousands of worker hours
10. Investment	millions of $
11. Price Index of Investment	index
12. Real Capital Stock	millions of $1987
13. Real Gross Domestic Product	billions of $1987

SAS Release 8.2 for Windows was used to econometrically estimate the price elasticity of demand. Two-stage least squares econometric models were estimated for the forklift industry using the price indices of manufacturing and wholesale trade as the end-use products, respectively. Relying on price indices for entire sectors of the economy to represent specific end-use products is not ideal, but price data on specific products that forklifts are used to manufacture are not readily available. Additionally, forklifts are used in the production of a large variety of goods and it would therefore be difficult to determine which products to focus on for the estimation of demand elasticity. The data limitations are recognized and the demand elasticity estimates generated here are therefore, interpreted with caution.

Overall, the models using price indices for these end products were not successful. This may be due in part to the fact that price indices for entire sectors of the economy are not reliable instruments for the prices of the final products that forklifts are used to produce. The coefficient for the price index of shipments for SIC 3537 was not statistically different from zero in the model which included manufacturing. In the second model, which used the price index of wholesale trade in lieu of price index of manufacturing, the coefficient on the price index of shipments for SIC 3537 was significantly different than zero, but was equal to -5.8, an extremely large estimate of demand elasticity. The model results using the price indices of manufacturing and wholesale trade as the final product prices are reported in Table 9.5-4. with p-values listed below each coefficient estimate. Each of the coefficients reported has the anticipated sign, however not all of the estimates are significantly different from zero.

The price elasticity of demand estimate reflects an elastic demand for forklifts. Regulatory control costs are less likely to be paid by consumers of products with elastic demand when compared to products with inelastic demand, all other things held constant. Price increases for products with elastic price elasticity of demand lead to decreases in revenues for producers, however it does say anything with regard to producer profits.

A degree of uncertainty is associated with this method of demand estimation. The estimation is not robust since the model results vary depending upon the instruments used in the estimation process. For this reason, the above results are used as an indication that the elasticity of demand is elastic and we instead rely upon an assumed measure of -1.5 for the own-price elasticity of demand for forklifts.

Table 9.5-4
Derived Demand Coefficients Equations for the Forklift Industry

Variables	Estimation 1	Estimation 2
Own Price β	-3.03	-5.76*
ln(PI of Shipments for SIC 3537)	(0.1113)	(<.0001)
End-Use β_{FP}	0.17	
ln(PI of Manufacturing)	(0.9203)	
End-Use β_{FP}		3.11*
ln(PI of Wholesale Trade)		(0.0142)
ln(Real GDP)	3.44*	4.23*
	(<.0001)	(<.0001)
F value	24.25*	32.96*
	(<.0001)	(<.0001)
Adjusted R-Square	0.76	0.813

* statistically significant.

Supply Elasticity

Published sources of the price elasticity of forklift supply were not readily available. For this reason, an econometric analysis of the price elasticity of supply for forklifts was conducted using the same approach as the one used to estimate the supply elasticity for boat manufacturing described above.

The estimated model reflects the production function for forklifts, using annual time series data for the years from 1958 through 1999. The data used to estimate supply elasticity are enumerated in Table 9.5-5. The data for the price elasticity of supply estimation model includes: the value of domestic shipments of SIC 3537 in millions of dollars; the price index for value of domestic shipments (the value of domestic shipments deflated by the price index represents the quantity variable which is the dependent variable in the analysis); a technology time variable; production wages in millions of dollars; the implicit GDP deflator (used to deflate production wages), the material inputs in millions of dollars; the price index for value of materials; investment in millions of dollars; the price index of investment; and real net capital stock in millions of dollars.

Data to estimate the production function for the forklifts exclusively were largely unavailable; therefore, data for SIC code 3537 is utilized for each of the variables previously enumerated with the exception of the time variable. All data for the supply elasticity estimation were retrieved from the National Bureau of Economic Research-Center for Economic Studies (NBER-CES) Productivity Database and the U.S. Census Bureau's Annual Survey of Manufactures (ASM), with the exception of the technology time trend, the implicit GDP deflator, the price index for investment for SIC 3537 for the years 1997 through 1999, the price indices of shipments and material inputs for SIC 3537 for the years 1998 and 1999, and real capital stock for the years 1998 and 1999 (these data for real capital stock were not available). These variables (except the time trend and real capital stock for 1998 and 1999), were retrieved from the Bureau of Economic Analysis (BEA).

More specifically, the price index of shipments for SIC 3537 for the years 1998 and 1999 was retrieved from the BEA's Shipments of Manufacturing Industries. Similar to the boat manufacturing industry, a price index of material inputs for SIC 3537 was not available beyond 1997. We therefore relied upon a general price index for intermediate materials from BEA's Survey of Current Business. A price index for investment for SIC 3537 was also not available beyond 1996, so a general price index for capital equipment was used for the years 1997 - 1999 from the same source. Real capital stock for the years 1998 and 1999 was derived for SIC 3537 (see Equation 9-13 for the equation used to calculate real capital stock for these years).

Again, the capital stock variable was the most difficult variable to quantify for use in the econometric model. Ideally, this variable should represent the economic value of the capital stock actually used by each facility to produce forklifts for each year of the study. The most reasonable data for this variable would be the number of machine hours actually used to produce forklifts each year, but we do not possess this information. In lieu of machine hours data, the dollar value of net capital stock in constant 1987 prices, or real net capital stock, is used as a proxy for this variable.

Table 9.5-5
Data Inputs for the Estimation of Supply Elasticity for the Forklift Industry[33,3435,36,37,38]

Variable	Unit of Measure
1. Value of Shipments for the Industrial Truck, Tractor, Trailer, and Stacker Machinery Industry (SIC 3537)	millions of $
2. Price Index of Shipments for the Industrial Truck, Tractor, Trailer, and Stacker Machinery Industry (SIC 3537)	index
3. Time trend	-
4. Production Worker Wages	millions of $
5. Implicit GDP Deflator	index
6. Cost of Material Inputs	millions of $
7. Price Index of Material Inputs	index
8. Investment	millions of $
9. Price Index of Investment	index
8. Real Capital Stock	millions of 1987$

SAS Release 8.2 for Windows was used to estimate econometric estimates of the price elasticity of supply for the forklift manufacturing industry. A restricted least squares estimator was used to estimate the coefficients of the production function model. A log-linear specification was estimated with the sum of the α_i restricted to unity. This procedure is consistent with the assumption of constant returns to scale. The model was further adjusted to correct for first-order serial correlation using the Yule-Walker estimation method. The results of the estimated model are presented in Table 9.5-6 with p-values listed in parentheses below each coefficient estimate.

Table 9.5-6
Estimated Supply Model Coefficients for the Forklift Industry

Variables	Estimated Coefficients
ln(Time) (t)	0.1676 (.2066)
ln(Real Capital Stock) (K_t)	0.5833* (0.0070)
ln(Real Production Wages) (L_t)	1.1632* (<0.0001)
ln(Real Material Inputs) (M_t)	-0.7466* (0.0002)

* statistically significant

The coefficients for real capital and real production wages have the anticipated signs and are significant at a high level of confidence. The real material inputs coefficient does not have the anticipated sign and also tests significantly different from zero. Using the estimated coefficients and the formula for supply elasticity shown above, the price elasticity of supply for forklift manufacturing is derived to be 0.714. The calculation of statistical significance for this elasticity measure is not a straightforward calculation since the estimated function is non-linear. No attempt has been made to assess the statistical significance of the estimated elasticity. The corrections for serial correlation and the restricted model results yield inaccurate standard measures of goodness of fit (R^2). However, the model that is unrestricted and unadjusted for serial correlation has an R^2 of 0.99.

The estimated price elasticity of supply for the forklift manufacturing industry reflects that the industry in the United States will increase production of forklifts by 0.714 percent for every 1.0 percent increase in the price of this product. The preceding methodology does not directly estimate the supply elasticities for forklifts due to a lack of necessary data. The assumption implicit in the use of this price elasticity of supply estimate is that the supply elasticity of forklifts will not differ significantly from the price elasticity of supply for all products classified under SIC code 3537.

9.5.2.3 Price Elasticity Estimation for Snowmobiles

Demand Elasticity

The price elasticity of demand is an important input into the market model, and this information is required to characterize the demand for snowmobiles. Econometric estimation of the price elasticity of demand for snowmobiles was unsuccessful despite numerous model specifications and varied statistical techniques evaluated. A search of the literature did not provide snowmobile price elasticity of demand estimates. A study was conducted for the recreational boat industry in 1987.[39] This study estimates the price elasticity of demand for boats to be -1.78. The price elasticity of demand for a variety of pleasure boat categories were estimated. These estimates range from -1.4 to -2.17. For purposes of this analysis a price elasticity of demand for snowmobiles of -2 is postulated. Since this estimate does not relate specifically to the snowmobile market but to another category of recreational vehicles, and there are uncertainties associated with elasticity estimates, a sensitivity analysis of the impact of this estimate on model results is shown in the Appendix to Chapter 9 of this report.

Supply Elasticity

The price elasticity of supply for snowmobiles is a necessary input into the market model. A literature search did not provide any estimates of this required input. An econometric analysis is conducted and a value for this parameter is estimated. Several approaches were considered including a simultaneous equation approach, a production function approach and a simple supply function specification. Econometric results from the latter approach are presented. With this approach, the quantity of snowmobiles produced is hypothesized to be a function of the price of the product and the price of factors of production including the materials, labor, and capital as follows:

$$Q_t = f\,(P_t, P_{M\,t,}, P_{L\,t,}\, P_{K\,t}) + u_t,$$

Where Q_t is the quantity of snowmobiles produced and sold in period t and $P_{M\,t,}$, $P_{L\,t,}$ $P_{K\,t}$ are the factor prices for inputs of production (materials, labor and capital, respectively) in period t. The data used to estimate the elasticity are enumerated in Table 9.5-7. Consistent time series data for the years 1986 through 2000 are used in the analysis. All price data have been restated into real values using the implicit GDP deflator. Snowmobile price and quantity data are provided by ISMA. The quantity of snowmobiles sold are restated to be values sold on a per household basis. Cost of production data for the snowmobile industry are largely unavailable. In lieu of the cost production data specific to snowmobile production, cost of production data for SIC 3799/NAICS code 336999 Other Transportation Equipment (includes snowmobiles as a product category) are used in the analysis as a proxy for the cost of production data for snowmobiles. The data used for the analysis are listed in Table 9.5-7.

Table 9.5-7
Data Inputs for the Estimation of Supply Elasticity for the Snowmobile Industry[40,41,42,43,44,45,46,47]

Variable	Unit of Measure
1. Quantity of Snowmobiles Sold	units
2. US Households	number of households
3. Average price of snowmobiles sold	dollars
4. Price Index - Materials (SIC 3799 /NAICS 336999)	price index
5. Price Index - Investment (SIC 3799 /NAICS 336999)	price index
6. Wages per employee (SIC 3799 /NAICS 336999)	dollars
7. Real Implicit Gross Domestic Product Deflator	price index

SAS Release 8.2 for Windows was used to develop econometric estimates of the price elasticity of supply for the snowmobile industry. A log-log specification of the model was estimated. The price of capital was omitted from the model specification due to high correlation with the snowmobile price data. The model was further adjusted to correct for serial correlation using the Yule-Walker estimation method. Alternative lag periods were considered. The results of the estimated model are presented in Table 9.5-8 with related standard errors. Based upon this analysis the price elasticity of supply for the snowmobile industry is estimated to be 2.10.

Table 9.5-8
Estimated Supply Model Coefficients for the Snowmobile Industry

Variables	Estimated Coefficient	Standard Errors
Intercept	-16.4236	1.9094*
log (real price of snowmobiles)	2.1043	0.2441*
log (real wages per employee) (P_{Lt})	-0.2858	0.5479
log (real price of materials)(P_{Mt})	0.1617	0.1322
Total R-Square	0.9771	
Durbin-Watson Statistic	1.9728	

* Statistically significant at the 1% significance level.

The estimated model is statistically significant. The coefficient for real wages per employee has the anticipated signs but is not statistically significant. The coefficient for the materials variable does not have the anticipated sign and is not statistically significant. The coefficient for the price variable has the expected sign and is statistically significant. This value provides an estimate for the price elasticity of supply for snowmobiles. The estimated model is statistically significant. This value of 2.10 represents the price elasticity of supply used in the study. The uncertainty associated with this estimate is acknowledged. A sensitivity analysis of this model input is conducted in the appendix to this chapter.

9.5.2.4 Price Elasticity Estimation for All-Terrain Vehicles

Demand Elasticity

The price elasticity of demand is an important input to the market model, and this information is required to characterize the demand for ATVs. Econometric estimation of the price elasticity of demand for this market was unsuccessful despite numerous model specifications and varied statistical techniques evaluated. A search of the literature did not provide ATV price elasticity of demand estimates. A study was conducted for the recreational boat industry in 1987.[48] This study estimates the price elasticity of demand for boats to be -1.78. The price elasticity of demand for a variety of pleasure boat categories were estimated. These estimates range from -1.4 to -2.17. For purposes of this analysis, a price elasticity of demand for ATVs of -2 is postulated. Since this estimate does not relate specifically to the ATV market but another category of recreational vehicles and there are uncertainties associated with elasticity estimates in general, a sensitivity analysis of the impact of this estimate on model results is shown in the Appendix to Chapter 9 of this report.

Supply Elasticity

The price elasticity of supply is a necessary input in the market model. This estimate is required to characterize the way producers of ATVs respond to a change in the price of the product. A search of the economic literature was conducted without success. Econometric estimation of this variable were undertaken also without success. Numerous model specification and variable combinations were investigated, but the results were not satisfactory from a statistical perspective. The price elasticity of supply for off-highway motorcycles was estimated to be -0.93. Since the productive processes are similar for ATVs and off-highway motorcycles and many of the producers of ATVs also produce off-highway motorcycles, the supply elasticity for off-highway motorcycles appears to be a reasonable proxy for the supply elasticity for ATVs. A discussion of the techniques and data used to econometrically estimate this value follows in Section 9.5.2.5.

9.5.2.5 Price Elasticity Estimation for Off-Highway Motorcycles

Demand Elasticity

The price elasticity of demand is an important component of the market model and this information is required to characterize the demand for off-highway motorcycles. Econometric estimation of the price elasticity of demand for this market was unsuccessful despite numerous model specifications and varied statistical techniques evaluated. A search of the literature did not provide off-highway motorcycle price elasticity of demand estimates. A study was conducted for the recreational boat industry in 1987.[49] This study estimates the price elasticity of demand for boats to be -1.78. The price elasticity of demand for a variety of pleasure boat categories were estimated. These estimates range from -1.4 to -2.17. For purposes of this analysis a price elasticity of demand for off-highway motorcycles of -2 is postulated. Since this estimate does not relate specifically to the off-highway motorcycle market but another category of recreational vehicles and there are uncertainties associated with elasticity estimates in general, a sensitivity analysis of the impact of this estimate on model results is shown in the Appendix to Chapter 9 of this report.

Supply Elasticity

The price elasticity of supply for off-highway motorcycles is econometrically estimated. Data for the study is provided by the MIC and collected from publicly available sources. A description of the data used in the study, the modeling techniques used, and the model results are presented.

Methodology

A partial equilibrium market demand/supply model is specified as a system of interdependent equations in which the price and output of a product are simultaneously determined by the interaction of producers and consumers in the market. In simultaneous equation models, where variables in one equation feed back into variable in other equations, the error terms are correlated with the endogenous variables (price and output). In this case, single-equation ordinary least squares (OLS) estimation of individual equations will lead to biased and inconsistent parameter estimates. Thus, simultaneous estimation of this system to obtain elasticity estimates requires that each equation be identified through the inclusion of exogenous variable to control for shifts in the supply and demand curves over time.

The supply/demand system for OHM over time (t) is defined as follows:

$$Q_t^d = f(P_t, Z_t) + u_t$$

$$Q_t^s = (P_t, W_t) + v_t$$

$$Q_t^d = Q_t^s$$

The first equation above shows quantity demanded in year t as a function of price, P_t and an array of demand factors (e.g., measures of economic activity and substitute prices), and an error term, u_t. The second equation characterizes supply for the OHM market. The quantity supplied, Q_t^s in year t is a function of price and other supply factors, W_t (e.g., input prices) and an error term, v_t. The third equation specifies the equilibrium condition that quantity supplied equals quantity demanded in year t creating a system of three equations in three variables . The interaction of the specified market forces solves this system generating equilibrium values for the variables P_t* and $Q_t^* = Q_t^{d*} = Q_t^{s*.}$

Since the objective is to generate estimates of the supply equation for use in the economic model, the EPA employed the two-stage least squares (2SLS) regression procedure to estimate only the parameters of the supply equation. Similar techniques for the demand equation were unsuccessful. EPA specified the logarithm of the quantity supplied as a linear function of the logarithm of the price so that the coefficient on the price variable yields the estimate of the constant elasticity of supply for OHM. All prices employed in the estimation process were deflated by the gross domestic product (GDP) implicit price deflator to reflect real rather than nominal prices. The first stage produces fitted (or predicted) values for the price variables that are, by definition, highly correlated with the error term. In the second stage, these fitted values are then employed as observations of the right hand side price variable in the supply function. This fitted value is uncorrelated with the error term by construction and thus does not incur the endogeneity bias.

Data

Price and quantity data were provided by MIC for the period 1990 through 2000. Thus the study uses annual data for the period 1990 through 2000. For the supply equation estimated, supply is postulated to be a function of price, a trend variable to recognize technology changes over time, and the price of inputs of production. A number of factor prices were considered including the price of materials, labor, and capital. Unfortunately these inputs price are some cases highly correlated. For this reason, the price of materials is used in estimation. A listing of the data used in the analysis and the source of the data are shown in Table 9.5-9. All data used in the analysis are deflated to real values using the real gross domestic product implicit price deflator. Sales quantities and income values are restated to per US household values. All values are restated to natural logs.

Table 9.5-9
Data Inputs for Off-Highway Motorcycle Supply Estimation[50,51,52,53,54,55,56,57]

Variable	Unit of Measure
1. Quantity of OHM sold	units
2. US households	number
3. Average price OHM	dollars
4. Time trend	N/A
5. Price index for materials used in production	price index
6. Price of a substitute product (SIC 3799/NAICS 336999)	price index
7. Disposable household income	dollars
8. Real implicit GDP deflator	price index

Results

The results of the supply estimation are shown in Table 9.5-10

Table 9.5-10
Estimated Supply Model for the Off-Highway Motorcycle Industry

Parameter	Parameter Estimate	Standard Error
Intercept	-10.7632*	0.179407
log (Trend Variable)	-0.03399*	0.005626
log (Real Price)	0.93323*	0.017468
log (Price of materials used in production of OHM)	-0.36977	0.294203
Adjusted R Square	0 .9996	
F-Value	8867.69*	
Durbin Watson	1.65	

* Statistically significant at the 1% significance level.

The estimated equation and coefficients have the expected sign and are statistically significant at a 1% significance level with the exception of the cost of materials variable. While the coefficient for the price of materials variable has the expected sign, it is not statistically significant. The coefficient for the natural log of the real price variable of 0.93 is the estimate of the price elasticity of supply for the off-highway motorcycle market. The uncertainty surrounding this estimate is recognized and a sensitivity analysis of this model input is conducted in the appendix to this chapter.

9.6 Marine

The following section describes the baseline characterization of the market in the year 2001, the per unit regulatory control costs incurred by producers of recreational diesel marine vessels, and the economic impacts that would have resulted had the emissions control program been implemented in the baseline year. We also examine the economic impacts on the diesel inboard cruiser market using baseline year data for each change in the per unit control costs that occurs. This section concludes with a comparison of the stream of engineering costs and estimated welfare losses (excluding fuel efficiency gains) projected to occur after the regulation's implementation. No fuel efficiency gains are projected to occur from the standard affecting diesel recreational marine vessels, therefore the social costs (surplus losses net fuel cost savings) are equal to the surplus losses projected from the model.

9.6.1 Marine Baseline Market Characterization

Inputs to the economic analysis are a year 2001 baseline characterization of the diesel inboard cruiser market that includes the domestic quantity produced, quantity of imports, baseline market price, demand elasticity, and domestic and foreign supply elasticity measures. Table 9.6-1 provides the baseline data on the U.S. diesel inboard cruiser market used in this analysis.

Table 9.6-1
Baseline Characterization of the U.S. Diesel Inboard Cruiser Market: 2001

Inputs	Baseline Observation
Market price ($/boat)	$341,945.00
Market output (boats)	8435
Domestic	8098
Foreign	337
Elasticities	
Domestic supply (estimated)	1.57
Foreign supply (assumed)	1.57
Demand (previously estimated)	-1.44

The total market output of diesel inboard cruiser marine vessels was derived from data taken from publications of the National Marine Manufacturers Association[58,59]. EPA projected the quantity of CI marine engines for the years 1998 through 2030 based upon NMMA's historical data on the quantity of inboard cruisers sold in the U.S. For the year 2001, EPA's projection shows that 16,068 engines were sold domestically. This total includes those engines sold in the U.S. whether they were produced domestically or abroad. A simplifying assumption has been made that all of these engines are used in inboard cruisers, though we acknowledge that there is an extremely small fraction of these engines that are used in inboard runabouts (approximately 2 percent) and an even smaller fraction used in marine vessels with outboard engine configurations.[60] A majority (95 percent) of inboard cruisers contain two engines.[61] Using this information, we find that the 16,068 recreational diesel marine engines sold in 2001 would yield 8,435 diesel inboard cruisers.

Market output is not partitioned into domestically produced and imported quantities of recreational diesel marine engines. In order to determine the share of imported boats, historical import quantities of inboard cruisers were compared with the domestically produced quantities reported in Table 2.1-7 for the years 1992 to 2000[62]. On average, imported inboard cruisers were equal to about 4 percent of the inboard cruisers produced and sold in the U.S. This information was used to partition the total quantity of diesel inboard boats for the year 2001.

The price of diesel inboard cruisers was taken to be equal to the average retail price of all inboard cruisers sold in the year 2001. NMMA quotes this price at $341,945.[63] The estimates of demand and supply elasticity have been discussed in detail in Section 9.5.2.1. A separate estimate of foreign supply elasticity has not been carried out. For modeling purposes, we assume that the foreign supply elasticity is equal to the domestic supply elasticity.

9.6.2 Marine Control Costs

In order to determine a per diesel inboard cruiser cost over the years 2006 to 2030 for use in the economic analysis, the future stream of engineering costs (without fuel savings) provided in Chapter 7 is divided by the number of boats EPA projected from the NMMA data. This yields a stream of average cost per diesel inboard cruiser. As stated in the section above, the EPA projected the quantity of recreational diesel marine engines sold in the U.S. for the years 1998 through 2030. Using these engine quantities and the fact that approximately 95 percent of inboard cruisers contain two engines, we developed a projected stream of domestic diesel inboard cruiser sales. The total stream of engineering costs from Chapter 7, the projected number of diesel inboard cruisers, and the average regulatory cost per boat are provided in Table 9.6-2. During the initial years of implementation, the per unit costs change but by 2014, they are projected to remain the same.

Table 9.6-2
Projected Future Stream of Engineering Costs ($\$10^3$), Quantity of Diesel Inboard Cruisers, and Per Diesel Inboard Cruiser Regulatory Costs

Year	Estimated Engineering Costs	Projected Quantity of Diesel Inboard Cruisers	Cost Per Diesel Inboard Cruiser
2006	$7,806.0	9665	$808
2007	$8,365.3	9913	$844
2008	$8,573.8	10159	$844
2009	$9,413.5	10407	$905
2010	$9,637.0	10653	$905
2011	$5,213.4	10899	$478
2012	$5,176.7	11145	$464
2013	$5,290.8	11390	$464
2014	$4,958.1	11636	$426
2015	$5,062.7	11882	$426
2016	$5,167.7	12128	$426
2017	$5,272.7	12374	$426
2018	$5,377.6	12621	$426
2019	$5,482.6	12867	$426
2020	$5,587.6	13113	$426
2021	$5,692.5	13360	$426
2022	$5,797.5	13606	$426
2023	$5,902.5	13853	$426
2024	$6,007.4	14099	$426
2025	$6,112.4	14345	$426
2026	$6,217.2	14591	$426
2027	$6,322.0	14837	$426
2028	$6,426.9	15083	$426
2029	$6,531.7	15329	$426
2030	$6,636.5	15575	$426

9.6.3 Marine Economic Impact Results

The economic impacts of the emissions control program for recreational diesel marine vessels are estimated for each year in which the per vessel regulatory costs change, assuming the baseline year 2001 price and quantity. Though we possess projected quantities of diesel inboard cruiser marine vessels through the year 2030, we do not have future year prices. We are therefore unable to estimate the economic impacts of the future costs assuming future year quantities and prices. For this reason, we rely upon the most current year of data to inform the model when we impose the future costs per vessel on producers. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The estimated percent changes in price and quantity, the changes consumer and producer surplus, and the total loss in surplus are presented for various years in Tables 9.6-3 and 9.6-4.

Table 9.6-3
Price and Quantity Changes for the Diesel Inboard Cruiser Market*

Impact Measure	2006	2007/8	2009/10	2011	2012/13	2014+
Cost Per Unit	$808	$844	$905	$478	$464	$426
Change in Market Price	0.12%	0.13%	0.14%	0.07%	0.07%	0.06%
Change in Market Output	-0.18%	-0.19%	-0.20%	-0.10%	-0.10%	-0.09%
Domestic	-0.18%	-0.19%	-0.20%	-0.10%	-0.10%	-0.09%
Foreign	-0.18%	-0.19%	-0.20%	-0.10%	-0.10%	-0.09%

*Results are the same for the years 2007 and 2008, 2009 and 2010, and for the years 2012 and 2013. They are also the same for the years 2014 and beyond. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2001 market conditions and fuel cost savings are not included.

Table 9.6-4
Annual Losses in Consumer and
Producer Surplus and for the Diesel Inboard Cruiser Market*

Impact Measure	2006	2007/8	2009/10	2011	2012/13	2014+
Loss in CS** ($$10^3$)	$3,551.8	$3,709.9	$3,977.7	$2,101.9	$2,040.4	$1,873.4
Loss in PS*** ($$10^3$)	$3,251.9	$3,396.4	$3,641.1	$1,925.8	$1,869.5	$1,716.6
Domestic	$3,122.0	$3,260.7	$3,495.6	$1,848.9	$1,794.8	$1,648.0
Foreign	$129.9	$135.7	$145.5	$76.9	$74.7	$68.6
Loss in Surplus ($$10^3$)	$6,083.7	$7,106.3	$7,618.8	$4,027.7	$3,909.9	$3,590.0

*Results are the same for the years 2007 and 2008, 2009 and 2010, and for the years 2012 and 2013. They are also the same for the years 2014 and beyond. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2001 market conditions and fuel cost savings are not included.
** CS refers to consumer surplus and is rounded to the nearest hundredths. For a description of the change in consumer surplus, see Section 9.2.2
*** PS refers to producer surplus and is rounded to the nearest hundredths. For a description of the change in producer surplus, see Section 9.2.2.

As Table 9.6-3 shows, the relative increases in price due to the regulatory costs are less than two-tenths of a percent while the reductions in output are less than one-quarter of a percent. These impacts are considered minimal. Also notable is that the percent changes in price and quantity peak in the years 2009 and 2010 but then are smaller further out into the future. The percent reduction in quantity is the same for both domestic and foreign output because it has been assumed that domestic and foreign supply have the same price elasticity.

Table 9.6-4 presents the loss in consumer surplus, the loss in producer surplus, and the loss in surplus (equal to the sum of the changes in consumer and producer surplus). These results show that the losses in consumer and producer surplus are approximately equal in size, though the loss in producer surplus is slightly less than the loss in consumer surplus. Consumer surplus losses range from a high of just under $4 million to a low of $1.9 million, while the losses in producer surplus vary from $3.6 million to $1.7 million. Like the price and quantity changes, these measures are largest in the years 2009 and 2010. They then decline to their lowest value in 2014 and beyond.

9.6.4 Marine Engineering Cost and Surplus Loss Comparison

Table 9.6-5 presents the future stream of estimated engineering costs holding quantity constant to the baseline year quantity and the loss in surplus that has been estimated from the economic impact model. Because economic modeling takes into account consumer and producer behavior, the estimated surplus losses are less than the engineering costs under a perfectly competitive market setting. In this case, surplus losses are, on average equal to over 99 percent of the calculated engineering costs. Note that the costs provided in this table are not discounted.

Based upon the annual ratio of surplus losses to engineering costs holding quantity constant to baseline year quantity, a projection of surplus losses over the future year stream is calculated from the future stream of engineering costs that appear in Chapter 7. The projected future stream of surplus loss is calculated by multiplying the annual ratio by the future stream of engineering costs and is presented in Table 9.6-6. Again, these costs are not discounted.

9.6.5 Marine Economic Impact Results with Fuel Cost Savings

No fuel savings are projected for the recreational diesel marine engine category, therefore there are no alternative results to present for this vehicle category. The stream of social costs for this vehicle category are equal to the stream of estimated surplus losses shown in Table 9.6-6.

Table 9.6-5
Interim Engineering Cost and Surplus Loss Comparison for the Recreational Diesel Marine Vessel Market Based on Year 2001 Quantity (Q =8,435 inboard cruisers)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$6,812,980	$6,803,645
2007	$7,119,006	$7,106,227
2008	$7,119,006	$7,106,227
2009	$7,630,744	$7,618,828

2010	$7,630,982	$7,618,828
2011	$4,035,120	$4,027,788
2012	$3,918,352	$3,909,937
2013	$3,918,326	$3,909,937
2014	$3,594,386	$3,590,020
2015	$3,594,365	$3,590,020
2016	$3,594,403	$3,590,020
2017	$3,594,441	$3,590,020
2018	$3,594,328	$3,590,020
2019	$3,594,365	$3,590,020
2020	$3,594,401	$3,590,020
2021	$3,594,436	$3,590,020
2022	$3,594,470	$3,590,020
2023	$3,594,365	$3,590,020
2024	$3,594,399	$3,590,020
2025	$3,549,432	$3,590,020
2026	$3,594,373	$3,590,020
2027	$3,594,444	$3,590,020
2028	$3,594,388	$3,590,020
2029	$3,594,456	$3,590,020
2030	$3,594,401	$3,590,020

Table 9.6-6
Engineering Costs and Surplus Loss Comparison for the Recreational Diesel Marine Vessel Market

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$7,806,010	$7,795,314
2007	$8,365,319	$8,350,303
2008	$8,573,839	$8,558,165
2009	$9,413,530	$9,398,831
2010	$9,637,035	$9,621,686
2011	$5,213,411	$5,203,938
2012	$5,176,672	$5,165,555
2013	$5,290,764	$5,279,437
2014	$4,958,052	$4,952,029
2015	$5,062,713	$5,056,593
2016	$5,167,682	$5,161,380

2017	$5,272,652	$5,266,167
2018	$5,377,623	$5,371,178
2019	$5,482,592	$5,475,965
2020	$5,587,562	$5,580,752
2021	$5,692,532	$5,685,539
2022	$5,797,503	$5,790,326
2023	$5,902,472	$5,895,337
2024	$6,007,442	$6,000,124
2025	$6,112,413	$6,104,911
2026	$6,217,227	$6,209,698
2027	$6,322,042	$6,314,262
2028	$6,426,858	$6,419,049
2029	$6,531,673	$6,523,512
2030	$6,636,488	$6,628,400

9.7 Large SI Engines

As described in Chapter 2 and illustrated in Table 6.2.2-1, Large SI engines are used in nearly 50 different applications ranging from fairly small, low horsepower equipment used in lawncare applications to agricultural and construction equipment exceeding 100 horsepower. Forklifts are clearly the dominant application in this category, accounting for about 52 percent of the 2000 populations of Large SI engines. The next largest applications are generators, accounting for about 15 percent, and commercial turf applications, accounting for about 6 percent. Forklifts are also used more than other applications, for about 15,000 hours over the average operating life of the equipment, compared to about 6,000 hours for the next most-used applications (e.g., aerial lifts, refrigeration/AC, cranes). Similarly, forklifts accounted for nearly 81 percent of the NOx, 64 percent of the HC, 54 percent of the CO, and 76 percent of the PM emissions from Large SI engines in 2000. Because of their dominant position in this category, the following economic impact analysis focuses on the forklift segment. Specifically, we estimate the change in price and quantity, and the sum of consumer and producer surplus losses only for forklifts. To estimate the total social costs/gains for Large SI, we use the engineering costs to approximate the sum of consumer and producer surplus losses for Large SI engines other than forklifts. This approach slightly overestimates the surplus losses for the category since engineering costs are higher than surplus losses.

While it would be possible to perform a market analysis for each of the Large SI applications, we chose not to. Annual sales in some of these categories are so small that the results of separate analysis would not be meaningful and would imply a degree of precision that would not be reflected in the data inputs. Grouping the applications by horsepower, load factor, or usage rates would not necessarily reduce the complexity of the analysis because equipment that use similar size engines are often not used with the same intensity. In addition, their markets may not necessarily share the same demand and supply characteristics.

The results of our economic impact analysis for forklifts with regard to price and quantity changes is not meant to be interpreted as representing the estimated impacts for all Large SI engines. Changes in price and quantity are likely to be different for applications other than forklifts due to differences in their market characteristics.

The remainder of this section describes the baseline characterization of the forklift market in the year 2000, the regulatory control costs incurred by producers of forklifts, and the economic impacts that would have resulted had the emissions control program been imposed in the baseline year. We examine the economic impacts on the forklift market using the baseline year data for each change in the per unit control costs that occurs. A comparison is then made between the engineering cost and surplus loss streams projected to occur after the regulation's implementation. This initial comparison of the cost streams assumes no fuel cost savings. A comparison is then made between engineering costs and social costs/gains accounting for fuel cost savings of the emissions control program. Finally, an estimate of the social costs/gains for Large SI engines other than forklifts is presented, using engineering costs as a substitute for consumer and producer surplus losses.

9.7.1 Forklift Baseline Market Characterization

Inputs to the economic analysis are a year 2000 baseline characterization of the forklift market that includes the domestic quantity produced, quantity of imports, baseline market price, demand elasticity, and domestic and foreign supply elasticity measures. Table 9.7-1 provides the baseline data on the U.S. forklift market used in this analysis.

Table 9.7-1
Baseline Characterization of the U.S. Forklift Market: 2000

Inputs	Baseline Observation
Market price ($/forklift)	$26,380.00
Market output (forklifts)	65000
Domestic	48750
Foreign	16250
Elasticities	
Domestic supply (estimated)	0.714
Foreign supply (assumed)	0.714
Demand (assumed)	-1.5

The total quantity of Large SI engines sold in the U.S. was retrieved from the PSR database, which contains projections of U.S. sales of Large SI engines for the year 2000 and the years 2004 through 2030. Though we possess year 2000 quantity of imports and domestic shipments of forklifts from the International Trade Commission and the Industrial Truck Association, respectively, we have chosen to rely on PSR's database to maintain consistency with the projections of forklift engines used in other sections of this rule's analysis. Based on the PSR database, we have determined that approximately 50 percent of the population of Large SI engines are used in the production of forklifts. This quantity of engines is taken as a measure of the quantity of forklifts sold, based on the assumption that each forklift contains one engine.

The PSR database does not separate the quantity of forklift engines that are produced and used in the U.S. from those that are imported. In order to determine the share of imported forklifts of this total, historical import quantities of forklifts were compared with domestically produced quantities. On average, imported forklifts were equal to about 25 percent of forklifts produced in the U.S. in the past 10 years. This information was used to partition the total quantity of forklifts listed in the PSR database into the share of domestically produced forklifts and the share of imports for the year 2000.

The price of forklifts used in the model is taken as the year 2000 price of a representative model of Class 5 forklift. The year 2000 price of Nissan's JC50 pneumatic tire IC engine forklift was $26,380 and it is used as the nationwide market price of forklifts. It is acknowledged that there are a variety of Class 4, 5, and 6 forklifts with varying prices. The range of prices of these forklifts are discussed in Chapter 2. However, we require a single price to operationalize the perfectly competitive national-level market model used to examine the economic impacts of this rule on the U.S. forklift market.

The estimates of demand and supply elasticity have been discussed in detail in Section 9.5.2.2. A separate estimate of foreign supply elasticity has not been carried out. For modeling purposes, we assume that the foreign supply elasticity is equal to the domestic supply elasticity.

9.7.2 Forklift Control Costs

The emissions control costs used in the economic analysis are developed and reported in Chapter 5. In this section, we briefly recount the estimated regulatory cost per forklift that are used to in the model. The regulatory cost per unit faced by forklift producers leads to a parallel shift inward of the market supply curve. As stated earlier, the compliance costs per forklift are projected to change in future years as different phases of the emissions control program are implemented and as the learning curve is applied (see Chapter 5 for a discussion of the learning curve). The regulatory cost per forklift are presented in Table 9.7-2 for the years in which they change.

Table 9.7-2
Regulatory Costs Per Forklift

Year	Cost Per Forklift	Cost Description
2004/5	$610	Phase 1/year 1 costs
2006	$493	Phase 1/year 3 costs
2007/8	$537	Phase 1/year 3 costs + Phase 2/year 1 costs
2009/10/11	$418	Phase 1/year 6 costs + Phase 2/year 3 costs
2012 - 2030	$390	Phase 1/year 6 costs + Phase 2/year 6 costs

Economic impacts are estimated based upon these costs. In the model, the baseline year quantity and price of forklifts are used and the per unit costs are imposed on the model to determine price, quantity, and consumer and producer surplus changes.

9.7.3 Forklift Economic Impact Results

The economic impacts of the regulation on the forklift market are estimated for each year in which the per engine regulatory costs change, assuming the baseline year 2000 price and quantity. We possess projected quantities of forklifts through the year 2030, however we do not have projected future year prices. Without this information, we cannot estimate the economic impacts of the future costs assuming future year quantities and prices. We instead rely upon the most current year of data to inform the model when we impose the future costs per forklift on producers. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The estimated percent changes in price and quantity, the losses in consumer and producer surplus, and total surplus loss are presented for various years in Tables 9.7-3 and 9.7-4. These results do not account for fuel cost savings that may arise from this emissions control program.

Table 9.7-3
Price and Quantity Changes for the Forklift Market*

Impact Measure	2004/5	2006	2007/8	2009	2012
Cost Per Unit	$610	$493	$537	$418	$390
Change in Market Price	0.75%	0.60%	0.66%	0.51%	0.48%
Change in Market Output	-1.12%	-0.90%	-0.98%	-0.77%	-0.72%
Domestic	-1.12%	-0.90%	-0.98%	-0.77%	-0.72%
Foreign	-1.12%	-0.90%	-0.98%	-0.77%	-0.72%

*Results are the same for the years 2004 and 2005, 2007 and 2008, and the years 2009, 2010, and 2011. They are also the same for the years 2012 and beyond. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2000 market conditions and fuel cost savings are not included.

Table 9.7-4
Annual Losses in Consumer and Producer Surplus for the Forklift Market*

Impact Measure	**2004/5**	**2006**	**2007/8**	**2009**	**2012**
Loss in CS ($\$10^3$)**	$12,715.3	$10,287.6	$11,201.2	$8,728.6	$8,146.0
Loss in PS* ($\$10^3$)**	$26,412.4	$21,416.3	$23,299.1	$18,196.2	$16,990.5
Domestic	$19,809.3	$16,062.2	$17,474.3	$13,647.2	$12,742.9
Foreign	$6,603.1	$5,354.1	$5,824.8	$4,549.0	$4,247.6
Loss in Surplus ($\$10^3$)	$39,127.7	$31,703.9	$34,500.3	$26,924.8	$25,136.5

*Results are the same for the years 2004 and 2005, 2007 and 2008, and the years 2009, 2010, and 2011. They are also the same for the years 2012 and beyond. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2000 market conditions and fuel cost savings are not included.
** CS refers to consumer surplus and is rounded to the nearest hundredths. For a description of the change in consumer surplus, see Section 9.2.2
*** PS refers to producer surplus and is rounded to the nearest hundredths. For a description of the change in producer surplus, see Section 9.2.2.

For the per forklift engine costs resulting from the implementation of the emissions control program, the relative increases in price over the future time period examined are three-quarters of one percent or less. By the year 2014, the relative price increase falls to approximately one-half of one percent. The percent reductions in the market quantity of forklifts are initially projected to be slightly greater than one percent, but by 2006, the relative reduction in market quantity falls below one percent. Though these impacts are larger than those in the inboard diesel cruiser market, they are still considered minimal. Note that the percent reduction in quantity is the same for both domestic and foreign output because it has been assumed that domestic and foreign supply have the same price elasticity.

Table 9.7-4 above presents the loss in consumer surplus, the loss in producer surplus, and the total loss in surplus (equal to the sum of the changes in consumer and producer surplus) without fuel cost savings. As the table shows, the consumer surplus loss is approximately half the size of the loss in producer surplus. Consumer surplus losses range from $12.7 million in year 2004 when the rule is first implemented to $8.1 million in 2012 and the years beyond through 2030. The losses in producer surplus are at their largest at $26.4 million in the first year of implementation and they reach their lowest value in 2012 and the years beyond at just below $17 million. Note that the annual surplus loss associated with the forklift market declines as the per forklift engine costs fall. Loss in surplus is equal to $39.1 million in 2004 and it falls to $25.1 million by 2012.

9.7.4 Forklift Engineering Cost and Surplus Loss Comparison

This section presents a comparison of the future stream of engineering costs (excluding fuel cost savings) and surplus losses for the forklift market. In Table 9.7-5, we first present an interim comparison of the estimated engineering costs, holding quantity constant to the baseline year quantity, with the surplus losses that were estimated from the economic impact model. Because economic modeling takes into account consumer and producer behavior, the estimated loss in surplus is less than the engineering costs under a perfectly competitive market setting. In this case, the annual surplus losses are, on average, equal to 98 to 99 percent of the calculated engineering costs. The cost numbers in this table and Table 9.7-6 are not discounted.

Based upon a ratio of the loss in surplus to engineering costs, holding baseline quantity constant, a projection of the surplus loss over the future year stream is calculated from the future stream of engineering costs that appear in Chapter 7. This projection of the future stream of surplus losses is compared to the future stream of engineering costs in Table 9.7-6. Note that these results are not discounted nor do they account for fuel cost savings.

9.7.5 Forklift Economic Impact Results with Fuel Cost Savings

In Table 9.7-7, the social costs/gains are calculated by adding the annual savings in fuel costs (presented initially in Chapter 7) to the projected annual surplus loss. These social gains are compared to the engineering costs with fuel efficiency gains. As you can see from this table, the emissions control program is expected to yield social gains rather than losses beyond the initial year of implementation. Only the initial year of implementation results in a social loss from this regulation for the forklift market.

Table 9.7-5
Interim Engineering Cost and Surplus Loss Comparison for the Forklift Market Based on Year 2000 Quantity (Q = 65,000 forklifts)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2004	$39,645,853	$39,127,756
2005	$39,645,853	$39,127,756
2006	$32,047.483	$31,703,880
2007	$34,914,619	$34,500,273
2008	$34,914,619	$34,500,273
2009	$27,143,050	$26,924,774
2010	$27,143,050	$26,924,774
2011	$27,143,050	$26,924,774
2012	$25,329,069	$25,136,527
2013	$25,329,069	$25,136,527
2014	$25,329,069	$25,136,527
2015	$25,329,069	$25,136,527
2016	$25,329,069	$25,136,527
2017	$25,329,069	$25,136,527
2018	$25,329,069	$25,136,527
2019	$25,329,069	$25,136,527
2020	$25,329,069	$25,136,527
2021	$25,329,069	$25,136,527
2022	$25,329,069	$25,136,527
2023	$25,329,069	$25,136,527
2024	$25,329,069	$25,136,527
2025	$25,329,069	$25,136,527
2026	$25,329,069	$25,136,527
2027	$25,329,069	$25,136,527
2028	$25,329,069	$25,136,527
2029	$25,329,069	$25,136,527
2030	$25,329,069	$25,136,527

Table 9.7-6
Engineering Cost and Surplus Loss Comparison for the Forklift Market without Fuel Cost Savings

Year	Estimated Engineering Costs	Estimated Surplus Loss
2004	$44,403,355	$43,823,087
2005	$45,592,731	$44,996,919
2006	$37,816,030	$37,410,578
2007	$42,246,689	$41,745,330
2008	$43,294,128	$42,780,339
2009	$34,471,674	$34,194,463
2010	$35,285,965	$35,002,206
2011	$36,100,257	$35,809,949
2012	$34,447,534	$34,185,677
2013	$35,207,406	$34,939,773
2014	$35,967,278	$34,693,868
2015	$36,727,150	$36,447,964
2016	$37,487,022	$37,202,060
2017	$38,246,894	$37,956,156
2018	$39,006,766	$38,710,252
2019	$39,766,638	$39,464,347
2020	$40,526,510	$40,218,443
2021	$41,286,382	$40,972,539
2022	$42,046,254	$41,726,635
2023	$42,806,126	$42,480,731
2024	$43,565,998	$43,234,826
2025	$44,325,871	$43,988,922
2026	$45,085,743	$44,743,018
2027	$45,845,615	$45,497,114
2028	$46,605,487	$46,251,210
2029	$47,365,359	$47,005,305
2030	$48,125,231	$47,759,401

Table 9.7-7
Engineering and Social Cost Comparison for the Forklift Market with Fuel Cost Savings

Year	Estimated Engineering Costs with Fuel Cost Savings	Estimated Social Costs/Gains (Surplus Loss - Fuel Savings)*
2004	$7,305,024	$6,724,756
2005	($29,112.307)	($29,708,119)
2006	($74,949,193)	($75,354,645)
2007	($107,719,996)	($108,221,355)
2008	($142,910,106)	($143,423,895)
2009	($186,910,292)	($187,187,502)
2010	($220,128,020)	($220,411,779)
2011	($248,696,789)	($248,987,097)
2012	($263,429,050)	($263,690,906)
2013	($273,365,256)	($273,632,888)
2014	($282,258,050)	($282,531,460)
2015	($290,155,574)	($290,434,760)
2016	($297,059,701)	($297,344,663)
2017	($303,544,978)	($303,835,716)
2018	($309,618,970)	($309,915,484)
2019	($315,291,768)	($315,594,059)
2020	($320,384,517)	($320,692,585)
2021	($325,478,111)	($325,791,955)
2022	($330,572,494)	($330,892,113)
2023	($336,095,973)	($336,421,369)
2024	($341,680,638)	($342,011,810)
2025	($347,267,003)	($347,603,952)
2026	($352,193,263)	($352,535,988)
2027	($357,123,770)	($357,472,271)
2028	($362,058,551)	($362,412,827)
2029	($366,996,593)	($367,356,646)
2030	($371,938,165)	($372,303,995)

* ( ) represents a negative cost (social gain). Cost estimates are based upon 2000$.

9.7.6 Economic Impacts - Other Large SI Engines

To complete the analysis of the economic impacts of this rulemaking on Large SI engines, we used engineering costs as a surrogate for consumer and producer surplus losses. As noted above, this approach slightly overestimates the surplus losses, suggesting that the standards will have a slightly larger total impact on consumers and producers. This approach does not allow disaggregating to determine the portion of the costs borne by consumers and the portion borne by producers. The estimated fuel cost savings for Large SI engines other than forklifts are based on the methodology used for forklifts. The results of this analysis are contained in Table 9.7-8. According to this analysis, the emissions control program is expected to yield social gains rather than losses beyond the first two years of implementation.

Table 9.7-8
Engineering Cost and Surplus Loss Comparison for Large SI Engines Other Than Forklifts

Year	Estimated Surplus Loss (Engineering Costs)	Estimated Fuel Savings	Estimated Social Costs/Gains (Surplus Loss - Fuel Savings)*
2004	$44,403,355	($15,627,144)	$28,776,211
2005	$45,592,731	($28,275,848)	$17,316,883
2006	$37,816,030	($40,160,970)	($2,344,940)
2007	$42,246,689	($48,976,681)	($6,729,992)
2008	$43,294,128	($56,624,806)	($13,330,678)
2009	$34,471,674	($63,712,068)	($29,240,394)
2010	$35,285,965	($70,327,718)	($35,041,753)
2011	$36,100,257	($76,172,728)	($40,072,471)
2012	$34,447,534	($81,521,871)	($47,074,337)
2013	$35,207,406	($86,460,491)	($51,253,085)
2014	$35,967,278	($90,759,859)	($54,792,581)
2015	$36,727,150	($94,347,999)	($57,620,849)
2016	$37,487,022	($97,888,686)	($60,401,664)
2017	$38,246,894	($101,329,714)	($63,082,820)
2018	$39,006,766	($104,666,222)	($65,659,456)
2019	$39,766,638	($107,916,691)	($68,150,053)
2020	$40,526,510	($111,080,698)	($70,554,188)
2021	$41,286,382	($114,155,459)	($72,869,077)
2022	$42,046,254	($117,123,427)	($75,077,173)
2023	$42,806,126	($117,123,427)	($74,317,301)
2024	$43,565,998	($122,621,375)	($79,055,377)
2025	$44,325,871	($125,268,725)	($80,942,854)
2026	$45,085,743	($128,102,036)	($83,016,293)
2027	$45,845,615	($130,896,877)	($85,051,262)
2028	$46,605,487	($133,533,546)	($86,928,059)
2029	$47,365,359	($135,988,425)	($88,623,066)
2030	$48,125,231	($138,409,359)	($90,284,128)

9.8 Snowmobiles

The following section describes the baseline characterization of the snowmobile market in the year 2001, the regulatory control costs incurred by producers of snowmobiles, and the economic impacts that would have resulted had the emissions control program been imposed in the baseline year. We examine the economic impacts on the snowmobile market using the baseline year data for each change in the per unit control costs that occurs. A comparison is then made between the engineering cost and surplus loss streams projected to occur after the regulation's implementation. This initial comparison of the cost streams assumes no fuel cost savings. A comparison is then made between engineering costs and social costs/gains accounting for fuel cost savings of the emissions control program.

9.8.1 Snowmobile Baseline Market Characterization

Inputs to the economic analysis are provide a baseline characterization for the snowmobile market for the year 2001. Baseline market data include the domestic quantity produced, quantity of imports, baseline market price, demand elasticity, and domestic and foreign supply elasticity measures. Table 9.8-1 provides the baseline data for the U.S. snowmobile market used in this analysis.

Table 9.8-1
Baseline Characterization of the U.S. Snowmobile Market: 2001[64,65]

Inputs	Baseline Observation
Market price ($/snowmobile)	$6,360.00
Market output (snowmobiles)	140,629
Domestic	80,015
Foreign	60,614
Elasticities	
Domestic supply (estimated)	2.1
Foreign supply (assumed)	2.1
Demand (assumed)	-2

The market sales and quantity data are available from the ISMA website. Import and export estimates are based upon data from the PSR. PSR lists vehicles that are imports. For the year 2000, approximately 60 percent of snowmobiles produced by the 4 largest producers were produced domestically by Polaris and Arctic Cat. It is assumed that the production relationship between imports and exports is mirrored in sales for 2001. Based upon this import ratio, we estimate that approximately 61 thousand of the snowmobiles sold in the US in 2001 were imported.

The estimates of demand and supply elasticity have been discussed in detail in Section 9.5.2.3. A separate estimate of foreign supply elasticity has not been carried out. For modeling purposes, we assume that the foreign supply elasticity is equal to the domestic supply elasticity. It is important to note that imports and domestically produced vehicles must meet the US emission standards in order to be sold in this country.

9.8.2 Snowmobile Control Costs

The emissions control costs used in the economic analysis are developed and reported in Chapter 5. In this section, we briefly recount the estimated regulatory cost per snowmobile that are used in the model. The regulatory cost per unit faced by snowmobile producers leads to a parallel shift inward of the market supply curve. As stated earlier, the compliance costs per snowmobile are projected to change in future years as different phases of the emissions control program are implemented and as the learning curve is applied (see Chapter 5 for a discussion of the learning curve). The regulatory cost per snowmobile are presented in Table 9.8-2 for the years in which they change.

Table 9.8-2
Regulatory Costs Per Snowmobile

Year	Cost Per Snowmobile	Cost Description
2006	$35	Phase 1/year 1 costs
2007	$69	Phase 1/year 2 costs
2008-2009	$65	Phase 1/year 3 and 4 costs
2010	$185	Phase 2/year 1 costs
2011	$181	Phase 2 /year 2 costs
2012	$239	Phase 3 /year 1 costs
2013	$239	Phase 3/year 2 costs
2014	$202	Phase 3/year 3 costs
2015	$196	Phase 3/year 4 costs
2016	$182	Phase 3/year 5 costs
2017-2030	$180	Phase 3/year 6 and years thereafter costs

Economic impacts are estimated based upon these costs. In the model, the baseline year quantity and price of snowmobiles are used and the per unit costs are imposed on the model to determine price, quantity, and consumer and producer surplus changes.

9.8.3 Snowmobile Economic Impact Results

The economic impacts of the regulation on the snowmobile market are estimated for each year in which the per engine regulatory costs change, assuming the baseline year 2001 price and quantity. We possess projected quantities of snowmobiles through the year 2030, however we do not have projected future year prices. Without this information, we cannot estimate the economic impacts of the future costs assuming future year quantities and prices. We instead rely upon the most current year of data to inform the model when we impose the future costs per snowmobile on producers. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The estimated percent changes in price and quantity, the losses in consumer and producer surplus, and total surplus loss are presented for various years in Tables 9.8-3 and 9.8-4. These results do not account for fuel cost savings that may arise from this emissions control program.

Table 9.8-3
Price and Quantity Changes for the Snowmobile Market*

Impact Measure	2006	2007	2008-2009	2010	2011	2012-2013	2014	2015	2016	2017-2030
Cost Per Unit	$35	$69	$65	$185	$181	$239	$202	$196	$182	$180
Change in Price	0.28%	0.56%	0.52%	1.49%	1.46%	1.92%	1.63%	1.58%	1.47%	1.45%
Change in Output:	-0.56%	-1.11%	-1.05%	-2.98%	-2.92%	-3.85%	-3.25%	-3.16%	-2.93%	-2.9%

*Based upon 2001baseline market conditions and impacts estimated to occur from the regulation. Assumes 2001$.

Table 9.8-4
Annual Losses in Consumer and Producer Surplus for the Snowmobile Market*

Impact Measure	Year			
	2006	**2007**	**2008-2009**	**2010**
Loss in CS** ($$10^3$)	$2,513.9	$4,942.4	$4,657.4	$13,126.9
Loss in PS*** ($$10^3$)	$2,380.7	$4,654.5	$4,338.9	$12,123.7
Domestic	$1,354.6	$2,648.3	$2,497.2	$6,898.1
Foreign	$1,026.1	$2,006.2	$1,891.7	$5,225.6
Loss in Surplus ($$10^3$)	$4,894.6	$9,596.9	$9,049.4	$25,250.6
	2011	**2012-2013**	**2014**	**2015**
Loss in CS** ($$10^3$)	$12,847.3	$16,883.7	$14,313.3	$13,894.9
Loss in PS*** ($$10^3$)	$11,873.5	$15,448.6	$13,180.8	$12,808.8
Domestic	$6,755.8	$8,798.9	$7,499.6	$7,287.9
Foreign	$5,117.7	$6,658.7	$5,681.2	$5,520.9
Loss in Surplus ($$10^3$)	$24,720.8	$32,332.3	$27,494.1	$26,703.7
	2016	**2017-2030**		
Loss in CS** ($$10^3$)	$12,917.2	$12,777.4		
Loss in PS*** ($$10^3$)	$11,936.1	$11,810.9		
Domestic	$6,791.4	$6,720.2		
Foreign	$5,144.7	$5,090.8		
Loss in Surplus ($$10^3$)	$24,853.3	$24,588.3		

* Based upon 2001 baseline market conditions and the impact of the regulations on those market conditions. Assumes 2001$.

** CS refers to consumer surplus and is rounded to the nearest hundredths. For a description of the change in consumer surplus, see Section 9.2.2

*** PS refers to producer surplus and is rounded to the nearest hundredths. For a description of the change in producer surplus, see Section 9.2.2.

For the per snowmobile engine costs resulting from the implementation of the emissions control program, the relative increases in price over the future time period examined ranges from 0.28% to approximately 1.92% and achieve a steady state in 2017 of approximately 1.45%. The percent reductions in the market quantity of snowmobiles are initially projected to be 0.28% but increase to around 3.85% in 2012, the first year of the Phase 3 regulations. The steady state quantity reductions begin in 2017 and are approximately 2.9%. The percentage change in domestic and foreign production are the same. This is based upon the assumption that the foreign price elasticity of demand is equivalent to the domestic price elasticity of demand, and the fact that both foreign and domestic snowmobiles are subject to the emission standards. All price quantity change estimates are based upon 2001 baseline market conditions and the impact of the regulation on those baseline market conditions.

Table 9.8-4 above presents the loss in consumer surplus, the loss in producer surplus, and the total loss in surplus (equal to the sum of the changes in consumer and producer surplus) without fuel cost savings. As the table shows, the consumer surplus loss is approximately half the size of the loss in producer surplus. Producer surplus losses range from $2.4 million to $15.4 million in 2012 and reach a steady state value of $11.8 million in 2017 and beyond. The losses in consumer surplus range from $2.5 to $16.9 million and reach a steady state of $12.8 in 2017. Note that the annual surplus loss associated with the snowmobile market increases as the per snowmobile engine costs increase and declines as the per snowmobile engine costs fall. Annual loss in surplus ranges from $4.9 million to $32.3 million in 2010 and decrease to a steady state level in 2017 of $24.6 million. It is important to note that these estimates are based upon 2001 baseline conditions and the impact of the regulation on those market conditions.

9.8.4 Snowmobile Engineering Cost and Surplus Loss Comparison

This section presents a comparison of the future stream of engineering costs (excluding fuel cost savings) and surplus losses for the snowmobile market. In Table 9.8-5, we first present an interim comparison of the estimated engineering costs, holding quantity constant to the baseline year quantity. The surplus losses are estimated from the economic impact model. Because economic modeling takes into account consumer and producer behavior, the estimated loss in surplus is less than the engineering costs under a perfectly competitive market setting. In this case, the annual surplus losses are, on average, equal to 96 to 99 percent of the calculated engineering costs. It is important to note that the relationship between engineering and economic costs are based upon this comparison. It is the relationship between these costs that are assumed to actually occur in the market in future years. The cost numbers in Table 9.8-5 and 9.8-6 are not discounted.

Based upon a ratio of the loss in surplus to engineering costs, holding baseline quantity constant, a projection of the surplus loss over the future year stream is calculated from the future stream of engineering costs that appear in Chapter 7. This projection of future stream of engineering costs is based upon projected snowmobiles sales provided by ISMA and estimated per unit engineering engine modification costs. This projection of the future stream of surplus losses is compared to the future stream of engineering costs in Table 9.8-6. Note that these results are not discounted nor do they account for fuel cost savings. The relationship between engineering costs and surplus losses are determined using the market model are assumed to occur in future years. Thus the engineering costs and surplus losses shown in Table 9.8-6 are based upon forecasted sales volumes in the future, the engineering cost estimate for those sales.

Surplus losses represent the estimated value of those losses as informed by the market model, but accounting for projected sales growth in the future.

Table 9.8-5
Interim Engineering Cost and Surplus Loss Comparison for the Snowmobile Market Based on Year 2001 Baseline Market Conditions
(millions of 2001 $)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$4.9	$4.9
2007	$9.7	$9.6
2008 - 2009 (annually)	$9.1	$9.0
2010	$26.0	$25.2
2011	$25.5	$24.7
2012 - 2013 (annually)	$33.6	$32.3
2014	$28.4	$27.5
2015	$27.6	$26.7
2016	$25.6	$24.9
2017 - 2030 (annually)	$25.3	$24.6

9.8.5 Snowmobile Economic Impact Results with Fuel Cost Savings

In Table 9.8-7, the social costs/gains are calculated by adding the annual savings in fuel costs (presented initially in Chapter 7) to the projected annual surplus loss. These social gains are compared to the engineering costs with fuel efficiency gains. As you can see from this table, the emissions control program is expected to yield social gains rather than losses beyond the year 2014.

Table 9.8-6
Engineering Cost and Surplus Loss Comparison for the Snowmobile Market without Fuel Cost Savings Assumes Sales Growth in Future Years*
(millions of 2001 $)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$6.6	$6.5
2007	$13.5	$13.4
2008	$13.2	$13.0
2009	$13.5	$13.3
2010	$38.9	$37.8
2011	$38.7	$37.6
2012	$52.0	$50.0
2013	$52.7	$50.7
2014	$45.3	$43.9
2015	$44.4	$43.0
2016	$41.9	$40.6
2017	$41.7	$40.5
2018	$42.2	$41.0
2019	$42.7	$41.5
2020-2030	$43.1	$41.9

* Snowmobile sales growth provided by ISMA. Sales are not projected to grow after 2020.

Table 9.8-7
Engineering and Social Cost Comparison for the Snowmobile Market with Fuel Cost Savings - Assumes Sales Growth In Future Years*
(millions of 2001$)

Year	Estimated Engineering Costs with Fuel Cost Savings	Estimated Social Costs/Gains (Surplus Loss - Fuel Savings)*
2006	$6.2	$6.2
2007	$12.3	$12.1
2008	$10.7	$10.6
2009	$9.7	$9.6
2010	$29.4	$28.2
2011	$23.1	$21.9
2012	$26.9	$24.9
2013	$17.8	$15.8
2014	$0.4	($1.0)
2015	($10.5)	($12.0)
2016	($23.2)	($24.4)
2017	($33.2)	($34.4)
2018	($42.3)	($43.5)
2019	($50.9)	($52.1)
2020	($59.0)	($60.3)
2021	($67.0)	($68.3)
2022	($73.5)	($74.8)
2023	($78.4)	($79.6)
2024	($82.0)	($83.3)
2025	($84.5)	($85.8)
2026	($86.5)	($87.8)
2027	($88.3)	($89.5)
2028	($89.8)	($91.0)
2029	($90.9)	($92.2)
2030	($91.8)	($93.2)

* ( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

9.8.6 Economic Impacts on Individual Engine Manufacturers, Snowmobile Retailers and Snowmobile Rental Firms

Insufficient data were obtained to conduct an analysis of the impact of the regulation on individual producers in the market. Thus, this analysis does not address individual producer impacts. Each snowmobile manufacturer must meet the emission standards for vehicles sold domestically. Since Yamaha and Bombardier produce their own engines, it is possible that these firms may be at a competitive advantage relative to Arctic Cat and Polaris who purchase engines from other firms. No analysis has been conducted to determine the impact of the difference in cost of production or cost of compliance for the individual firms within the industry. The EPA sought information concerning individual firm's cost of producing snowmobiles, but was unable to obtain sufficient data to conduct an analysis.

With regard to snowmobile retail and rental firms. To the extent that the price of snowmobiles increases, these firms will be impacted by the regulation The increase in market price estimated for the steady state of 1.45% does not appear sufficient to create significant impacts for these firms. In addition, most retail firms sell a variety of products, and snowmobiles are only one product in their product line. This will tend to mitigate the impact for these firms.

9.9 All-Terrain Vehicles (ATVs)

9.9.1 ATV Baseline Market Characterization

Inputs to the economic analysis are for the year 2001. Baseline characterization of the ATV market includes the domestic quantity of ATVs produced, quantity of imports, baseline market price, demand elasticity, and domestic and foreign supply elasticity measures. Table 9.9-1 provides the baseline data on the U.S. ATV market used in this analysis.

Table 9.9-1
Baseline Characterization of the U.S. ATV Market: 2001

Inputs	Baseline Observation
Market price ($/ATV)	$5,123.00
Market output (ATV)	880000
Domestic	874746
Foreign	5254
Elasticities	
Domestic supply (assumed)	1
Foreign supply (assumed)	1
Demand (assumed)	-2

The total quantity of ATVs sold in the U.S. was retrieved from the MIC. Trade data specific to the ATV market were unavailable. However, the International Trade Commission publishes international trade data for NAICS code 336999 - Other Transportation Equipment.

According to ITC data, imports for NAICS code 336999 account for less than 1 percent of domestic sales. The import ratio for Other Transportation Equipment is assumed to be a reasonable proxy for imports for the ATV market.

The price of ATVs used in the model is the average ATV price in 2001 provided by MIC. An average ATV market price is required to operationalize the perfectly competitive national-level market model used to examine the economic impacts of this rule on the U.S. ATV market.

The estimates of demand and supply elasticity have been discussed in detail in Section 9.5.2.4. A separate estimate of foreign supply elasticity has not been carried out. For modeling purposes, we assume that the foreign supply elasticity is equal to the domestic supply elasticity.

9.9.2 ATV Control Costs

The emission control costs used in the economic analysis are developed and reported in Chapter 5. In this section, we briefly recount the estimated regulatory cost per ATV that are used in the model. The regulatory cost per unit faced by ATV producers leads to a parallel shift inward of the market supply curve. As stated earlier, the compliance costs per ATV are projected to change in future years as different phases of the emissions control program are implemented and as the learning curve is applied (see Chapter 5 for a discussion of the learning curve). The regulatory cost per ATV are presented in Table 9.9-2 for the years in which these costs change.

Table 9.9-2
Regulatory Costs Per ATV

Year	Cost Per ATV	Cost Description
2006	$43	Phase 1/year 1 costs
2007	$82	Phase 1/year 2 costs
2008	$78	Phase 1/year 3 costs
2009	$71	Phase 1/year 4 costs
2010	$66	Phase 1/year 5 costs
2011	$57	Phase 1/year 6 costs
2012-2015	$53	Phase 1/year 7-10 costs
2016	$51	Phase 1/year 11 costs
2017-2030	$48	Phase 1/year 12-25 costs

Economic impacts are estimated based upon these costs. In the model, the baseline year quantity and price of ATVs are used and the per unit costs are imposed on the model to determine price, quantity, and consumer and producer surplus changes.

9.9.3 ATV Economic Impact Results

The economic impacts of the regulation on the ATV market are estimated for each year in which the per engine regulatory costs change, assuming the baseline year 2001 price and quantity. Estimated projected quantities of ATVs sales through the year 2030 are available, however we do not have projected future year prices. Any price projections would be subject to significant uncertainties. Without this information, we cannot estimate the economic impacts of the future costs assuming future year quantities and prices. We instead rely upon the most current year of data to inform the model when we impose the future costs per ATV on producers. Assuming annual sales and average prices are increasing for ATVs, this model approach tends to overstate potential price and quantity impacts. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The estimated percent changes in price and quantity, the losses in consumer and producer surplus, and total surplus loss are presented for various years in Tables 9.9-3 and 9.9-4. These results do not account for fuel cost savings that may arise from this emissions control program.

Table 9.9-3
Price and Quantity Changes for the ATV Market*

Impact Measure	Year				
	2006	**2007**	**2008**	**2009**	**2010**
Cost Per Unit	$43	$82	$78	$71	$66
Change in Market Price	0.28%	0.53%	0.51%	0.46%	0.43%
Change in Market Output	-.56%	-1.07%	-1.02%	-.92%	-.86%
Domestic	-.56%	-1.07%	-1.02%	-.92%	-.86%
Foreign	-.56%	-1.07%	-1.02%	-.92%	-.86%
	2011	**2012/2015**	**2016**	**2017/2030**	
Cost Per Unit	$57	$53	$51	$48	
Change in Market Price	0.37%	0.34%	0.33%	0.31%	
Change in Market Output	-.74%	-.69%	-0.66%	-0.62%	
Domestic	-.74%	-.69%	-0.66%	-0.62%	
Foreign	-.74%	-.69%	-0.66%	-0.62%	

*Results are the same for the years 2012 through 2015 and for 2017 through 2030. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2001 market conditions and fuel cost savings are not included.

Table 9.9-4
Annual Losses in Consumer and Producer Surplus for the ATV Market*

Impact Measure	Year				
	2006	**2007**	**2008**	**2009**	**2010**
Loss in CS** ($$10^3$)	$12,578.0	$23,925.0	$22,763.9	$20,730.5	$19,276.9
Loss in PS*** ($$10^3$)	$25,015.0	$47,336.7	$45,063.3	$41,076.0	$38,221.2
Domestic	$24,865.6	$47,054.0	$44,794.2	$40,830.8	$37,993.0
Foreign	$149.4	$282.6	$269.1	$245.2	$228.2
Loss in Surplus ($$10^3$)	$37,593.0	$71,261.7	$67,827.2	$61,806.5	$57,498.0
	2011	**2012-2015**	**2016**	**2017-2030**	
Loss in CS** ($$10^3$)	$16,658.0	$15,493.0	$14,910.4	$14,036.0	
Loss in PS*** ($$10^3$)	$33,068.0	$30,771.7	$29,622.1	$27,896.2	
Domestic	$32,870.5	$30,587.9	$29,445.3	$27,729.6	
Foreign	$197.4	$183.7	$176.9	$166.6	
Loss in Surplus ($$10^3$)	$49,726.0	$46,264.7	$44,532.5	$41,932.2	

*Results are based on baseline year 2001 market conditions and fuel cost savings are not included.
** CS refers to consumer surplus and is rounded to the nearest hundred. For a description of the change in consumer surplus, see Section 9.2.2
*** PS refers to producer surplus and is rounded to the nearest hundred. For a description of the change in producer surplus, see Section 9.2.2.

For the per ATV engine costs resulting from the implementation of the emissions control program, the relative increases in price over the future time period examined are one-half of one percent or less. The market quantity reductions are estimated to be approximately one percent or less and reach a steady state decrease of 0.62 percent in 2017. Note that the percent reduction in quantity is the same for both domestic and foreign output because it has been assumed that domestic and foreign supply have the same price elasticity.

Table 9.9-4 above presents the loss in consumer surplus, the loss in producer surplus, and the total loss in surplus (equal to the sum of the changes in consumer and producer surplus) without fuel cost savings. As the tables show, the consumer surplus loss is approximately half the size of the loss in producer surplus. Consumer surplus losses range from nearly $12.6 million in year 2006 when the rule is first implemented, it rises to $23.9 million in 2007 and falls to $14 million in 2017 and the years beyond. The losses in producer surplus range from $25 million in the first year of implementation, rising to $47.3 million in 2007 and falls to $27.9 million in 2012 and the years beyond. Note that the annual surplus loss associated with the ATV market declines as the per ATV engine costs fall starting in 2008. Loss in surplus is equal to $37.6 million in 2006, rises to 71.3 in 2007 and it falls to $42 million by 2017. The surplus estimate presented in Table 9.9-4 is based upon 2001 baseline market conditions and do not consider fuel cost savings.

9.9.4 ATV Engineering Cost and Surplus Loss Comparison

This section presents a comparison of the future stream of engineering costs (excluding fuel cost savings) and surplus losses for the ATV market. In Table 9.9-5, we first present an interim comparison of the estimated engineering costs, holding quantity constant to the baseline year quantity, with the surplus losses that were estimated from the economic impact model. Because economic modeling takes into account consumer and producer behavior, the estimated loss in surplus is less than the engineering costs under a perfectly competitive market setting. In this case, the annual surplus losses are, on average, equal to 98 to 99 percent of the calculated engineering costs. The cost numbers in Table 9.9-5 are not discounted.

Based upon a ratio of the loss in surplus to engineering costs, holding baseline quantity constant, a projection of the surplus loss over the future year stream is calculated from the future stream of engineering costs that appear in Chapter 7. This projection of the future stream of surplus losses is compared to the future stream of engineering costs in Table 9.9-6. Note that these results are not discounted nor do they account for fuel cost savings.

Table 9.9-5
Interim Engineering Cost and Surplus Loss Comparison for the ATV Based on Year 2001 Quantity (Q = 880,000 ATV)*

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$37,840.0	$37,593.0
2007	$72,160.0	$71,261.7
2008	$68,640.0	$67,827.2
2009	$62,480.0	$61,806.5
2010	$58,080.0	$57,498.0
2011	$50,160.0	$49,726.0
2012	$46,640.0	$46,264.7
2013	$46,640.0	$46,264.7
2014	$46,640.0	$46,264.7
2015	$46,640.0	$46,264.7
2016	$44,880.0	$44,532.5
2017-2030	$42,240.0	$41,932.2

*Estimates are based on baseline year of 2001 and reflect 2001 dollars.

Table 9.9-6
Engineering Cost and Surplus Loss Comparison for the ATV Market without Fuel Cost Savings (Q = ATV projected sales for 2006 through 2030)*

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$42,463.9	$42,186.6
2007	$81,270.6	$80,258.8
2008	$76,518.0	$75,611.8
2009	$70,287.0	$69,529.4
2010	$65,302.2	$64.681.3
2011	$56,379.5	$55,891.6
2012	$52,441.5	$52,019.5
2013	$52,441.5	$52,019.5
2014	$52,441.5	$52,019.5
2015	$52,441.5	$52,019.5
2016	$50,000.0	$49,612.0
2017-2030	$47,556.8	$47,210.3

*Estimates reflect growth in sales projected in the future and are based on 2001 dollars.

9.7.5 ATV Economic Impact Results with Fuel Cost Savings

In Table 9.9-7, the social costs/gains are calculated by adding the annual savings in fuel costs (presented initially in Chapter 7) to the projected annual surplus loss. These social gains are compared to the engineering costs with fuel efficiency gains. As you can see from this table, the emissions control program is expected to yield social gains rather than losses beginning in 2019.

Table 9.9-7
Engineering and Social Cost Comparison for the ATV Market with Fuel Cost Savings (Q = ATV projected sales for 2006 through 2030)

Year	Estimated Engineering Costs with Fuel Cost Savings	Estimated Social Costs/Gains (Surplus Loss - Fuel Savings)*
2006	$41,529.9	$41,252.7
2007	$77,878.5	$76,563.7
2008	$69,563.1	$68,657.0
2009	$59,363.1	$58,605.5
2010	$50,192.8	$49,541.9
2011	$36,888.3	$36,400.4
2012	$28,565.3	$28,143.4
2013	$24,252.7	$23,830.7
2014	$20,127.2	$19,705.2
2015	$16,223.2	$15,801.2
2016	$10,167.9	$9,780.7
2017	$4,433.1	$4,086.6
2018	$1,706.8	$1,360.2
2019	($109.4)	($456.0)
2020	($1,283.9)	($1,630.4)
2021	($2,083.2)	($2,429.8)
2022	($2,577.5)	($2,924.0)
2023	($2,951.6)	($3,298.2)
2024	($3,234.2)	($3,580.7)
2025	($3,443.4)	($3,790.0)
2026	($3,596.0)	($3,942.6)
2027	($3,707.7)	($4,054.2)
2028	($3.786.4)	($4,132.9)
2029	($3,842.7)	($4,189.3)
2030	($3,881.4)	($4,227.9)

* ( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

9.10 Off-Highway Motorcycles

9.10.1 Off-Highway Motorcycle Baseline Market Characterization

Inputs to the economic analysis are for the year 2001. Baseline characterization of the off-highway motorcycle market includes the domestic quantity of off-highway motorcycles produced, quantity of imports, baseline market price, demand elasticity, and domestic and foreign supply elasticity measures. Table 9.10-1 provides the baseline data on the U.S. off-highway motorcycle market used in this analysis.

Table 9.10-1
Baseline Characterization of the U.S. Off-Highway Motorcycle Market: 2001

Inputs	Baseline Observation
Market price ($/off-highway motorcycle)	$2,253.00
Market output (off-highway motorcycle)	195250
Domestic	82463
Foreign	112787
Elasticities	
Domestic supply (estimated)	0.93
Foreign supply (assumed)	0.93
Demand (assumed)	-2

The total quantity of off-highway motorcycle sold in the U.S. was obtained from the MIC The quantity of imports of off-highway motorcycle from the International Trade Commission. According to ITC data, imports for NAICS code 336991 account for nearly 58 percent of domestic sales.

The price of off-highway motorcycles used is the average off-highway motorcycle price in 2001 provide by MIC. An average off-highway motorcycle market price is required to operationalize the perfectly competitive national-level market model used to examine the economic impacts of this rule on the U.S. off-highway motorcycle market. The import ratios for Motorcycles, Bicycles, and Parts Manufactures are assumed to be a reasonable proxy for off-highway motorcycle imports.

The estimates of demand and supply elasticity have been discussed in detail in Section 9.5.2.5. A separate estimate of foreign supply elasticity has not been carried out. For modeling purposes, we assume that the foreign supply elasticity is equal to the domestic supply elasticity.

9.10.2 Off- Highway Motorcycle Control Costs

The emissions control costs used in the economic analysis are developed and reported in Chapter 5. In this section, we briefly recount the estimated regulatory cost per off-highway motorcycle that are used to in the model. The regulatory cost per unit faced by off-highway motorcycle producers leads to a decrease in the market supply curve. As stated earlier, the compliance costs per off-highway motorcycle are projected to change in future years as different phases of the emissions control program are implemented and as the learning curve is applied (see Chapter 5 for a discussion of the learning curve). The regulatory cost per off-highway motorcycles are presented in Table 9.10-2 for the years in which they change.

Table 9.10-2
Regulatory Costs Per Off-Highway Motorcycle

Year	Cost Per Off-Highway Motorcycle	Cost Description
2006	$79	Phase 1/year 1 costs
2007	$155	Phase 1/year 2 costs
2008	$143	Phase 1/year 3 costs
2009	$128	Phase 1/year 4 costs
2010	$117	Phase 1/year 5 costs
2011	$102	Phase 1/year 6 costs
2012-2030	$99	Phase 1/year 7 costs

Economic impacts are estimated based upon these costs. In the model, the baseline year quantity and price of off-highway motorcycle are used and the per unit costs are imposed on the model to determine price, quantity, and consumer and producer surplus changes.

9.10.3 Off-Highway Motorcycles Economic Impact Results

The economic impacts of the regulation on the off-highway motorcycle market are estimated for each year in which the per engine regulatory costs change, assuming the baseline year 2001 price and quantity. Estimated projected quantities of off-highway motorcycle sales through the year 2030 are available, however we do not have projected future year prices. Without this information, we cannot estimate the economic impacts of the future costs assuming future year quantities and prices. Any price projections would be subject to significant uncertainties. We instead rely upon the most current year of data to inform the model when we impose the future costs per off-highway motorcycle on producers. Assuming annual sales and average prices are increasing for off-highway motorcycles, this model approach tends to overstate the potential price and quantity impacts. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The estimated percent changes in price and quantity, the losses in consumer and producer surplus, and total surplus loss are presented for various years in Tables 9.10-3. These results do not account for fuel cost savings that may arise from this emissions control program.

Table 9.10-3
Price and Quantity Changes for the Off-Highway Motorcycle Market*

Impact Measure	2006	2007	2008	2009	2010	2011	2012-2030
Cost Per Unit	$79	$155	$143	$128	$117	$102	$99
Change in Market Price	1.11%	2.18%	2.01%	1.80%	1.65%	1.44%	1.39%
Change in Market Output	-2.23%	-4.37%	-4.03%	-3.61%	-3.30%	-2.87%	-2.79%
Domestic	-2.23%	-4.37%	-4.03%	-3.61%	-3.30%	-2.87%	-2.79%
Foreign	-2.23%	-4.37%	-4.03%	-3.61%	-3.30%	-2.87%	-2.79%

*Results are the same for the years 2012 through 2030. These results are not reported in separate columns to avoid repetition. Results are based on baseline year 2001 market conditions and fuel cost savings are not included.

For the per off-highway motorcycle engine costs resulting from the implementation of the emissions control program, the relative increases in price over the future time period examined are 2.18 percent or less. By the year 2012, the relative price increase falls to approximately 1.4 percent. The percent reductions in the market quantity of off-highway motorcycles ranges from 2.23 percent to 4.37 percent, reaching a steady state of 2.79 percent in 2012. Note that the percent reduction in quantity is the same for both domestic and foreign output because it has been assumed that domestic and foreign supply have the same price elasticity.

Table 9.10-4 presents the loss in consumer surplus, the loss in producer surplus, and the total loss in surplus (equal to the sum of the changes in consumer and producer surplus) without fuel cost savings. As the table shows, the consumer surplus loss is approximately half the size of the loss in producer surplus. Consumer surplus losses range from nearly $5 million in year 2006 when the rule is first implemented, it rises to $9 million in 2007 and falls to $ 6 million in 2012 and the years beyond. The losses in producer surplus range from $10 million in the first year of implementation, rising to $19 million in 2007 and falls to $12.7 million in 2012 and the years beyond. Note that the annual surplus loss associated with the off-highway motorcycle market declines as the per off-highway motorcycle engine costs fall starting in 2008. Loss in surplus is equal to $15 million in 2006, rises to 28.7 in 2007 and it falls to $18.7 million by 2012. The surplus estimate presented in Table 9.10-4 is based upon 2001 baseline market conditions and do not consider fuel cost savings.

Table 9.10-4
Annual Losses in Consumer and
Producer Surplus for the Off-Highway Motorcycle Market*

Impact Measure	Year			
	2006	**2007**	**2008**	**2009**
Loss in CS** ($\$10^3$)	$ 4,841.4	$ 9,369.1	$ 8,683.7	$ 7,789.6
Loss in PS*** ($\$10^3$) Domestic Foreign	$10,177.3 $ 4,298.3 $ 5,879.0	$19,304.6 $ 8,153.2 $11,151.4	$17,906.7 $ 7,562.8 $10,343.9	$16,136.5 $ 6,815.2 $ 9,321.3
Loss in Surplus ($\$10^3$)	$15,018.7	$28,700.7	$26,590.3	$23,926.1
	2010	**2011**	**2012-2030**	
Loss in CS** ($\$10^3$)	$ 7,131.4	$ 6,230.5	$ 6,049.8	
Loss in PS*** ($\$10^3$) Domestic Foreign	$14,822.3 $ 6,260.2 $ 8,562.1	$13,008.2 $ 5,493.9 $ 7,514.2	$12,642.3 $ 5,339.4 $ 7,302.9	
Loss in Surplus ($\$10^3$)	$21,953.7	$19,238.6	$18,692.1	

*Results are based on baseline year 2001 market conditions and fuel cost savings are not included.
** CS refers to consumer surplus and is rounded to the nearest hundredths. For a description of the change in consumer surplus, see Section 9.2.2
*** PS refers to producer surplus and is rounded to the nearest hundredths. For a description of the change in producer surplus, see Section 9.2.2.

9.10.4 Off-Highway Motorcycle Engineering Cost and Surplus Loss Comparison

This section presents a comparison of the future stream of engineering costs (excluding fuel cost savings) and surplus losses for the off-highway motorcycle market. In Table 9.10-5, we first present an interim comparison of the estimated engineering costs, holding quantity constant to the baseline year quantity, with the surplus losses that were estimated from the economic impact model. Because economic modeling takes into account consumer and producer behavior, the estimated loss in surplus is less than the engineering costs under a perfectly competitive market setting. In this case, the annual surplus losses are, on average, equal to 98 to 99 percent of the calculated engineering costs. The cost numbers in this table and Table 9.10-6 are not discounted.

Based upon a ratio of the loss in surplus to engineering costs, holding baseline quantity constant, a projection of the surplus loss over the future year stream is calculated from the future stream of engineering costs that appear in Chapter 7. This projection of the future stream of surplus losses is compared to the future stream of engineering costs in Table 9.10-6. Note that these results are not discounted nor do they account for fuel cost savings.

9.10.5 Off-Highway Motorcycle Economic Impact Results with Fuel Cost Savings

In Table 9.10-7, the social costs/gains are calculated by adding the annual savings in fuel costs (presented initially in Chapter 7) to the projected annual surplus loss. These social gains are compared to the engineering costs with fuel efficiency gains. As you can see from this table, the emissions control program is expected to yield social gains rather than losses beyond the initial year of implementation. Only the initial year of implementation results in a social loss from this regulation for the off-highway motorcycle market.

Table 9.10-5
Interim Engineering Cost and Surplus Loss Comparison for the
Off-Highway Motorcycle Market Based on Year 2001 Quantity
(Q = 195,250 off-highway motorcycle)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$15,424.8	$15,018.7
2007	$30,263.8	$28,700.7
2008	$27,920.8	$26,590.3
2009	$24,992.0	$23,926.1
2010	$22,844.3	$21,953.7
2011-2030	$19,915.5	$19,238.6

Table 9.10-6

Engineering Cost and Surplus Loss Comparison for the Off-Highway Motorcycle Market without Fuel Cost Savings

(Q = Off-Highway Motorcycle projected sales for 2006 through 2030)

Year	Estimated Engineering Costs	Estimated Surplus Loss
2006	$16,269.1	$15,840.8
2007	$32,215.0	$30,551.2
2008	$29,846.5	$28,424.3
2009	$27,127.3	$25,970.3
2010	$24,957.7	$23,984.8
2011	$22,079.4	$21,328.9
2012	$21,630.7	$20,895.5
2013	$21,847.0	$21,104.4
2014	$22,065.4	$21,315.5
2015	$22,286.1	$21,528.6
2016	$22,508.9	$21,743.9
2017	$22,734.0	$21,961.4
2018	$22,961.4	$22.181.0
2019	$23,191.0	$22,402.8
2020	$23,422.9	$22.626.8
2021	$23,657.1	$22,853.1
2022	$23,893.7	$23,081.6
2023	$24,132.6	$23,312.4
2024	$24,374.0	$23,545.6
2025	$24,617.7	$23,781.0
2026	$24,863.9	$24,018.8
2027	$25,112.5	$24,259.0
2028	$25,363.6	$24,501.6
2029	$25,617.3	$24,746.6
2030	$25,873.5	$24,994.1

Table 9.10-7
Engineering and Social Cost Comparison for the Off-Highway Motorcycle Market with Fuel Cost Savings
(Q = Off-Highway Motorcycle projected sales for 2006 through 2030)

Year	Estimated Engineering Costs with Fuel Cost Savings	Estimated Social Costs/Gains (Surplus Loss - Fuel Savings)*
2006	$15,635.6	$15,207.4
2007	$30,153.2	$28,489.4
2008	$26,080.9	$24,658.7
2009	$21,459.3	$20,302.3
2010	$17,305.2	$16,332.2
2011	$12,409.1	$11,658.7
2012	$9,978.0	$9,242.8
2013	$8,293.5	$7,551.0
2014	$6,660.8	$5,910.8
2015	$5,090.2	$4,332.7
2016	$3,658.5	$2,893.5
2017	$2,529.9	$1,757.2
2018	$1,818.9	$1,039.5
2019	$1,397.3	$609.1
2020	$1,121.1	$325.0
2021	$923.2	$119.2
2022	$777.1	($35.0)
2023	$686.8	($133.4)
2024	$633.0	($195.4)
2025	$596.1	($240.6)
2026	$589.0	($256.0)
2027	$601.6	($252.0)
2028	$617.6	($244.9)
2029	$656.3	($214.4)
2030	$708.7	($170.7)

* ( ) represents a negative cost (social gain). Cost estimates are based upon 2001$

Appendix to Chapter 9: Sensitivity Analyses

This appendix presents the results from a series of sensitivity analyses completed for the recreational vehicles emissions standard. The sensitivity analyses examine how the market impacts for each vehicle category would be affected if different measures of supply and demand elasticities were used. For each vehicle category, changes in market price, quantity, and loss of consumer and producer surplus are calculated by first varying the elasticity of supply, holding the elasticity of demand fixed at the original value and then varying the elasticity of demand, holding supply elasticity fixed at its original value. The sensitivity analyses are conducted using the highest per vehicle costs over the future time stream of the regulation. We use the highest annual per vehicle costs to ensure that our sensitivity analysis examines a worst-case scenario. Analysis results are presented in comparison tables.

In order to estimate the economic impacts of the regulation on the each of the vehicle markets, we rely upon the most current year of data (either 2000 or 2001, depending on the vehicle category) to inform the model when we impose the regulatory costs per vessel on producers. Using baseline year data allows us to estimate relative changes in price and quantity as opposed to absolute changes. The results presented in these sensitivity analyses do not account for fuel cost savings that may arise from this emissions control program.

Some general observations can be made about the market impacts resulting from a regulation that affects production costs when different measures of supply and demand elasticity are used and when demand and supply are assumed to be linear. The changes in market price and quantity are smaller for an inward shift in the supply curve the more inelastic is the supply curve. The more inelastic is the demand curve, the larger is the equilibrium change in market price and the smaller is the change in market quantity from an inward shift in the supply curve.

9A.1 Sensitivity Analyses for Marine

The original estimates of supply and demand elasticity for the diesel inboard cruiser market are $\varepsilon = 1.57$ (for domestic and foreign supply) and $\eta = -1.44$, both of which are elastic. Using the highest per vessel costs of $905 which first occur in the year 2009, the market impacts on price, quantity, and surplus losses are calculated first by varying measures of supply elasticity holding demand elasticity constant and then by varying measures of demand elasticity holding supply elasticity constant. These results are presented in Tables 9A.1-1 and 9A.1-2.

In the first column of Table 9A.1-1, we reproduce the original market impacts for the year 2009 that were originally presented in Section 9.6 and compare them to the market impacts calculated when supply elasticity is assumed to be equal to $\varepsilon = 1.00$ (supply is unit elastic) and ε

= 0.50 (supply is inelastic). Demand elasticity is assumed to equal -1.44 for each of these cases. As the results show, the relative increase in market price and decrease in market output are smaller as supply becomes more inelastic. Additionally, the more inelastic is supply, the smaller is the loss in consumer surplus and larger is the loss in producer surplus. Consumer surplus loss falls to just below $2 million from approximately $4 million while producer surplus losses increases to $5.7 million from $3.6 million. While there is a change in the distribution of surplus loss across consumers and producers, there is almost no change in the overall loss in surplus with more inelastic supply. The overall surplus loss increases only by $5.6 thousand.

Table 9A.1-1
Supply Elasticity Sensitivity Analysis: Market Impacts for the Diesel Inboard Cruiser Market*

Impact Measures	**Original Results** $\xi = 1.57, \eta = -1.44$	**Unit Elastic Supply** $\xi = 1.00, \eta = -1.44$	**Inelastic Supply** $\xi = 0.50, \eta = -1.44$
Change in Market Price	0.14%	0.11%	0.07%
Change in Market Output	-0.20%	-0.16%	-0.10%
Loss in CS ($\$10^3$)**	$3,977.7	$3,126.1	$1,966.5
Loss in PS* ($\$10^3$)**	$3,641.1	$4,494.6	$5,657.9
Loss in Surplus ($\$10^3$)	$7,618.8	$7.620.7	$7,624.4

*Results are calculated using the highest per vehicle regulatory costs, which are equal to $905 and are projected to occur in the year 2009/10. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

Table 9A.1-2 presents a comparison of the market impacts when demand elasticity is varied while holding supply elasticity constant at 1.57. We calculate the changes in market price, quantity, and surplus losses assuming η = -1.00 (demand is unit elastic) and η = -0.50 (demand is inelastic) and compare these results to the original results first presented in Section 9.6. As we assume a more inelastic demand curve, the change in market price increases while the change in quantity decreases. However, even when we assume inelastic demand, the change in market price for diesel inboard cruisers is still under one-quarter of one percent. We also can examine the change in consumer and producer surplus. In this case, consumer surplus loss increases and producer surplus loss decreases as demand becomes more inelastic. The loss in consumer surplus rises from $3.9 million to $5.9 million while producer surplus loss decreases from $3.6 million to $1.8 million. Overall surplus loss rises by approximately $9.2 thousand as demand becomes more inelastic, again a minuscule amount.

Table 9A.1-2
Demand Elasticity Sensitivity Analysis: Market Impacts for the Diesel Inboard Cruiser Market*

Impact Measures	Original Results	Unit Elastic Demand	Inelastic Demand
	$\xi=1.57, \eta=-1.44$	$\xi=1.57, \eta=-1.00$	$\xi=1.57 \eta=-0.50$
Change in Market Price	0.14%	0.16%	0.20%
Change in Market Output	-0.20%	-0.16%	-0.10%
Loss in CS ($\$10^3$)**	$3,977.7	$4,659.6	$5,786.9
Loss in PS* ($\$10^3$)**	$3,641.1	$2,963.1	$1,841.1
Loss in Surplus ($\$10^3$)	$7,618.8	$7,622.7	$7,628.0

*Results are calculated using the highest per vehicle regulatory costs, which are equal to $1,552 and are projected to occur in the year 2009/10. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

9A.2 Sensitivity Analyses for Forklifts

For the forklift market, the original economic impact analysis used an inelastic estimate of supply, equal to $\varepsilon = 0.714$ (for domestic and foreign supply), and an elastic estimate of demand, equal to $\eta = -1.5$. The highest per vehicle costs for the forklift market, $610, are incurred during 2004, which is the first year the regulation is implemented. Tables 9A.2-1 and 9A.2-2 present the sensitivity analyses assuming varying supply elasticities and varying demand elasticities, respectively. The results include the changes in market price, quantity, and losses in consumer and producer surplus.

Table 9A.2-1 presents the original results for the year 2004 from Section 9.7 of the analysis and then presents the market impacts assuming $\varepsilon = 1.00$ (supply is unit elastic) and $\varepsilon = 1.50$ (supply in elastic). According to these results, we find that as the supply curve becomes more elastic, the changes in both market price and quantity are larger. Assuming elastic supply, we find that the increase in market price is equal to 1.16 percent and the decrease in market quantity is equal to -1.73 percent. These market impacts, though larger than those we find when supply is assumed to be inelastic, are not significant. We also examine the changes in consumer and producer surplus to find that as supply becomes more elastic, the loss in consumer surplus increases from $12.7 million to $19.7 million and the loss in producer surplus falls from $26.4 million to $19.3 million. Along with this redistribution of surplus loss is a reduction in the overall loss in surplus as supply is assumed to be elastic. The overall loss in surplus originally was equal to $39.1 million but falls to just under $39 million when ε = 1.50.

Table 9A.2-1
Supply Elasticity Sensitivity Analysis: Market Impacts for the Forklift Market*

Impact Measures	Original Results $\xi = 0.714, \eta = -1.50$	Unit Elastic Supply $\xi = 1.00, \eta = -1.50$	Elastic Supply $\xi = 1.50, \eta = -1.50$
Change in Market Price	0.75%	0.92%	1.16%
Change in Market Output	-1.12%	-1.39%	-1.73%
Loss in CS ($\$10^3$)**	$12,715.3	$15,750.0	$19,653.1
Loss in PS* ($\$10^3$)**	$26,412.4	$23,294.9	$19,309.3
Loss in Surplus ($\$10^3$)	$39,127.7	$29,044.9	$38,962.4

*Results are calculated using the highest per vehicle regulatory costs, which are projected to occur in the year 2004 and are equal to $610 per forklift. Results are based on baseline year 2000 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

In the next table, demand elasticity is varied holding supply elasticity constant. The original results were generated assuming ε = 0.714 and η = -1.5. To conduct the sensitivity analysis, we estimated the market impacts when demand elasticity was equal to -1 (unit elastic) and also when it was equal to -0.5 (inelastic). The results in Table 9A.2-2 show that as demand becomes more inelastic, the change in market price increases while the change in quantity decreases. The largest change in market price is approximately 1.4 percent, which is still small in scale. An examination of the surplus measures shows that the loss in consumer surplus increases and the loss in producer surplus decreases as demand is more inelastic. Originally, consumer surplus loss was equal to $12.7 million and producer surplus was equal to $26.4 million. For the inelastic demand case, consumer surplus loss increases to $23.4 million while the loss in producer surplus falls to $16.2 million. Like the diesel marine vessel case, the overall change in the total loss in surplus is negligible, approximately $3 thousand.

A sensitivity analysis for forklifts was also conducted using the estimated elasticity of demand discussed in Section 9.5 of Chapter 9. The demand elasticity estimated is equal to -5.76, a rather large estimate. Table 9A.2-3 presents a comparison of the original market impacts originally presented in Chapter 9 with the market impacts when ε = 0.714 and η = -5.76. From this sensitivity analysis, EPA finds that the relative increase in market price is one-quarter of one percent while the decrease in market output is approximately one and one-half percent. The price increase is smaller relative to the original results because of the extremely elastic demand measure. Overall, these market impacts are not very different from the original results.

What does differ a great deal is the distribution of the loss in welfare. Originally, the loss in producer surplus was approximately two times the size of the loss in consumer surplus. When the elasticity of demand is equal to -5.76, however, virtually all of the loss in economic welfare is incurred by producers. Almost 90 percent of the loss in welfare is borne by producers while 10 percent is borne by consumers.

Table 9A.2-2
Demand Elasticity Sensitivity Analysis: Market Impacts for the Forklift Market*

Impact Measures	**Original Results** $\xi = 0.714, \eta = -1.50$	**Unit Elastic Demand** $\xi = 0.714, \eta = -1.00$	**Inelastic Demand** $\xi = 0.714, \eta = -0.50$
Change in Market Price	0.75%	0.96%	1.36%
Change in Market Output	-1.12%	-0.96%	-0.68%
Loss in CS ($\$10^3$)**	$12,715.3	$16,437.4	$23,240.4
Loss in PS* ($\$10^3$)**	$26,412.4	$22,798.8	$16,163.7
Loss in Surplus ($\$10^3$)	$39,127.7	$39,236.2	$39,404.1

*Results are calculated using the highest per vehicle regulatory costs, which are projected to occur in the year 2004 and are equal to $610 per forklift. Results are based on baseline year 2000 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

Table 9A.2-3
Alternative Demand Elasticity Sensitivity Analysis: Market Impacts for the Forklift Market*

Impact Measures	Original Results $\xi = 0.714, \eta = -1.50$	Alternative Elastic Demand $\xi = 0.714, \eta = -5.76$
Change in Market Price	0.75%	0.25%
Change in Market Output	-1.12%	-1.47%
Loss in CS ($10^3)**	$12,715.3	$4,340.8
Loss in PS* ($10^3)**	$26,412.4	$34,499.8
Loss in Surplus ($10^3)	$39,127.7	$38,840.6

*Results are calculated using the highest per vehicle regulatory costs, which are projected to occur in the year 2004 and are equal to $610 per forklift. Results are based on baseline year 2000 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

9A.3 Sensitivity Analyses for Snowmobiles

For the snowmobile market, the original economic impact analysis used an elastic estimate of supply, equal to $\varepsilon = 2.1$ (for domestic and foreign supply), and an elastic estimate of demand, equal to $\eta = -2.0$. The steady state per vehicle engine modification costs resulting from the regulation for the snowmobiles market of $180, are incurred during 2017 through 2030. This per unit vehicle cost of emission controls is based upon 2001 price levels, Phase 3 regulatory requirements, and incorporates the impact of the learning curve for the engine modification costs. The EPA contends these per unit costs represent those the snowmobile manufacturers will experience on an ongoing basis due to this regulation. Tables 9A.3-1 and 9A.3-2 present the sensitivity analyses assuming varying supply elasticities and varying demand elasticities, respectively. The results include the changes in market price, quantity, and losses in consumer and producer surplus. All estimates are based upon the 2001 baseline market conditions.

Table 9A.3-1 presents the original results for the year 2017-2030 from Section 9.8 of the analysis and then presents the market impacts assuming $\varepsilon = 2.6$ (supply is more elastic) and $\varepsilon = 1.60$ (supply is less elastic). According to these results, we find that as the supply curve becomes more elastic, the changes in both market price and quantity are somewhat larger. These market impacts, though larger than those we find when supply is assumed to be 2.1, are not significantly different. We also examine the changes in consumer and producer surplus to find that as supply becomes more elastic, the loss in consumer surplus increases from $12.8 million to $14.1 million and the loss in producer surplus falls from $11.8 million to $10.5 million. Along with this redistribution of surplus loss is a reduction in the overall loss in surplus as supply is assumed to be more elastic. When supply is assumed to be less elastic, price and quantity impacts decrease. With less elastic supply producers bear more of the cost of the regulation. As illustrated by this sensitivity analysis, price and quantity market impacts do not change substantially with reasonable changes in the supply elasticity measures. As supply become less elastic producers bear more of the cost of the regulation.

Table 9A.3-1
Supply Elasticity Sensitivity Analysis: Market Impacts for the Snowmobile Market*

Impact Measures	**Original Results** $\xi = 2.1, \eta = -2.0$	**More Elastic Supply** $\xi = 2.6, \eta = -2.0$	**Less Elastic Supply** $\xi = 1.60, \eta = -.2.0$
Change in Market Price	1.45%	1.60%	1.26%
Change in Market Output	-2.90%	-3.20%	-2.52%
Loss in CS ($\$10^3$)**	$12,777.4	$14,078.6	$11,108.8
Loss in PS* ($\$10^3$)**	$11,810.9	$10,447.6	$13,532.7
Loss in Surplus ($\$10^3$)	$24,588.3	$24,556.2	$24,641.0

*Results are calculated using the steady-state per vehicle regulatory costs, which are projected to occur in the year 2015 through 2030 and are equal to $178 per snowmobile. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundred.
*** PS refers to producer surplus and is rounded to the nearest hundred.

In the next table, demand elasticity is varied holding supply elasticity constant. The original results were generated assuming ε = 2.1 and η = -2.0. To conduct the sensitivity analysis, we estimated the market impacts when demand elasticity was equal to -2.5 (more elastic) and also when it was equal to -1.5 (less elastic). The results in Table 9A.3-2 show that as demand becomes more elastic, the change in market price decreases while the change in quantity increases. With more elastic demand, producers bear more of the burden of the regulation, while consumers bear less. The overall surplus loss declines slightly. With less elastic demand, the price change increases and quantity change decreases somewhat. Consumers pay a larger share of the cost of the regulation with less elastic demand and producers a smaller share. The surplus losses associated with the regulation increase slightly.

On August 2, 2002, National Economic Research Associates (NERA) provided the EPA with the document *Economic Assessments of Alternative Emission Standards for Snowmobile Engines* on behalf of ISMA. In this report, an estimate of the price elasticity of demand for snowmobiles is presented. The EPA does not accept the validity of this elasticity estimate for a number of reasons (see September 11, 2002 memorandum from Chris Lieske and Linda Chappell to Docket A-2000-01, Document IV-B-45). In an effort to provide additional information to quantify the market impacts of a more elastic price elasticity of demand, market impacts for a price elasticity of demand estimate of -4.63 are presented in Table 9A.3-2. As shown in the third column of this table, projected price increases are smaller and market quantity decreases are somewhat larger assuming a price elasticity of demand estimate of -4.63. In addition, producers bear a greater portion of the burden of the regulation assuming the more elastic price elasticity of demand.

$$x = 2.1, h = -4.63$$

Table 9A.3-2
Demand Elasticity Sensitivity Analysis: Market Impacts for the Snowmobile Market*

Impact Measures	Original Results $x = 2.1, h = -2.0$	More Elastic Demand $\xi = 2.1, \eta = -2.5$	More Elastic Demand	Less Elastic Demand $\xi = 2.1, \eta = -1.5$
Change in Market Price	1.45%	1.29%	0.88%	1.65%
Change in Market Output	-2.90%	-3.23%	-1.09%	-2.48%
Loss in CS ($\$10^3$)**	$12,777.4	$11,369.4	$7,737.1	$14,583.2
Loss in PS* ($\$10^3$)**	$11,810.9	$13,090.6	$16,364.5	$10,155.4
Loss in Surplus ($\$10^3$)	$24,588.3	$24,460.0	$24,083.6	$24,738.6

*Results are calculated using the steady-state per vehicle regulatory costs, which are projected to occur in the year 2015 through 2030 and are equal to $$178 per snowmobile. Results are based on baseline year 2001 market conditions.

** CS refers to consumer surplus and is rounded to the nearest hundred.

*** PS refers to producer surplus and is rounded to the nearest hundred.

In general, the sensitivity analysis indicates that market impacts are not particularly sensitive to reasonable changes in the price elasticity of supply and demand. However, this sensitivity analysis does indicate that the surplus losses borne by consumers and producers are impacted by these estimates. Less elastic supply leads to the producer bearing a greater percentage of the losses due to the regulation. Less elastic demand leads to consumers bearing more of the cost of the regulation.

9A.4 Sensitivity Analyses for ATV

For the ATV market, the original economic impact analysis used an original estimate of supply, equal to ε = 1.0 (for domestic and foreign supply), and an elastic estimate of demand, equal to η = -2.0. The steady state per vehicle costs for the ATV market, $48, are incurred during 2012 through 2030. Tables 9A.4-1 and 9A.4-2 present the sensitivity analyses assuming varying supply elasticities and varying demand elasticities, respectively. The results include the changes in market price, quantity, and losses in consumer and producer surplus.

Table 9A.4-1 presents the original results for the year 2012 from Section 9.9 of the analysis and then presents the market impacts assuming ε = 1.50 (supply is more elastic) and ε = .50 (supply in elastic). Assuming the more elastic supply of ε = 1.50, we find that the increase in market price is equal to 0.40 percent and the decrease in market quantity is equal to -0.80 percent. Assuming the in elastic supply of ε = 0.50, we find that the increase in market price is equal to 0.19 percent and the decrease in market quantity is equal to -0.37 percent. We also examine the changes in consumer and producer surplus to find that as supply becomes more elastic, the loss in consumer surplus increases were $18.0 million and $8.4 million and the loss in producer surplus are $23.8 million and $33.4 million, respectively . The overall loss in surplus originally was equal to $41.9 million and $42.0 million, respectively.

Table 9A.4-1
Supply Elasticity Sensitivity Analysis: Market Impacts for the ATV Market*

Impact Measures	Original Results $\xi = 1.0, \eta = -2.0$	More Elastic Supply $\xi = 1.5, \eta = -2.0$	InElastic Supply
Change in Market Price	0.31%	0.40%	0.19%
Change in Market Output	-0.62%	-0.80%	-0.37%
Loss in CS (10^3)**	$14,036.0	$18,030.2	$8,432.2
Loss in PS* (10^3)**	$27,896.2	$23,846.4	$33,401.4
Loss in Surplus (10^3)	$41,932.2	$41,876.5	$42,034.2

*Results are calculated using the steady state per vehicle regulatory costs, which are projected to occur in the year 2012 through 2030 and are equal to $48 per ATV. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

In the next table, demand elasticity is varied holding supply elasticity constant. The original results were generated assuming ε = 1.0 and η = -2.0. To conduct the sensitivity analysis, we estimated the market impacts when demand elasticity was equal to -2.5 (more elastic) and also when it was equal to -1.5 (less elastic). The results in Table 9A.4-2 show that as demand becomes more inelastic, the change in market price increases while the change in quantity decreases. An examination of the surplus measures shows that the loss in consumer surplus increases and the loss in producer surplus decreases as demand is more inelastic. Originally, consumer surplus loss was equal to $14.0 million and producer surplus was equal to $27.9 million. For the more elastic demand case, consumer surplus loss falls to $12.0 million while the loss in producer surplus increase to $29.9 million. The overall change in the total loss in surplus is negligible, approximately $20.

Table 9A.4-2
Demand Elasticity Sensitivity Analysis: Market Impacts for the ATV Market*

Impact Measures	Original Results a2	More Elastic Demand -2	Inelastic Demand x = 1.0, h = −1.5
Change in Market Price	0.31%	0.27%	0.37%
Change in Market Output	-0.62%	-0.67%	-0.56%
Loss in CS (10^3)**	$14,036.0	$12,028.2	$16,848.5
Loss in PS* (10^3)**	$27,896.2	$29,868.6	$25,130.3
Loss in Surplus (10^3)	$41,932.2	$41,876.7	$41,978.8

*Results are calculated using the steady state per vehicle regulatory costs, which are projected to occur in the year 2012 through 2030 and are equal to $48 per ATV. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

9A.5 Sensitivity Analyses for Off-Highway Motorcycle

For the off-highway motorcycle market, the original economic impact analysis used an original estimate of supply, equal to ε = 0.93 (for domestic and foreign supply), and an elastic estimate of demand, equal to η = -2.0. The steady state per vehicle costs for the off-highway motorcycle market, $99, are incurred during 2012 through 2030. Tables 9A.5-1 and 9A.5-2 present the sensitivity analyses assuming varying supply elasticities and varying demand elasticities, respectively. The results include the changes in market price, quantity, and losses in consumer and producer surplus.

Table 9A.5-1 presents the original results for the year 2012 from Section 9.10 of the analysis and then presents the market impacts assuming ε = 1.50 (supply is more elastic) and ε = .50 (supply in elastic). Assuming the more elastic supply of ε = 1.50, we find that the increase in market price is equal to 1.88 percent and the decrease in market quantity is equal to -3.77 percent. Assuming the in elastic supply of ε = 0.50, we find that the increase in market price is equal to 0.88 percent and the decrease in market quantity is equal to -1.76 percent. We also examine the changes in consumer and producer surplus to find that as supply becomes more elastic, the loss in consumer surplus increases were $8.1 million and $3.8 million and the loss in producer surplus are $10.4 million and $15.1 million, respectively . The overall loss in surplus originally was equal to $18.6 million and $18.9 million, respectively.

Table 9A.5-1
Supply Elasticity Sensitivity Analysis: Market Impacts for the Off-highway Motorcycle Market*

Impact Measures	Original Results $x = 0.93, h = -2.0$	More Elastic Supply $x = 1.5, h = -2.0$	InElastic Supply $x = .50, h = -2.0$
Change in Market Price	1.39%	1.88%	.88%
Change in Market Output	-2.79%	-3.77%	-1.76%
Loss in CS (10^3)**	$6,049.8	$8,128.2	$3,832.0
Loss in PS* (10^3)**	$12,642.3	$10,421.5	$15,056.1
Loss in Surplus (10^3)	$5,339.42	$18,549.7	$18,888.1

*Results are calculated using the steady state per vehicle regulatory costs, which are projected to occur in the year 2012 through 2030 and are equal to $99 per off-highway motorcycle. Results are based on baseline year 2001 market conditions.
** CS refers to consumer surplus and is rounded to the nearest hundredths.
*** PS refers to producer surplus and is rounded to the nearest hundredths.

In the next table, demand elasticity is varied holding supply elasticity constant. The original results were generated assuming ε = 0.93 and η = -2.0. To conduct the sensitivity analysis, we estimated the market impacts when demand elasticity was equal to -2.5 (more elastic) and also when it was equal to -1.5 (less elastic). The results in Table 9A.2-5 show that as demand becomes more inelastic, the change in market price increases while the change in quantity decreases. An examination of the surplus measures shows that the loss in consumer surplus increases and the loss in producer surplus decreases as demand is more inelastic. Originally, consumer surplus loss was equal to $6.1 million and producer surplus was equal to

$12.7 million. For the more elastic demand case, consumer surplus loss falls to $5.6 million while the loss in producer surplus increase to $13.5 million. The overall change in the total loss in surplus is negligible, approximately $10.

Table 9A.5-2
Demand Elasticity Sensitivity Analysis: Market Impacts for the Off-highway Motorcycle Market*

Impact Measures	**Original Results** $\xi = 0.93, \eta = -2.0$	**More Elastic Demand** $\xi = 0.93, \eta = -2.5$	**Inelastic Demand** $\xi = 0.93, \eta = -1.5$
Change in Market Price	1.39%	1.19%	1.68%
Change in Market Output	-2.79%	-2.98%	-2.52%
Loss in CS ($\$10^3$)**	$6,049.8	$5,163.0	$7,304.5
Loss in PS* ($\$10^3$)**	$12,649.3	$13,459.3	$11,480.5
Loss in Surplus ($\$10^3$)	$18,692.1	$18,622.2	$18,785.0

*Results are calculated using the steady state per vehicle regulatory costs, which are projected to occur in the year 2012 through 2030 and are equal to $99 per off-highway motorcycle. Results are based on baseline year 2001 market conditions.

** CS refers to consumer surplus and is rounded to the nearest hundredths.

*** PS refers to producer surplus and is rounded to the nearest hundredths.

Chapter 9 References

1. International Snowmobile Manufacturing Association. www.snowmobile.org. 2002. Docket A-2000-01, Document IV-A-140.

2. U.S. EPA. 1999. OAQPS Economic Analysis Resource Document. Office of Air Quality Planning and Standards, Air Quality Strategies and Standards Division, Innovative Strategies and Economics Group. April. Docket A-2000-01, Document IV-A-71.

3. National Park Service *News Release*. Final Snowmobile Regulations For Yellowstone and Grand Teton National Parks Published in Federal Register. January 23, 2001. Docket A-2000-01, Document No. IV-A-119.

4. See Letter from Linc Wehrly to Docket, titled "News Articles for Yamaha 4-Stroke Snowmobile." Docket A-2000-01. Docket A-2000-01, Document IV-B-25.

5. Internet Search. www.yamaha-motors.com. August 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-121, and IV-A-139.

6. Production data were taken from OELINK Database owned by Power Systems Research.

7. Internet Search. www.yamaha-motors.com. June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-121, and IV-A-139.

8. Estimated based upon submission of data by ISMA manufacturers and Southwest Research Institute. Carroll (1999), White et.al. (1997), Hare and Springer 1974, White and Wright (1998). These documents can be found in Docket A-2000-01, Documents II-B-19, II-D-15, IV-A-142, II-A-50, and II-D-05.

9. Estimated based upon submission of data by ISMA manufacturers and Southwest Research Institute. Carroll (1999), White et.al. (1997), Hare and Springer 1974, White and Wright (1998). These documents can be found in Docket A-2000-01, Documents II-B-19, II-D-15, IV-A-142, II-A-50, and II-D-05.

10. Internet Search. www.polarisindustries.com/product/default.asp?contentid=sno June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, and IV-A-139.

11. Internet Search. www.yamaha-motors.com. June 2002 Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, and IV-A-139.

12. Internet Search. www.yamaha-motors.com. June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, and IV-A-139.

13. Internet Search. http://www.arctic-cat.com/snowmobiles/index.asp June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, and IV-A-139.

14. Internet Search. www.polarisindustries.com/product/default.asp?contentid=sno, www.yamaha-motors.com., www.yamaha-motors.com., http://www.arctic-cat.com/snowmobiles/index.asp June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, IV-A-121, and IV-A-139.

15. Internet Search. www.polarisindustries.com/product/default.asp?contentid=sno, www.yamaha-motors.com., www.yamaha-motors.com., http://www.arctic-cat.com/snowmobiles/index.asp June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, IV-A-121, and IV-A-139

16. Internet Search. www.polarisindustries.com/product/default.asp?contentid=sno, www.yamaha-motors.com., www.yamaha-motors.com., http://www.arctic-cat.com/snowmobiles/index.asp June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, IV-A-121, and IV-A-139.

17. Internet Search. www.polarisindustries.com/product/default.asp?contentid=sno, www.yamaha-motors.com., www.yamaha-motors.com., http://www.arctic-cat.com/snowmobiles/index.asp June 2002. Docket A-2000-01, Document Nos. IV-A-111, IV-A-120, IV-A-121, and IV-A-139.

18. Raboy, David G. 1987. Results of an Economic Analysis of Proposed Excise Taxes on Boats mimeo. Washington DC: Patton, Boggs, and Blow. Prepared for the National Marine Manufacturing Association. Docket A-2000-01, Document IV-A-129.

19. National Bureau of Economic Research and U.S. Census Bureau, Center for Economic Research. 2002. NBER-CES Manufacturing Industry Database, 1958 - 1996. http://www.nber.org/nberces/nbprod96.htm Docket A-2000-01, Document IV-A-48 and IV-A-190.

20. U.S. Department of Commerce. 2001. 1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58

21. Bureau of Economic Analysis. 2002. Survey of Current Business - D. Domestic Perspectives. January. http://www.bea.doc.gov/bea/ARTICLES/2002/01January/D-Pages/0102DpgD.pdf. Docket A-2000-01, Document IV-A-55.

22. Bureau of Economic Analysis.1999. Survey of Current Business - D. Domestic Perspectives. December. http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPAREL/1999/1299dpgd.pdf. Docket

A-2000-01, Document IV-A-56.

23. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://www.bea.doc.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

24. Bureau of Economic Analysis. National Income and Product Accounts Tables. Table 7.1 - Quantity and Price Indices for GDP. http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=Y#s7 Docket A-2000-01, Document IV-A-192.

25. Pindyck, Robert S. and Daniel L. Rubinfeld. Econometric Models and Economic Forecasts, 2nd edition. McGraw Hill Publishing. 1981. Pages174-201.

26. Industrial Truck Association. 2002. Membership Handbook. http://www.indtrk.com/ Copies of relevant pages can be found in Docket A-2000-01, Document IV-A-188.

27. National Bureau of Economic Research and U.S. Census Bureau, Center for Economic Research. 2002. NBER-CES Manufacturing Industry Database, 1958 - 1996. http://www.nber.org/nberces/nbprod96.htm Docket A-2000-01, Document IV-A-48 and IV-A-190.

28. U.S. Department of Commerce. 2001. 1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58.

29. Bureau of Economic Analysis. 2002. Survey of Current Business - D. Domestic Perspectives. January. http://www.bea.doc.gov/bea/ARTICLES/2002/01January/D-Pages/0102DpgD.pdf Docket A-2000-01, Document IV-A-55

30. Bureau of Economic Analysis. 1999. Survey of Current Business - D. Domestic Perspectives. December. http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPAREL/1999/1299dpgd.pdf Docket A-2000-01, Document IV-A-56.

31. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://www.bea.doc.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

32. Bureau of Economic Analysis. National Income and Product Accounts Tables. Table 7.1 - Quantity and Price Indices for GDP. http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=Y#s7 Docket A-2000-01, Document IV-A-192.

33. National Bureau of Economic Research and U.S. Census Bureau, Center for Economic Research. 2002. NBER-CES Manufacturing Industry Database, 1958 - 1996. http://www.nber.org/nberces/nbprod96.htm Docket A-2000-01, Document IV-A-48 and IV-A-190.

34. U.S. Department of Commerce. 2001. 1999 Annual Survey of Manufactures - Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office. Docket A-2000-01, Document IV-A-58.

35. Bureau of Economic Analysis. 2002. Survey of Current Business - D. Domestic Perspectives. January. http://www.bea.doc.gov/bea/ARTICLES/2002/01January/D-Pages/0102DpgD.pdf Docket A-2000-01, Document IV-A-55.

36. Bureau of Economic Analysis. 1999. Survey of Current Business - D. Domestic Perspectives. December. http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPAREL/1999/1299dpgd.pdf Docket A-2000-01, Document IV-A-56.

37. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://www.bea.doc.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

38. Bureau of Economic Analysis. National Income and Product Accounts Tables. Table 7.1 - Quantity and Price Indices for GDP. http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=Y#s7 Docket A-2000-01, Document IV-A-192.

39. Raboy, David G. 1987. Results of an Economic Analysis of Proposed Excise Taxes on Boats mimeo. Washington DC: Patton, Boggs, and Blow. Prepared for the National Marine Manufacturing Association. Docket A-2000-01, Document IV-A-129.

40. National Bureau of Economic Research and U.S. Census Bureau, Center for Economic Research. 2002 NBER-CES Manufacturing Industry Database, 1958 - 1996. Docket A-2000-01, Document IV-A-48 and IV-A-190.

41. U. S. Department of Commerce. 2001. 1999 Annual Survey of Manufacturers - Statistics for Industry Groups and Industries. Washington, DC Government Printing Office. Docket A-2000-01, Document IV-A-58.

42. U. S. Department of Commerce. 2001. 2000 Annual Survey of Manufacturers - Statistics for Industry Groups and Industries. Washington, DC Government Printing Office.

43. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://bea.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

44. Bureau of Economic Analysis. 2002. Survey of Current Business -D Domestic Perspectives. January. http://www.bea.doc/bea/ARTICLES/2002/01January/D-Pages/0102Dpg.pdf Docket A-2000-01, Document IV-A-55.

45. Bureau of Economic Analysis. 1999. Survey of Current Business -D Domestic Perspectives. December. http://www.bea.doc/bea/ARTICLES/NATIONAL/NIPAREL/19991299dpgd.pdf Docket A-2000-01, Document IV-A-56.

46. International Snowmobile Manufacturers Association. www.snowmobile.org. June 2002.

47. US Census Bureau, Historical Income Tables – Households, Table H-6, Regions – Households (All Races) by Median and Mean Income, 1975-2000. A copy of this information can be found in Docket A-2000-01, Document VI-A-203.

48. Raboy, David G. 1987. Results of an Economic Analysis of Proposed Excise Taxes on Boats mimeo. Washington DC: Patton, Boggs, and Blow. Prepared for the National Marine Manufacturing Association. Docket A-2000-01, Document IV-A-129.

49. Raboy, David G. 1987. Results of an Economic Analysis of Proposed Excise Taxes on Boats mimeo. Washington DC: Patton, Boggs, and Blow. Prepared for the National Marine Manufacturing Association. Docket A-2000-01, Document IV-A-129.

50. National Bureau of Economic Research and U.S. Census Bureau, Center for Economic Research. 2002 NBER-CES Manufacturing Industry Database, 1958 - 1996. Docket A-2000-01, Document IV-A-48 and IV-A-190.

51. U. S. Department of Commerce. 2001. 1999 Annual Survey of Manufacturers - Statistics for Industry Groups and Industries. Washington, DC Government Printing Office. Docket A-2000-01, Document IV-A-58.

52. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://bea.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

53. Bureau of Economic Analysis. 2002. Survey of Current Business -D Domestic Perspectives. January. http://www.bea.doc/bea/ARTICLES/2002/01January/D-Pages/0102Dpg.pdf Docket A-2000-01, Document IV-A-55.

54. Bureau of Economic Analysis. 2002. Shipments of Manufacturing Industries. http://bea.gov/bea/dn2/gpo.htm Docket A-2000-01, Document IV-A-44 and IV-A-191.

55. Bureau of Economic Analysis. 1999. Survey of Current Business -D Domestic Perspectives. December. http://www.bea.doc/bea/ARTICLES/NATIONAL/NIPAREL/19991299dpgd.pdf Docket A-2000-01, Document IV-A-56.

56. Motorcycle Industry Council, Inc. 2002. Docket A-2000-01, Document No. IV-A-138.

57. US Census Bureau, Historical Income Tables – Households, Table H-6, Regions – Households (All Races) by Median and Mean Income, 1975-2000. A copy of this information can be found in Docket A-2000-01, Document VI-A-203.

58. National Marine Manufacturing Association. *U.S. Recreational Boating Domestic Shipment Statistics, 1970 - 1998*. http://63.236.237.146/facts/history.pdf Docket A-2000-01, Document IV-A-49.

59. National Marine Manufacturing Association. Boating 2001 - Facts and Figures at a Glance. http://www.nmma.org/facts/boatingstats/2001/ Docket A-2000-01, Document IV-A-50.

60. Teleconference with John McKnight of the National Marine Manufacturers Association on April 15, 2002.

61. Boating Industry. 1996. The Boating Business, 1995 Annual Industry Review. January. Docket A-2000-01, Document IV-A-43.

62. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Table 4 - Product Analysis: Inboard Boats, Imports. Docket A-2000-01, Document IV-A-53.

63. National Marine Manufacturing Association. 2002. Economic Impact Analysis of the Diesel Engine Rule on the U.S. Boat Market. Docket A-2000-01, Document IV-A-53.

64. ISMA Snowmobile Statistics www.snowmobile.org. June 2002.

65. Production data were taken from OELINK Database owned by Power Systems Research.

Chapter 10: Benefit-Cost Analysis

10.1 Introduction

This chapter contains EPA's analysis of the economic benefits of the Large SI/Recreational Vehicle rule. The analysis presented here attempts to answer three questions

- What are the physical health and welfare effects of changes in ambient air quality resulting from reductions in nitrogen oxides (NOx), hydrocarbons (HC) (including air toxics), carbon monoxide (CO), and particulate matter (PM) emissions?
- What is the value placed on these emission reductions by U.S. citizens as a whole?
- How do these estimated benefits compare to the estimated costs associated with this rule?

In the benefits analysis, we calculate a limited set of PM-related health benefits (our base-case estimate). In this part of the analysis, we estimate nationwide PM health effects benefits associated with reduction of Nox and direct PM emissions from Large SI only. Reductions related to ATVs, OHMs, snowmobiles and recreational marine diesel are not quantified. This analysis is based on estimated reductions in NOx and PM emissions and uses a benefits transfer technique to determine the changes in human health and welfare, both in terms of physical effects and monetary value

These analyses yield a stream of monetized benefits which we compare to the costs of the standards. It is important to note that there are significant categories of benefits associated with the control program which cannot be monetized (or in many cases even quantified), including visibility, ozone health benefits, ecological effects, most species of air toxics' health and ecological effects. We identify these benefits in the discussion below and carry them through our estimates as nonmonetized health benefits.

10.2 General Methodology

10.2.1 PM Methodology - Benefits Transfer

In performing the analysis for the PM benefits, we relied on the results of a similar analysis performed for our emission controls for on-highway heavy-duty engines (called the

HD07 rule.[ll] see 99 FR 5002, January 18, 2001). This approach was necessary due to time and resource constraints. To apply that analysis to this control program, we used a benefits transfer technique, described below. Benefits transfer is the science and art of adapting primary benefits research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors in order to improve the accuracy and robustness of benefits estimates. Additional information on the technique used can be found in Hubbell 2002 memorandum to the Docket (Docket A-2000-01, Document IV-A-146).

The HD07 analysis followed the same general methodology used in the benefits analysis for the passenger vehicle Tier 2/Gasoline Sulfur final rule[mm] and other EPA air benefits reports, with routine updates in response to public comment and to reflect advances in modeling and the literature for economics and health effects. This analysis also reflects the advice of its independent Science Advisory Board (SAB) in determining the health and welfare effects considered in the benefits analysis and in establishing the most scientifically valid measurement and valuation techniques.

10.2.2 CO and Air Toxics Methodology : WTP

In this component of the analysis, we discuss the benefits of reducing air toxics pollution from vehicles subject to the rule. The only segment for which willingness to pay for reductions in pollution were reported in the literature was for use-values for snowmobiles; however, the estimates pertained only to use value and were not judged to be reliable. There were no studies estimating the changes in consumer surplus to other non-snowmobilers such as cross-country skiers, nature enthusiasts, and residents near where snowmobiles are operated. We are not able to estimate the value of changes in air toxics or CO from other engines subject to this rule.

[ll] Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents. Information can also be found in the docket for the HD07 rulemaking: A-99-06.

[mm] US EPA. Regulatory Impact Analysis: Control of Air Pollution from New Motor Vehicles: Tier 2 Emission Standards. Report No EPA420-R-99-023. December 1999. A copy of this document can be found in Docket A-99-06, Document IV-A-09.

10.2.3 Benefits Quantification

We use the term *benefits* to refer to any and all positive effects of emissions changes on social welfare that we expect to result from the final rule. We use the term environmental costs (also commonly referred to as “disbenefits”) to refer to any and all negative effects of emissions changes on social welfare that result from the final rule. We include both benefits and environmental costs in this analysis. Where it is possible to quantify benefits and environmental costs, our measures are those associated with economic surplus in accepted applications of welfare economics. They measure the value of changes in air quality by estimating (primarily through benefits transfer) the willingness of the affected population to pay for changes in environmental quality and associated health and welfare effects.

Not all the benefits of the rule can be estimated with sufficient reliability to be quantified and included in monetary terms. The omission of these items from the total of monetary benefits reflects our inability to measure them. It does not indicate their lack of importance in the consideration of the benefits of this rulemaking.

This analysis presents estimates of the potential benefits from the Large SI/Recreational Vehicle rule expected to occur in 2030 as well as a stream of benefits and net present value from 2002 to 2030. The predicted emissions reductions that will result from the rule have yet to occur, and therefore the actual changes in human health and welfare outcomes to which economic values are ascribed are predictions. These predictions are based on the best available scientific evidence and judgment, but there is unavoidable uncertainty associated with each step in the complex process between regulation and specific health and welfare outcomes.

Changes in ambient concentrations will lead to new levels of environmental quality in the U.S., reflected both in human health and in non-health welfare effects. Thus, the predicted changes in ambient air quality serve as inputs into functions that predict changes in health and welfare outcomes. We use the term “endpoints” to refer to specific effects that can be associated with changes in air quality. Table 10.2-1 lists the human health and welfare effects identified for changes in air quality as they related to ozone, PM, CO, and HC.[nn] This list includes both those effects quantified (and/or monetized) in this analysis and those for which we are unable to provide quantified estimates.

For changes in risks to human health from changes in PM, quantified endpoints include changes in mortality and in a number of pollution-related non-fatal health effects. Only the benefits related to changes in NOx-related PM and directly emitted PM were estimated for Large SI. HC-related PM and any PM-related benefits for recreational marine, ATVs, OHMs, and

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[nn] The HC listed in Table 10.2-1 are also listed as hazardous air pollutants in the Clean Air Act. We are not able to quantify their direct effects. To the extent that they are precursors to ozone or PM, they are included in our quantitative results.

snowmobiles were not estimated because of uncertainties with the benefits transfer to those categories and due to lack of information about HC-related PM from the original data set.

The benefits related to changes in CO and HC are not directly quantified for our primary analysis due to a lack of direct estimates of willingness to pay or appropriate exposure and air quality models for these pollutants.

Table 10.2-1
Human Health and Welfare Effects of Pollutants
Affected by the Large SI/Recreational Vehicle Rule

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
Ozone/Health	Not quantified in this analysis	Minor restricted activity days Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Non-asthma respiratory emergency room visits Asthma symptoms Chronic asthma[C] Premature mortality[D] Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection
Ozone/Welfare	Not quantified in this analysis	Decreased worker productivity Decreased yields for commercial crops Decreased commercial forest productivity Decreased yields for fruits and vegetables Decreased yields for other commercial and non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
PM/Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular[B] Emergency room visits for asthma Asthma attacks Lower and upper respiratory illness Minor restricted activity days Work loss days	Infant mortality Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits
PM/Welfare	Not quantified in this analysis	Visibility in areas where people live, work and recreate Visibility in Class I national parks and forest areas Household soiling Materials damage
Nitrogen and Sulfate Deposition/ Welfare	Not quantified in this analysis	Impacts of acidic sulfate and nitrate deposition on commercial forests Impacts of acidic deposition on commercial freshwater fishing Impacts of acidic deposition on recreation in terrestrial ecosystems Impacts of nitrogen deposition on commercial fishing, agriculture, and forests Impacts of nitrogen deposition on recreation in estuarine ecosystems Costs of nitrogen controls to reduce eutrophication in estuaries Reduced existence values for currently healthy ecosystems
NOx/Health	Not quantified in this analysis	Lung irritation Lowered resistance to respiratory infection Hospital Admissions for respiratory and cardiac diseases
CO/Health	Not quantified in this analysis As a supplemental calculation, some behavior effects (choice-reaction time) are quantified for one category for which an exposure model was available	Premature mortality[B] Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina Non-asthma respiratory ER visits

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
HCs [E] Health	Not quantified in this analysis As a supplemental calculation, some behavior effects (choice-reaction time and toluene) are quantified for one category for which an exposure model was available	Cancer (diesel PM, benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucous membranes (formaldehyde) Respiratory and respiratory tract Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation & congestion (acrolein)
HCs [E] Welfare	Not quantified in this analysis	Direct toxic effects to animals Bioaccumulation in the food chain

[A] Primary quantified and monetized effects are those included when determining the base-case estimate of total monetized benefits of the Large SI/Recreational Vehicle rule.

[B] Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

[C] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, an epidemiological study shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in some non-smoking men (McDonnell, et al., 1999).

[D] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the American Cancer Society (ACS)/ Krewski, et al., 2000 C-R function we use for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants (ACS/ Krewski, et al., 2000).

[E] Many of the hydrocarbons (HCs) listed in the table are also hazardous air pollutants listed in the Clean Air Act.

This remainder of this chapter proceeds as follows: in Sections 10.3, we describe the categories of benefits that are estimated, present the techniques and inputs that are used, and provide a discussion of how we incorporate uncertainty into our analysis. In Section 10.4, we briefly discuss the CO and air toxics benefits in a qualitative manner. In Section 10.5, we report our estimates of total monetized benefits.

10.3 PM-Related Health Benefits Estimation

10.3.1 Emissions Inventory Implications

The national inventories for NOx, HC, CO and PM have already been presented and discussed in Chapters 1 and 6 and in the supporting documents referenced in those chapters. Interested readers desiring more information about the inventory methodologies or results should consult that chapter for details. This section explains the specific inventories that were used in our quantitative estimates of benefits and the implications of those inventories related to interpreting results.

As noted in the previous section, this analysis focuses on the PM-related health benefits from emission reductions from Large SI engines only. To quantify these PM-related health benefits, we used NOx and direct PM emission changes (both reductions and increases, where applicable) for the categories Large SI. Our underlying air quality modeling which forms the basis for the transfer technique considers NOx as a precursor for both PM and ozone; thus, oxidant chemistry in the model would not lead to over-estimation of secondary PM formation. We did not include HC-related PM because we do not currently have an appropriate transfer technique.

We did not quantify the NOx, direct PM, or HC-related PM benefits for ATVs, OHMs, recreational marine diesels or snowmobiles because in our judgement there are substantial uncertainties in making the transfer from the on-highway vehicle modeling to these categories. This is because their operating characteristics and the locations in which these nonroad engines are used can be very different from on-highway vehicles. We had more reason to believe that the distribution of vehicles with respect to human populations was more similar for Large SI. However, in the analyses of alternatives, we present a sensitivity calculation for ATVs, noting the large uncertainties inherent in that application of this technique.

As described in the previous chapters of this Regulatory Support Document, the emission controls for Large SI engines and recreational vehicles begin at various times and in some cases phase in over time. This means that during the early years of the program there would not be a consistent match between cost and benefits. This is especially true for the vehicle control portions and initial fuel changes required by the program, where the full vehicle cost would be incurred at the time of vehicle purchase, while the fuel cost along with the emission reductions and benefits resulting from all these costs would occur throughout the lifetime of the vehicle. Because of this inconsistency and our desire to more appropriately match the costs and emission reductions of our program, our analysis uses a future year when the fleet is nearly fully turned over (2030). Consequently, we developed emission inventories through 2030 for both baseline conditions and a control scenario. We present both the benefits as a snapshot in 2030 and as a stream of benefits in the years leading up to 2030. However, our discussion of this analysis focuses on 2030 because the benefits transfer technique applied to these inventories relies on air quality modeling conducted for the year 2030.

10.3.2 Benefits Transfer Methodology

This section summarizes the benefits transfer methodology used in this analysis. This method provides a relatively simple analysis of the health costs of NO_x, and direct PM emissions from Large SI engines. It is important to distinguish these estimates from an analysis that employs full-scale air quality modeling and benefits modeling. The transfer technique used here produces reasonable approximations. Nevertheless, the method also adds uncertainty to the analysis and the results may under or overstate actual benefits of the control program.

Our approach is to develop estimates of health costs expressed in per ton terms. From the Regulatory Model System for Aerosols and Deposition (REMSAD) air quality modeling used for the HD07 rule benefits analysis, we estimated environmental and health costs per ton of NOx and PM. Aggregate environmental and health cost estimates at the national level are scaled to account for human population changes between years of analysis. Complete details of the emissions, air quality, and benefits modeling conducted for the HD07 rule can be found at http://www.epa.gov/otaq/diesel.htm and http://www.epa.gov/ttn/ecas/regdata/tsdhddv8.pdf. Further details of the transfer technique calculations and inputs can be found in the supporting memorandum to the docket (Hubbell 2002a). An alternative approach is presented to provide some insight into the potential of importance of key elements underlying estimates of benefits (Hubbell 2002b).

We examined the impacts of NOx, and direct PM emissions. NOx emissions are associated with both ambient ozone and particulate matter (PM) levels. Due to data limitations, we are providing estimates only for PM related health impacts. The underlying REMSAD modeling partitions the NOx into formation of both ozone and PM in 2030, oxidant chemistry in the model would not lead to over-estimation of secondary PM formation.[oo] Note that we do not attempt to quantify ozone-related benefits. Because the vast majority of the benefits we are able

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[oo] Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents. Information can also be found in the docket for the HD07 rulemaking: A-99-06.

to measure and place a monetary value on are PM related, these estimates will capture most of the benefits we are able to monetize associated with the NO_x, and direct PM emission control. However, one important limitation is that benefits from ozone reductions, air toxics reductions, visibility improvement, and other unquantifiable health and welfare endpoints are not captured in these estimates. The results of this original analysis are summarized in Table 10.3-1.

The cost-per-ton estimate presented in Table 10.3-1 is for estimating tons reduced in 2001 based on a U.S. population of 277 million people. To apply this figure to future years, it is necessary to adjust for increases in population (e.g., in 2030, the U.S. population is estimated to be 345 million) and for growth in real income (see Hubbell 2002a and Equation 1 below).

Table 10.3-1
Summary of Health Effects and Economic Cost Estimates for Transfer

Health Effect[a]	Incidence/ton in 2001 based on U.S. population of 277 million		Estimated $/ton economic costs in 2001 based on U.S. population of 277 million (1999$)	
	NO_x	PM	NO_x	PM
All-cause Premature Mortality from Long-term Exposure	0.0016	0.0221	$9,726	$136,164
Chronic Bronchitis	0.0010	0.0143	$350	$5,012
Hospital Admissions - COPD	0.0002	0.0024	$2	$30
Hospital Admissions - Pneumonia	0.0002	0.0030	$3	$44
Hospital Admissions - Asthma	0.0002	0.0023	$1	$15
Hospital Admissions - Total Cardiovascular	0.0005	0.0072	$10	$132
Asthma-Related ER Visits	0.0004	0.0053	$0	$2
Asthma Attacks	0.0324	0.4566	$1	$19
Acute Bronchitis	0.0034	0.0479	<$1	$3
Upper Respiratory Symptoms	0.0368	0.5188	$1	$13
Lower Respiratory Symptoms	0.0373	0.5270	$1	$8
Work Loss Days	0.2849	4.0180	$30	$402
Minor Restricted Activity Days (minus asthma attacks)	1.3875	20.9184	$68	$1,023
Totals			$10,193	$142,867

Note that the wide discrepancy between the per ton values of NO_x and direct PM is due to differences in their relative contributions to ambient concentrations of $PM_{2.5}$. The underlying REMSAD modeling partitions NOx between ozone and secondary PM formation.The HD07 analysis examined the impacts in 2030 of reducing SO_2 emissions by 141,000 tons and NO_x emissions by 2,570,000 tons, as well as a 109,000 ton reduction in direct PM emissions.

[a] Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

10.3.3 Overview of Heavy Duty Engine/Diesel Fuel Benefits Analysis and Development of Benefits Transfer Technique

This section provides an overview of the original Heavy Duty Engine/Diesel Fuel 2007 rule (HD07) benefits analysis as it relates to the development of a benefits transfer technique. The HD07 analysis examined the impacts in 2030 of reducing SO_2 emissions by 141,000 tons and NO_x emissions by 2,570,000 tons, as well as a 109,000 ton reduction in direct PM emissions. Table 10.3-2 summarizes the NOx and direct PM results in aggregate and on a per ton basis.

Table 10.3-2
Summary of Results from 2030 HD Engine/Diesel Fuel Health Benefits Analysis

Health Outcome	**NO_x**		**PM**	
	Avoided Incidences		**Avoided Incidences**	
	Total	**Per Ton**	**Total**	**Per Ton**
Premature Mortality				
All-cause premature mortality from long-term exposure	5,027	0.00196	3,007	0.02759
Chronic Illness				
Chronic Bronchitis (pooled estimate)	3,243	0.00126	1,941	0.01781
Hospital Admissions				
COPD	554	0.00022	331	0.00304
Pneumonia	676	0.00026	404	0.00371
Asthma	523	0.00002	313	0.00289
Total Cardiovascular	1,635	0.00064	978	0.00897
Asthma-Related ER Visits	1,209	0.00047	723	0.00663
Other Effects				
Asthma Attacks	103,905	0.04043	62,135	0.57005
Acute Bronchitis	10,874	0.00423	6,515	0.05977
Upper Respiratory Symptoms	118,063	0.04594	70,601	0.64771
Lower Respiratory Symptoms	119,760	0.04660	71,711	0.65790
Work Loss Days	914,055	0.35566	546,744	5.01600
Minor Restricted Activity Days (minus asthma attacks)	4,763,239	1.85300	2,846,434	26.11407

In the original HD07 analyses, we used the air quality model, REMSAD, which is a three-dimensional grid-based Eulerian air quality model designed to estimate annual particulate concentrations and deposition over large spatial scales (e.g., over the contiguous U.S.) as summarized in Chapter 1 above. The HD07 RIA benefits analysis applies the modeling system to the entire U.S. for two future-year scenarios: a 2030 base case and a 2030 HD Engine/Diesel Fuel control scenario. The PM species modeled by REMSAD include a primary fine fraction (corresponding to particulates less than 2.5 microns in diameter) and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondary particles.

For the purposes of this analysis, we separated the predicted 2030 change in the primary and secondarily-formed components of $PM_{2.5}$ (i.e., sulfates and nitrates) to provide attributable health effects for SO_2 and NO_x. We did this by separating these chemically speciated fractions of PM (e.g., particulate elemental carbon, and total organic aerosols, sulfate, and particulate nitrate (PNO_3)). It is reasonable to separate these predicted concentrations because of the limited interactions of secondary sulfate and nitrates within the modeling system and the limited contribution of secondary organic aerosols (SOA) to TOA (i.e., since there little or no change in HCs in the original HD07 scenario). Because the original HD07 modeling did not examine the type of HC reductions that are present in this rulemaking, we are not able to create a transfer technique for the HC that would contribute to PM formation. Thus, we limit our consideration of secondary formation of PM to the NO_x emissions in this analysis.

To develop the NOx transfer values, we estimated the incidences of the health endpoints we are able to quantify using the population weighted change in nitrate of -0.388 micrograms per cubic meter into each of the concentration-response functions used in the HD07 benefits analysis. This yields estimates of the health effects associated with the NO_x emission reductions. Based on 2030 populations, this change leads to the estimated reductions in health effects listed in the second column of Table 10.3-2. Note that for concentration response (C-R) functions that use daily average $PM_{2.5}$ or PM_{10} levels, use of the annual mean as a proxy for daily averages will over or underestimate the annual incidence by a small amount (less than five percent). We then divided the attributable incidences by NO_x tons reduced in the HD07 analysis, resulting in incidences per ton of NO_x reduced in 2030 as listed in the third column of Table 10.3-2. We then scaled the incidences per ton by the ratio of population in the year of analysis to population in 2030 to obtain incidences per ton for each year (Hubbell 2002).

We conducted a similar operation to develop coefficients for direct PM. In this instance, we started with the population-weighted change in primary PM of -0.232 micrograms per cubic meter in the HD07 analysis.

$$Benefits_{YearI} = \sum I_{P,E} \times T_{YearI,p} \times RatioPop_{YearI} \times Value_{YearI,E} \quad \textbf{[1]}$$

Where

$Benefits_{YearI}$ = Monetized Benefits in Year *I*, pollutant *P*

$I_{P,E}$ = Avoided Incidence per ton pollutant *P* for endpoint *E*

$T_{year\ I,\ p}$ = Tons pollutant *P* in Year *I*

$RatioPop_{YearI}$ = Population ratio between year of analysis and 2030

$Value_{YearI,\ E}$ = Monetary value per avoided incidence of endpoint *E* in Year *I*

10.3.4. Quantifying and Valuing Individual Health Endpoints

This section summarizes the studies used to calculate the health incidences and valuation of those incidences both in the original HD07 benefits analysis and relied on here. Quantifiable health benefits of the final Large SI/Recreational Vehicle rule may be related to PM only, or both PM and ozone. We are not estimating any ozone-related benefits, so this analysis is only a partial quantification of the benefits associated with the emission controls for these categories. PM-only health effects include premature mortality, chronic bronchitis, acute bronchitis, upper and lower respiratory symptoms, and work loss days.[pp] Health effects related to both PM and ozone include hospital admissions, asthma attacks, and minor restricted activity days.

For this analysis, we rely on concentration response (C-R) functions estimated in published epidemiological studies relating serious health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table 10.3-3. A complete discussion of the C-R functions used for this analysis and information about each endpoint are contained in the HD07 RIA and supporting documents. It is important to note that although there may be biologically relevant differences between direct PM from diesels and from gasoline engines, the primary health studies on which the HD07 benefits assessment is based relied on ambient measurements of PM, not diesel-specific exposure information. Thus, we avoid an uncertainty of transferring a diesel-PM health estimate to gasoline-PM situation.

While a broad range of serious health effects have been associated with exposure to elevated PM levels (as noted for example in Table 10.2-1 and described more fully in the ozone and PM Criteria Documents (US EPA, 1996a, 1996b), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for four reasons:

(i) lack of an adequate benefits transfer technique;
(ii) the possibility of double counting (such as hospital admissions for specific respiratory diseases);

[pp] Some evidence has been found linking both PM and ozone exposures with premature mortality. The SAB has raised concerns that mortality-related benefits of air pollution reductions may be overstated if separate pollutant-specific estimates, some of which may have been obtained from models excluding the other pollutants, are aggregated. In addition, there may be important interactions between pollutants and their effect on mortality (EPA-SAB-Council-ADV-99-012, 1999; a copy of this document is available in Docket A-99-06, Document IV-A-20). Because of concern about overstating of benefits and because the evidence associating mortality with exposure to PM is currently stronger than for ozone, only the benefits related to the long-term exposure study (ACS/Krewkski, et al, 2000) of mortality are included in the total primary benefits estimate. A copy of Krewski, et al., can be found in Docket A-99-06, Document No. IV-G-75.

(iii) uncertainties in applying effect relationships based on clinical studies to the affected population; and
(iv) a lack of an established C-R relationship.

Table 10.3-3
Endpoints and Studies Included in the Primary Analysis

Endpoint	**Study**	**Study Population**
Premature Mortality		
Long-term exposure	Krewski, et al. (2000)[A]	Adults, 30 and older
Chronic Illness		
Chronic Bronchitis (pooled estimate)	Abbey, et al. (1995) Schwartz, et al. (1993)	> 26 years > 29 years
Hospital Admissions		
COPD	Samet, et al. (2000)	> 64 years
Pneumonia	Samet, et al. (2000)	> 64 years
Asthma	Sheppard, et al. (1999)	< 65 years
Total Cardiovascular	Samet, et al. (2000)	> 64 years
Asthma-Related ER Visits	Schwartz, et al. (1993)	All ages
Other Illness		
Asthma Attacks	Whittemore and Korn (1980)	Asthmatics, all ages
Acute Bronchitis	Dockery et al. (1996)	Children, 8-12 years
Upper Respiratory Symptoms	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	Schwartz et al. (1994)	Children, 7-14 years
Work Loss Days	Ostro (1987)	Adults, 18-65 years
Minor Restricted Activity Days (minus asthma attacks)	Ostro and Rothschild (1989)	Adults, 18-65 years

[A] Estimate derived from Table 31, PM2.5(DC), All Causes Model (Relative Risk =1.12 for a 24.5 μg/m^3 increase in mean PM$_{2.5}$).

Recently, the Health Effects Institute (HEI) reported findings by investigators at Johns Hopkins University and others that have raised concerns about aspects of the statistical methodology used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002). Some of the concentration-response functions used in this benefits analysis were derived from such short-term studies. The estimates derived from the long-term mortality studies, which account for a major share of the benefits in the Base

Estimate, are not affected. As discussed in HEI materials provided to sponsors and to the Clean Air Scientific Advisory Committee (Greenbaum, 2002) these investigators found problems in the default "convergence criteria" used in Generalized Additive Models (GAM) and a separate issue first identified by Canadian investigators about the potential to underestimate standard errors in the same statistical package.[qq] These and other investigators have begun to reanalyze the results of several important time series studies with alternative approaches that address these issues and have found a downward revision of some results. For example, the mortality risk estimates for short-term exposure to PM_{10} from The National Morbidity, Mortality and Air Pollution Study (NMMAPS) were overestimated (this study was *not* used in this benefits analysis of fine particle effects).[rr] However, both the relative magnitude and the direction of bias introduced by the convergence issue is case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. The preliminary reanalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks (Dominici et al., 2002; Schwartz and Zanobetti, 2002).

Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms in the both the Base and Alternative Estimates; and reduced premature mortality due to short-term PM exposures in the Alternative Estimate. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies used in our analyses (Dominici et al, 2002; Schwartz and Zanobetti, 2002; Schwartz, personal communication 2002) suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the estimated benefits, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

In Table 10.3-4, we present how we have valued the estimated changes in health effects and the value functions selected from the peer reviewed literature to provide monetized estimates. One of the most important effects is premature mortality. While the base value for a mortality incidence is $6.1 million (1999$), this number is always adjusted downward to reflect the impact of discounting over the assumed 5 year lag period between reductions in PM concentrations and full realization of reduced mortality. The lag-adjusted base VSL is $5.8

[qq] Most of the studies used a statistical package known as "S-plus." For further details, see http://www.healtheffects.org/Pubs/NMMAPSletter.pdf.

[rr] HEI sponsored the multi-city the National Morbidity, Mortality, and Air Pollution Study (NMMAPS). See http://biosun01.biostat.jhsph.edu/~fdominic/NMMAPS/nmmaps-revised.pdf for revised mortality results. A copy of this document can be found in Docket A-2000-01, Document IV-A-201.

million (1999$) when a 3% discount rate is assumed. Thus the attached table reflects income adjustments applied to these lag adjusted base values.

Table 10.3-4
Unit Values Used for Economic Valuation of Health Endpoints

Health or Welfare Endpoint	Estimated Value per Incidence (1999$) Central Estimate	Derivation of Estimates
Respiratory Ailments Not Requiring Hospitalization		
Premature Mortality	$6 million per statistical life	Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the Section 812 Costs and Benefits of the Clean Air Act, 1990-2010 (US EPA, 1999).
Chronic Bronchitis (CB)	$331,000	Value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Hospital Admissions		
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Elixhauser (1993).
Pneumonia (ICD codes 480-487)	$14,693	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Elixhauser (1993).
Asthma admissions	$6,634	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Elixhauser (1993).
All Cardiovascular (ICD codes 390-429)	$18,387	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular illnesses) reported in Elixhauser (1993).
Emergency room visits for asthma	$299	COI estimate based on data reported by Smith, et al. (1997).
Respiratory Ailments Not Requiring Hospitalization		
Upper Respiratory Symptoms (URS)	$24	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope, et al. result in

Lower Respiratory Symptoms (LRS)	$15	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al. result in 11 different “symptom clusters,” each describing a “type” of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Acute Bronchitis	$57	Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994)
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	Variable	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1999$) (US Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$48	Median WTP estimate to avoid one MRAD from Tolley, et al. (1986) .

10.3.5. Estimating Monetized Benefits Anticipated in Each Year

We applied these estimates of the value per incidence to calculate a stream of benefits in future years. We scaled the benefits to the appropriate future year national populations to reflect growth in population. Our projections reflect the U.S. Bureau of the Census predictions.

Our analysis accounts for expected growth in real income over time. Economic theory argues that willingness to pay (WTP) for most goods (such as environmental protection) will increase if real incomes increase. There is substantial empirical evidence that the income elasticity[ss] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. Thus, as real income increases the WTP for environmental improvements also increases. While many analyses assume that the income elasticity of WTP is unit elastic (i.e., ten percent higher real income level implies a ten percent higher WTP to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one and thus relatively inelastic. As real income rises, the WTP value also rises but at a slower rate than real income.

The effects of real income changes on WTP estimates can influence benefit estimates in two different ways: (1) through real income growth between the year a WTP study was conducted and the year for which benefits are estimated, and (2) through differences in income between study populations and the affected populations at a particular time. Empirical evidence

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[ss] Income elasticity is a common economic measure equal to the percentage change in WTP for a one percent change in income.

of the effect of real income on WTP gathered to date is based on studies examining the former. The Environmental Economics Advisory Committee (EEAC) of the SAB advised EPA to adjust WTP for increases in real income over time, but not to adjust WTP to account for cross-sectional income differences "because of the sensitivity of making such distinctions, and because of insufficient evidence available at present" (EPA-SAB-EEAC-00-013).

Based on a review of the available income elasticity literature, we adjust the valuation of human health benefits upward to account for projected growth in real U.S. income. Faced with a dearth of estimates of income elasticities derived from time-series studies, we applied estimates derived from cross-sectional studies in our analysis. Details of the procedure can be found in Kleckner and Neumann (1999). An abbreviated description of the procedure we used to account for WTP for real income growth between 1990 and 2030 is presented in the HD07 TSD.

Incidences in future years will have different values based on adjustments to WTP for growth in income over time. (The schedule of adjustment factors and adjusted WTP values to be applied for each year is listed in attachment 2 of the Hubbell 2002, Docket A-2000-01, Document number IV-A-146.) Adjustment factors should not be applied to the values for avoided hospital admissions, as these are cost-of-illness estimates and not WTP estimates. Likewise, adjustment factors should not be applied to the value of work loss days, as this is a wage-based estimate, not WTP.

10.3.6. Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty.[tt] This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of C-R functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are a foundation of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small

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[tt] It should be recognized that in addition to uncertainty, the annual benefit estimates for the final Large SI/Recreational Vehicle rule presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

uncertainties in emission levels can lead to much larger impacts on total benefits. A more thorough discussion of uncertainty can be found in the HD07 benefits TSD (Abt Associates, 2000).

Some key sources of uncertainty in each stage of the benefits analysis are:

- Gaps in scientific data and inquiry;
- Uncertainties in the benefit transfer process from the HD07 case to the vehicles covered in this rulemaking;
- Variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling;
- Errors in measurement and projection for variables such as population growth rates;
- Errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and
- Biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table 10.3-5. There are a wide variety of sources for uncertainty and the potentially large degree of uncertainty in our estimate. In the original HD07 benefits assessment, sensitivity analyses were performed including qualitative discussions, probabilistic assessments, alternative calculations, and bounding exercises. For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the information necessary to estimate an uncertainty distribution is not available. Even for individual endpoints, there is usually more than one source of uncertainty. This makes it difficult to provide a quantified uncertainty estimate. For example, the C-R function used to estimate avoided premature mortality has an associated standard error which represents the sampling error around the pollution coefficient in the estimated C-R function. It would be possible to report a confidence interval around the estimated incidences of avoided premature mortality based on this standard error. However, this would omit the contribution of air quality changes, baseline population incidences, projected populations exposed, and transferability of the C-R function to diverse locations to uncertainty about premature mortality. Thus, a confidence interval based on the standard error would provide a misleading picture about the overall uncertainty in the estimates. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the HD07 benefits TSD (Abt Associates, 2000). But, this information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Many benefits categories, while known to exist, do not have enough information available to provide a quantified or monetized estimate. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the serious effects listed in Table 10.2-1. The uncertainty regarding these endpoints is such that we could determine neither a primary estimate nor a plausible range of values. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table 10.3-5). The total benefits estimate may understate or overstate actual benefits of the rule. In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting these analyses mentioned throughout this chapter.

Table 10.3-5
Primary Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions	
-	The value of the PM-coefficient in each C-R function.
-	Application of a single C-R function to pollutant changes and populations in all locations.
-	Similarity of future year C-R relationships to current C-R relationships.
-	Correct functional form of each C-R relationship.
-	Extrapolation of C-R relationships beyond the range of PM concentrations observed in the study.
-	Application of C-R relationships only to those subpopulations matching the original study population.
2. Uncertainties Associated With Original Modeled Ambient PM Concentrations	
-	Responsiveness of the models to changes in precursor emissions resulting from the control policy.
-	Projections of future levels of precursor emissions, especially ammonia and crustal materials.
-	Model chemistry for the formation of ambient nitrate concentrations.
–	Comparison of model predictions of particulate nitrate with observed rural monitored nitrate levels indicates that REMSAD overpredicts nitrate in some parts of the Eastern US and underpredicts nitrate in parts of the Western US.
3. Uncertainties Associated with PM Mortality Risk	
-	No scientific literature supporting a direct biological mechanism for observed epidemiological evidence.
–	Direct causal agents within the complex mixture of PM have not been identified.
- the year	The extent to which adverse health effects are associated with low level exposures that occur many times in versus peak exposures.
–	The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.
-	Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects	
- levels	The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated With Baseline Incidence Rates	

–	Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates.
-	Current baseline incidence rates may not approximate well baseline incidence rates in 2030.
–	Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated With Economic Valuation	
- have	Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore uncertainty surrounding them.
–	Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors.
7. Uncertainties Associated With Aggregation of Monetized Benefits	
–	Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified or unmonetized benefits are not included.
8. Uncertainties introduced by Transferring Benefits from a Previous Mobile Source Benefits Analysis	
–	The reasonableness of the benefits transfer depends on the similarity of the original analysis and the emission reductions analyzed with respect to the relationship between emissions and human populations.

10.3.7. Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

Applying the techniques (including the C-R and valuation functions described above) to the estimated changes in NOx and direct PM emissions yields estimates of the number of avoided incidences (i.e. premature mortalities, cases, admissions, etc.) and the associated monetary values for those avoided incidences. These estimates are presented in Table 10.3-6 for 2030. All of the monetary benefits are in constant 2002 dollars.

Not all known PM- and ozone-related health effects could be quantified or monetized. These unmonetized benefits are indicated by place holders, labeled B_1 and B_2. In addition, unmonetized benefits associated with ozone, CO and HC reductions are indicated by the placeholders $B_{2,}$ $B_{3,}$ and B_4. Unquantified physical effects are indicated by U_1 through U_4. The estimate of total monetized health benefits is thus equal to the subset of monetized PM-related health benefits plus $\mathbf{B_H}$, the sum of the unmonetized health benefits.

The largest monetized health benefit is associated with reductions in the risk of premature mortality, which accounts for over $7.5 billion, which is over 95 percent of total monetized health benefits.[uu] The next largest benefit is for chronic bronchitis reductions, although this value

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[uu] Alternative calculations for premature mortality incidences and valuation are presented in the HD07 RIA in Tables VII-24 and VII-25, respectively. An alternative calculation is also provided in Table VII-25 for chronic bronchitis incidences and for chronic asthma incidences. The HD07 RIA can be found in Docket A-2000-01, Document II-A-13.

is more than an order of magnitude lower than for premature mortality. Minor restricted activity days, work loss days, and worker productivity account for the majority of the remaining benefits. The remaining categories account for less than $10 million each; however, they represent a large number of avoided incidences affecting many individuals.

Table 10.3-6
Base-Case Estimate of Annual Health Benefits Associated With Air Quality Changes Resulting from the Large SI Requirements Only in 2030

Endpoint	**Avoided Incidence[A] (cases/year)**	**Monetary Benefits[B] (millions 2002$, adjusted for growth in real income)**
PM-related Endpoints[C]		
Premature mortality[D] (adults, 30 and over)	1,000	$7,510
Chronic bronchitis (adults, 26 and over)	640	$280
Hospital Admissions – Pneumonia (adults, over 64)	100	<$5
Hospital Admissions – COPD (adults, 64 and over)	100	<$5
Hospital Admissions – Asthma (65 and younger)	100	<$1
Hospital Admissions – Cardiovascular (adults, over 64)	300	<$10
Emergency Room Visits for Asthma (65 and younger)	300	<$1
Asthma Attacks (asthmatics, all ages)[E]	20,600	<$1
Acute bronchitis (children, 8-12)	2,200	<$1
Lower respiratory symptoms (children, 7-14)	23,700	<$1
Upper respiratory symptoms (asthmatic children, 9-11)	23,400	<$1
Work loss days (adults, 18-65)	181,300	$20
Minor restricted activity days (adults, age 18-65)	944,400	$50
Other PM-related health effects[E]	U_1	B_1
Ozone-related Endpoints	U_2	B_2
CO and HC-related health effects[E]	U_3+U_4	B_3+B_4
Monetized Total Health-related Benefits[G]	—	$7,880+$\mathbf{B_H}$

[A] Incidences are rounded to the nearest 100.

[B] Dollar values are rounded to the nearest $10 million.

[C] PM-related benefits are based on the assumption that Eastern U.S. nitrate reductions are equal to one-fifth the nitrate reductions predicted by REMSAD (see HD07 RIA Chapter II for a discussion of REMSAD and model performance).

[D] Premature mortality associated with ozone is not separately included in this analysis (also note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure). Further, PM-related reductions are not quantified for ATVs, OHMs, snowmobiles and recreational marine diesel.

[E] A detailed listing of unquantified PM, ozone, CO, and HC related health effects is provided in Table 10.2-1.

[F] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship. Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

[G] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. $B_a+B_1+B_2+B_3+B_4$.

In Table 10.3-7, we present the benefits over time as the regulations phase in over time and a net present value, assuming a 3 percent social discount rate.

Table 10.3-7
Monetized Benefits for Large SI Category Only[A]

Year	Nox Reductions (tons)	PM Reductions (tons)	Total Large SI Benefits (thousands $)
2004	40117	0	$ 420,000
2005	74541	0	$ 800,000
2006	108754	0	$ 1,180,000
2007	152431	0	$ 1,670,000
2008	193218	0	$ 2,150,000
2009	233094	0	$ 2,630,000
2010	271554	0	$ 3,110,000
2011	306016	0	$ 3,820,000
2012	328022	0	$ 4,160,000
2013	347920	0	$ 4,480,000
2014	365688	0	$ 4,790,000
2015	378511	0	$ 5,030,000
2016	389820	0	$ 5,270,000
2017	400470	0	$ 5,490,000
2018	410477	0	$ 5,710,000
2019	419931	0	$ 5,900,000
2020	428805	0	$ 6,130,000
2021	437527	-1	$ 6,320,000
2022	446085	-1	$ 6,540,000
2023	454549	-1	$ 6,750,000
2024	462994	-1	$ 6,950,000
2025	471382	-1	$ 7,120,000
2026	479206	-1	$ 7,280,000
2027	486998	-1	$ 7,440,000
2028	494665	-1	$ 7,600,000
2029	502188	-1	$ 7,740,000
2030	509684	-1	$ 7,880,000
Net Present Value 2002 - 2030			$ 77,180,000

[A] This analysis excludes the health effects we are not able to quantify for PM, ozone, CO, and HC. A detailed list is provided in Table 10.2-1. Only NOx and PM reductions from Large SI are quantified. The sizable PM and Nox reductions from ATVs, OHMs, snowmobiles, and recreational marine diesel are not quantified.

[B] Dollar values are rounded to the nearest $10 million.

[c] A social discount rate of 3 percent is used to calculate the net present value. If a discount rate of 7 percent is used, the net present value (2002 - 2030) is $40.07 billion.

10.3.8 Alternative Calculations of Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

We have also evaluated an alternative, more conservative estimate, that can provide useful insight into the potential impacts of the key elements underlying estimates of the benefits of reducing NOx, and PM emissions from this rule through calculated alternative benefits for mortality and chronic bronchitis. The alternative estimate of mortality reduction relies on certain recent available scientific studies. These studies found an association between increased mortality and short-term exposure to PM over days to weeks. The alternative approach uses different data on valuation and makes adjustments relating to the health status and potential longevity of the populations most likely affected by PM (for more details see Hubbell 2002b). We are continuing to examine the merits of applying this alternative approach to the calculation of benefits. Some of the issues that warrant further investigation are described below.

10.3.9 Alternative Calculations of PM Mortality Risk Estimates and Associated Monetary Values

The Alternative Estimate addresses uncertainty about the relationship between premature mortality and long-term exposures to ambient levels of fine particles by assuming that there is no mortality effect of chronic exposures to fine particles. Instead, it assumes that the full impact of fine particles on premature mortality can be captured using a concentration-response function relating daily mortality to short-term fine particle levels. Specifically, a concentration-response function based on Schwartz et al. (1996) is employed, with an adjustment to account for recent evidence that daily mortality is associated with particle levels from a number of previous days (Schwartz, 2000). Previous daily mortality studies (Schwartz et al., 1996) examined the impact of $PM_{2.5}$ on mortality on a single day or over the average of two or more days. Recent analyses have found that impacts of elevated $PM_{2.5}$ on a given day can elevate mortality on a number of following days (Schwartz, 2000; Samet et al., 2000). Multi-day models are often referred to as "distributed lag" models because they assume that mortality following a PM event will be distributed over a number of days following or "lagging" the PM event. [vv]

There are no $PM_{2.5}$ daily mortality studies which report numeric estimates of relative risks from distributed lag models; only PM_{10} studies are available. Daily mortality C-R functions for PM_{10} are consistently lower in magnitude than $PM_{2.5}$-mortality C-R functions, because fine particles are believed to be more closely associated with mortality than the coarse fraction of PM. Given that the emissions reductions from heavy duty vehicles result primarily in reduced ambient concentrations of $PM_{2.5}$, use of a PM_{10} based C-R function results in a significant downward bias in the estimated reductions in mortality. To account for the full potential multi-day mortality

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[vv] It is of note that, based on recent preliminary findings from the Health Effects Institute (http://www.healtheffects.org), the magnitude of mortality from short-tern exposure may be under or overestimated.

impact of acute $PM_{2.5}$ events, we use the distributed lag model for PM_{10} reported in Schwartz (2000) to develop an adjustment factor which we then apply to the $PM_{2.5}$ based C-R function reported in Schwartz et al. (1996). If most of the increase in mortality is expected to be associated with the fine fraction of PM_{10}, then it is reasonable to assume that the same proportional increase in risk would be observed if a distributed lag model were applied to the $PM_{2.5}$ data. There are two relevant coefficients from the Schwartz et al. (1996) study, one corresponding to all-cause mortality, and one corresponding to chronic obstructive pulmonary disease (COPD) mortality (separation by cause is necessary to implement the life years lost approach detailed below).

These estimates, while approximating the full impact of daily pollution levels on daily death counts, do not capture any impacts of long-term exposure to air pollution. EPA's Science Advisory Board, while acknowledging the uncertainties in estimation of a PM-mortality relationship, has recommended the use of a study that does reflect the impacts of long-term exposure. The omission of long-term impacts accounts for an approximately 40 percent reduction in the estimate of avoided premature mortality in the alternative estimates relative to the primary estimates.

Furthermore, the alternative estimates reflect the impact of changes to key assumptions associated with the valuation of mortality. These include: 1) the impact of using wage-risk and contingent valuation-based value of statistical life estimates in valuing risk reductions from air pollution as opposed to contingent valuation-based estimates alone, 2) the relationship between age and willingness-to-pay for fatal risk reductions, and 3) the degree of prematurity in mortalities from air pollution.

The alternative estimates address this issue by using an estimate of the value of statistical life that is based only on the set of five contingent valuation studies included in the larger set of 26 studies recommended by Viscusi (1992) as applicable to policy analysis. The mean of the five contingent valuation based VSL estimates is $3.7 million (1999$), which is approximately 60 percent of the mean value of the full set of 26 studies.

The second issue is addressed by assuming that the relationship between age and willingness-to-pay for fatal risk reductions can be approximated using an adjustment factor derived from Jones-Lee (1989). The SAB has advised the EPA that the appropriate way to account for age differences is to obtain the values for risk reductions from the age groups affected by the risk reduction.

To show the maximum impact of the age adjustment, the Alternative Estimate is based on the Jones-Lee (1989) adjustment factor of 0.63, which yields a VSL of $2.3 million for populations over the age of 70. Deaths of individuals under the age of 70 are valued using the unadjusted mean VSL value of $3.7 million (1999$). Since these are acute mortalities, it is assumed that there is no lag between reduced exposure and reduced risk of mortality.

A simpler and potentially less biased approach is to simply apply a single age adjustment based on whether the individual was over or under 65 years of age at the time of death. This is consistent with the range of observed ages in the Jones-Lee studies and also agrees with the findings of more recent studies by Krupnick et al. (2000) that the only significant difference in WTP is between the over 70 and under 70 age groups. To correct for the potential extrapolation error for ages beyond 70, the adjustment factor is selected as the ratio of a 70 year old individual's WTP to a 40 year old individual's WTP, which is 0.63, based on the Jones-Lee (1989) results and 0.92 based on the Jones-Lee (1993) results.

The third issue is addressed in the Alternative Estimate by assuming that deaths from chronic obstructive pulmonary disease (COPD) are advanced by 6 months, and deaths from all other causes are advanced by 5 years. These reductions in life years lost are applied regardless of the age at death. Actuarial evidence suggests that individuals with serious preexisting cardiovascular conditions have a remaining life expectancy of around 5 years. While many deaths from daily exposure to PM may occur in individuals with cardiovascular disease, studies have shown relationships between all cause mortality and PM, and between PM and mortality from pneumonia (Schwartz, 2000). In addition, recent studies have shown a relationship between PM and non-fatal heart attacks, which suggests that some of the deaths due to PM may be due to fatal heart attacks (Peters et al., 2001). And, a recent meta-analysis has shown little effect of age on the relative risk from PM exposure (Stieb et al. 2002), which suggests that the number of deaths in non-elderly populations (and thus the potential for greater loss of life years) may be significant. Indeed, this analysis estimates that 21 percent of non-COPD premature deaths avoided are in populations under 65. Thus, while the assumption of 5 years of life lost may be appropriate for a subset of total avoided premature mortalities, it may over or underestimate the degree of life shortening attributable to PM for the remaining deaths.

In order to value the expected life years lost for COPD and non-COPD deaths, we need to construct estimates of the value of a statistical life year. The value of a life year varies based on the age at death, due to the differences in the base VSL between the 65 and older population and the under 65 population. The valuation approach used is a value of statistical life years (VSLY) approach, based on amortizing the base VSL for each age cohort. Previous applications have arrived at a single value per life year based on the discounted stream of values that correspond to the VSL for a 40 year old worker (U.S. EPA, 1999a). This assumes 35 years of life lost is the base value associated with the mean VSL value of $3.7 million (1999$). The VSLY associated with the $3.7 million VSL is $163,000, annualized assuming EPA's guideline value of a 3 percent discount rate, or $270,000, annualized assuming OMB's guideline value of a 7 percent discount rate.

The VSL applied in this analysis is then built up from that VSLY by taking the present value of the stream of life years, again assuming a 3% discount rate. Thus, if you assume that a 40 year-old dying from pneumonia would lose 5 years of life, the VSL applied to that death would be $0.79 million. For populations over age 65, we then develop a VSLY from the age-adjusted base VSL of $2.3 million. Given an assumed remaining life expectancy of 10 years, this gives a VSLY of $258,000, assuming a 3 percent discount rate. Again, the VSL is built based on the present value of 5 years of lost life, so in this case, we have a 70 year old individual dying from pneumonia losing 5 years of life, implying an estimated VSL of $1.25 million. COPD deaths for populations aged 65 and older are valued at $0.13 million per incidence. Finally, COPD deaths for populations aged 64 and younger are valued at $0.09 million per incidence. The implied VSL for younger populations is less than that for older populations because the value per life year is higher for older populations. Since we assume that there is a 5 year loss in life years for a PM related mortality, regardless of the age of person dying, this necessarily leads to a lower VSL for younger populations. As a final step, these estimated VSL values are multiplied by the appropriate adjustment factors to account for changes in WTP over time.

10.3.9.1 Alternative Calulations of Chronic Bronchitis Monetary Values

For the alternative estimate, a cost-of illness value is used in place of willingness-to-pay to reflect uncertainty about the value of reductions in incidences of chronic bronchitis. In the primary estimate, the willingness-to-pay estimate was derived from two contingent valuation studies (Viscusi et al., 1991; Krupnick and Cropper, 1992). These studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the SAB (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity-adjusted values from this study provide reasonable estimates of the WTP for avoidance of chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. In order to investigate the impact of using the CV based WTP estimates, the alternative estimates rely on a value for incidence of chronic bronchitis using a cost-of-illness estimate based Cropper and Krupnick (1990) which calculates the present value of the lifetime expected costs associated with the illness. The current cost-of-illness (COI) estimate for chronic bronchitis is around $107,000 per case, compared with the current WTP estimate of $330,000. Because the alternative estimate is based on cost-of-illness, no income adjustments are applied when applying the estimate in future year analyses.

10.3.9.2 Alternative Calulations Results

Applying the techniques (including the C-R and valuation alternatives described above) to the estimated changes in NOx and direct PM emissions for Large SI engines from this rule yields estimates of the number of avoided incidences of premature mortalities and chronic bronchitis cases and the associated monetary values for those avoided incidences. These estimates are presented in Table 10.3-8 for 2030. All of the monetary benefits are in constant 2002 dollars.

Table 10.3-8.
Alternative Benefits in 2030 from PM-related Reductions from the Large SI Categories.

	Alternative Estimate Incidence[A]	Alternative Estimation Valuation[B] (million $)
Short-term exposure mortality	600	$810
Chronic bronchitis	640	$90

[A] Incidences are rounded to the nearest 10.
[B] Dollar values are rounded to the nearest $10 million.

In Table 10.3-9, we present the benefits over time as the regulations phase in over time and a net present value, assuming a 3 percent social discount rate.

Table 10.3-9
Alternative Monetized Benefits Mortality and Chronic Bronchitis for Large SI Category Only[A]

Year	Nox Reductions	PM Reductions	Total Benefits (thousands)
2004	40,117	0	$ 50,000
2005	74,541	0	$ 90,000
2006	108,754	0	$ 130,000
2007	152,431	0	$ 190,000
2008	193,218	0	$ 250,000
2009	233,094	0	$ 300,000
2010	271,554	0	$ 350,000
2011	306,016	0	$ 440,000
2012	328,022	0	$ 470,000
2013	347,920	0	$ 510,000
2014	365,688	0	$ 550,000
2015	378,511	0	$ 570,000
2016	389,820	0	$ 600,000
2017	400,470	0	$ 620,000
2018	410,477	0	$ 650,000
2019	419,931	0	$ 670,000
2020	428,805	0	$ 700,000
2021	437,527	-1	$ 720,000
2022	446,085	-1	$ 750,000
2023	454,549	-1	$ 770,000
2024	462,994	-1	$ 790,000
2025	471,382	-1	$ 810,000
2026	479,206	-1	$ 830,000
2027	486,998	-1	$ 850,000
2028	494,665	-1	$ 870,000
2029	502,188	-1	$ 880,000
2030	509,684	-1	$ 900,000
Net Present Value 2002 to 2030			$8,800 million

[A] This alternative analysis excludes the health effects we are not able to quantify for PM, ozone, CO, and HC as well as excluding benefits from long-term exposure mortality, hospital admissions, emergency department visits, upper and lower respiratory symptoms, asthma attacks, acute bronchitis, work loss days and minor restricted activity days. A detailed list is provided in Table 10.2-1. Only NOx and PM reductions from Large SI are quantified. The sizable PM and Nox reductions from ATVs, OHMs, snowmobiles, and recreational marine diesel are not quantified.

[B] Dollar values are rounded to the nearest $10 million.

[c] A social discount rate of 3 percent is used to calculate the net present value. If a discount rate of 7 percent is used, the net present value (2002 - 2030) is $4.57 billion.

10.4 CO and Air Toxics Health Benefits Estimation

Although we achieve substantial reductions in CO and HC (many of which are hazardous air pollutants), we are unable to quantify benefits for these reductions. We present two techniques for estimating the economic benefits of changes in emissions from snowmobiles that are possible areas for further reserach.

10.4.1 Direct Valuation of "Clean" Snowmobiles

In general, economists tend to view an individual's willingness-to-pay (WTP) for a improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available and conservative measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate.

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or safety devices). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between use values and non-use values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman, 1993), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit, but might relate to existence values and bequest values. Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by the final Large SI/Recreational Vehicle rule cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

The most direct way to measure the economic value of air quality changes is in cases where the endpoints have market prices. More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used.

Estimating benefits for public land activities or its existence value is a more difficult and less precise exercise because the endpoints are not directly or indirectly valued in markets. For example, the loss of a species of animal or plant from a particular habitat does not have a well-defined price, neither does a crisp winter day of quietude. The contingent valuation (CV) method has been employed in the economics literature to value endpoint changes for both visibility and ecosystem functions (Chestnut and Dennis, 1997). There is an extensive scientific literature and body of practice on both the theory and technique of CV. EPA believes that well-designed and well-executed CV studies are valid for estimating the benefits of air quality regulation.[ww]

The contingent valuation (CV) method uses survey techniques to estimate values individuals place on goods and services for which no market exists. Contingent valuation has been widely applied (Mitchell and Carson 1989, and Walsh, Johnson, and McKean 1992), and the U.S. Water Resources Council recognizes this as an appropriate method. The U.S. Department of Interior’s federal guidelines have designated CV as the best available procedure for valuing damages arising in Superfund natural resource damage cases (U.S. DOI 1986, 1991).

The CV method values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. In a CV survey, individuals are asked about their willingness to pay for a given service or commodity contingent on their acceptance of a hypothetical but plausible and realistic market situation. Thus, there are three main elements in the approach: 1) a description of the commodity to be valued; 2) the payment vehicle (i.e., how the individual will pay for the good or service); and 3) the form of the question (e.g., open-ended or dichotomous choice questions). A study that

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[ww] Concerns about the reliability of value estimates from CV studies arose because research has shown that bias can be introduced easily into these studies if they are not carefully conducted. Accurately measuring WTP for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP; 2) whether the good to be valued is comprehended and accepted by the respondent; 3) whether the WTP elicitation format is designed to minimize strategic responses; 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income; 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods; and 6) the extent to which WTP responses are consistent with established economic principles.

contained information about use value for "clean, quiet" snowmobiles was recently conducted (Duffield and Neher 2000).[xx] However, the study was judged to have limitations in its application here. The National Park Service is endeavoring to conduct a new study that may address the short-comings of this study.

10.4.2 Overview of Benefits Estimation for CO and Air Toxics from the Final Rule

A large variety of substances is emitted from tail pipes of snowmobiles powered by two-stroke engines.[1] Some of these substances may be acutely neurotoxic at sufficiently high concentration, including volatile hydrocarbons (HC) and carbon monoxide (CO). The acute neurotoxicity of only two of the identified exhaust components have been studied extensively on an individual basis (toluene and CO), but the combined toxicity of the mixture of toluene and CO has not been evaluated.[2] Toluene comprises about 20 percent of the total amount of hydrocarbons in the exhaust of snowmobiles.[3] As discussed above, up to a third of the fuel and lubricating oil mixture delivered to the 2-stroke snowmobile engine is emitted directly without being burned.

Ideally, we would have quantified the economic benefit of reductions in all of these pollutants from vehicles subject to our final rule. In developing a method to quantify economic benefits for the reduction of these toxic pollutants, however, we were limited by the available exposure literature to modeling a specific common exposure scenario for snowmobiles. After detailed subsequent investigation of the limited exposure information, we judge the study to contain too many unresolved uncertainties to be used in this analysis. Further, we are not able to quantify exposures related to other high-emitting 2-stroke engines in ATVs or OHMCs. Furthermore, there are substantial uncertainties in the analysis and gaps in our underlying knowledge. More research is needed, especially regarding exposure to neurotoxicants emitted from these and other categories of 2-stroke engines to facilitate benefits calculations.

If after further study, we learn that off-road vehicle operators are exposed to combined levels of neurotoxicants at levels that impair skills related to driving ability,[4] then reductions in these exposures could result in fewer accidents and avoided medical and property damage costs. However, we were limited by gaps in knowledge about exposure estimates and health effects related to most neurotoxic compounds. For air toxics and CO, it can be important to consider both momentary blood dose as well as longer term exposures in evaluating the health effects and monetary benefits.

[xx] Duffield, JW and CJ Neher. Winter 1998-99 Visitor Survey: Yellowstone National Park, Grand Teton National Park, and Greater Yellowstone Area. May 2000. Docket A-2000-01, Document IV-A-113. The survey instrument and the report were independently peer-reviewed.

10.5 Total Benefits

We provide our base-case estimate of benefits for each health and welfare endpoint as well as the resulting base-case estimate of total benefits. To obtain this estimate, we aggregate dollar benefits associated with each of the effects examined, such as hospital admissions, into a total benefits estimate assuming that none of the included health and welfare effects overlap. The base-case estimate of the total benefits associated with the health and welfare effects is the sum of the separate effects estimates. Total monetized benefits associated with the final Large SI/Recreational Vehicle rule are listed in Table 10.5-1, along with a breakdown of benefits for the Large SI category only by endpoint. Note that the value of endpoints known to be affected by ozone and/or PM that we are not able to monetize are assigned a placeholder value (e.g., B_1, B_2, etc.). Unquantified physical effects are indicated by a U. The estimate of total benefits is thus the sum of the monetized benefits and a constant, B, equal to the sum of the unmonetized benefits, $B_1+B_2+...+B_n$.

A comparison of the incidence column to the monetary benefits column reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there many times more asthma attacks than premature mortalities, yet these asthma attacks account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as asthma attacks, are valued using a proxy measure of WTP. As such the true value of these effects may be higher than that reported in Table 10.5-1.

Table 10.5-1
Base-Case Estimate of Annual Health Benefits Associated With Air Quality Changes Resulting from the Large SI/Recreational Vehicle Rule in 2030

Endpoint	**Avoided Incidence[A] (cases/year)**	**Monetary Benefits[B] (millions 2002$, adjusted for growth in real income)**
PM-related Endpoints[C]		
Premature mortality[D] (adults, 30 and over)	1,000	$7,510
Chronic bronchitis (adults, 26 and over)	640	$280
Hospital Admissions – Pneumonia (adults, over 64)[F]	100	<$5
Hospital Admissions – COPD (adults, 64 and over)	100	<$5
Hospital Admissions – Asthma (65 and younger)	100	<$1
Hospital Admissions – Cardiovascular (adults, over 64)	300	<$10
Emergency Room Visits for Asthma (65 and younger)	300	<$1
Asthma Attacks (asthmatics, all ages)[E]	20,600	<$1
Acute bronchitis (children, 8-12)	2,200	<$1
Lower respiratory symptoms (children, 7-14)	23,700	<$1
Upper respiratory symptoms (asthmatic children, 9-11)	23,400	<$1
Work loss days (adults, 18-65)	181,300	$20
Minor restricted activity days (adults, age 18-65)	944,400	$50
Other PM-related health effects[E]	U_1	B_1
Ozone-related Endpoints	U_2	B_2
Quantified HC-related WTP	--	U_3
CO and HC-related health effects[E]	U_4+U_5	B_3
Monetized Total Health-related Benefits[G]	—	$7,880 +$\mathbf{B_H}$

[A] Incidences are rounded to the nearest 100. Nox and PM-related reductions are not quantified for ATVs, OHMs, snowmobiles and recreational marine diesel.

[B] Dollar values are rounded to the nearest $10 million.

[C] PM-related benefits are based on the assumption that Eastern U.S. nitrate reductions are equal to one-fifth the nitrate reductions predicted by REMSAD (see HD07 RIA Chapter II for a discussion of REMSAD and model performance).

[D] Premature mortality associated with ozone is not separately included in this analysis (also note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure).

[E] A detailed listing of unquantified PM, ozone, CO, and HC related health effects is provided in Table 10.2-1.

[F] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship. Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

[G] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_a+B_1

10.6 Comparison of Costs to Benefits

Benefit-cost analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, benefit-cost analysis helps illuminate important potential effects of alternative policies and helps set priorities for closing information gaps and reducing uncertainty. According to economic theory, the efficient policy alternative maximizes net benefits to society (i.e., social benefits minus social costs). However, not all relevant costs and benefits can be captured in any analysis. Executive Order 12866 clearly indicates that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. There are many important unquantified and unmonetized costs and benefits associated with reductions in emissions, including many health and welfare effects. Potential benefit categories that have not been quantified and monetized are listed in Table 10.2-1 of this chapter.

The estimated social cost (measured as changes in consumer and producer surplus) in 2030 to implement the final Large SI/Recreational Vehicle program from Chapter 9 is $216 million (2001$). The net social gain, considering fuel efficiency, is $553 million. The monetized benefits are approximately $7.8 billion, and EPA believes there is considerable value to the public of the benefits it could not monetize. The net benefit that can be monetized is $8.4 billion. Therefore, implementation of the Large SI/Recreational Vehicle program is expected to provide society with a net gain in social welfare based on economic efficiency criteria. Table 10.6-1 summarizes the costs, benefits, and net benefits.

Table 10.6-1

	Millions of 2001\$[a]
Social Gains	\$550
Monetized PM-related benefits[b,c]	\$7,880 + $\mathbf{B_{PM}}$
Monetized Ozone-related benefits[b,d]	not monetized ($\mathbf{B_{Ozone}}$)
HC-related benefits	not monetized ($\mathbf{B_{HC}}$)
CO-related benefits	not monetized ($\mathbf{B_{CO}}$)
Total annual benefits	\$7,880 +$\mathbf{B_{PM}}$ + $\mathbf{B_{Ozone}}$ + $\mathbf{B_{HC}}$ + $\mathbf{B_{CO}}$
Monetized net benefits[e]	\$8,430 + **B**

[a] For this section, all costs and benefits are rounded to the nearest 10 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.

[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table IX-E.2**.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.

[c] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship.

[d] There are substantial uncertainties associated with the benefit estimates presented here, as compared to other EPA analyses that are supported by specific modeling. This analysis used a benefits transfer technique described in the RSD.

[e] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HC.

The net present value of the future benefits has also been calculated, using a 3 percent discount rate over the 2002 to 2030 time frame. The net present value of the social gains, from Table 9.1-7 of Chapter 9, is \$4,930 million. The net present value of the total annual benefits, from Tables 10.3-7 and 10.4-3, is \$77,177 million + B. Consequently, the net present value of the monetized net benefits of this program is \$82,107 million.

For each of the vehicle categories, the net present value of the future streams of surplus losses, fuel savings, social costs/gains, health and environmental benefits and net cost/benefits have been calculated. The net present values of these future streams are calculated using a 3 percent discount rate (in Chapters 9, 10, and 11) and are calculated over the 2002 to 2030 time frame.

These net present value estimates are sensitive to the discount rate. Table 10.6-2 presents an alternative net present value calculation of the surplus loss, fuel savings, social costs/gains, health and environmental benefits, and net cost or benefits for the control programs being adopted in this rulemaking, for each vehicle category, for the period 2002 to 2030, assuming an alternative discount rate of 7%.

Table 10.6-2
Net Present Values*, Fuel Cost Savings, and Social Costs/Gains
(millions of 2001$)**

Vehicle Category	NPV of Surplus Loss	NPV of Fuel Cost Savings	NPV of Social Costs/Gains ***
CI Marine	$59.0	$0.0	$59.0
Forklifts	$415.8	$2,644.2	($2,228.4)
Other Large SI****	$419.7	$804.8	($385.1)
Snowmobiles	$296.9	$459.7	($162.8)
ATVs	$491.9	$253.0	$238.9
Off-Highway Motorcycles	$206.2	$120.6	$85.6
Total	**$1,889.5**	**$4,282.3**	**($2,392.8)**

* Net Present Values are calculated using a discount rate of 7 percent over the 2002 - 2030 time period.
** Figures are in year 2000 and 2001 dollars, depending on the vehicle category; ( ) represents a negative cost (social gain).
***Figures in this column exclude estimated health and environmental benefits.
****Figures in this row are engineering cost estimates. See Section 9.7.6 of Chapter 9.

The net present value of the future benefits has also been calculated, using a 7 percent discount rate over the 2002 to 2030 time frame. The net present value of the social gains from above, is $2,393 million. The net present value of the total annual health and environmental benefits that we were able to quantify using a 7 percent discount rate is $40,070 million + B. Consequently, the net present value of the monetized net benefits of this program using a 7 percent discount rate is $42,477 + B million.

Chapter 10 Bibliography

Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancuren, and P.K. Mills. 1995a. "Estimated Long-Term Ambient Concentrations of PM(10) and Development of Respiratory Symptoms in a Nonsmoking Population." *Archives of Environmental Health* 50(2): 139-152.

Abbey, D.E., F. Petersen, P. K. Mills, and W. L. Beeson. 1993. "Long-Term Ambient Concentrations of Total Suspended Particulates, Ozone, and Sulfur Dioxide and Respiratory Symptoms in a Nonsmoking Population." *Archives of Environmental Health* 48(1): 33-46.

Abt Associates Inc., 2000.. *Heavy Duty Engine/Diesel Fuel Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results*. Prepared for US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. November. A copy of this document can be found in Docket A-2000-01, Document IV-A-219.

Abt Associates, Inc., 1999a. *Tier2 Final Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results,* Prepared for the US Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, November.

Abt Associates Inc., 1999b. Memorandum to Lisa Conner, US EPA, Office of Air Quality Planning and Standards. "Derivation of 2030 Population Estimates for the Tier II Analysis." September.

Abt Associates Inc., 1998. *Air Quality Estimation for the NOx SIP Call RIA*. Prepared for US EPA, Office of Air Quality Planning and Standards, under contract no. 68-D-98-001. Research Triangle Park, NC. September. See EPA Air Docket A-96-56, Document No. VI-B-09.

American Lung Association, 1999. Chronic Bronchitis. Web site available at: http://www.lungusa.org/diseases/lungchronic.html.

Blumenschein, K. and M. Johannesson. 1998. "Relationship Between Quality of Life Instruments, Health State Utilities, and Willingness to Pay in Patients with Asthma." *Annals of Allergy, Asthma, and Immunology* 80:189-194.

Benignus, V, W Boyes, and P. Bushnell, US Environmental Protection Agency. National Health and Environmental Effects Research Laboratory. Memorandum to the Docket. Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust. September 2002. A copy of this document can be found in Docket A-2000-01, Document IV-A-143.

Chestnut, L.G. 1997. Draft Memorandum: *Methodology for Estimating Values for Changes in*

Visibility at National Parks. April 15.

Chestnut, L.G. and R.L. Dennis. 1997. Economic Benefits of Improvements in Visibility: Acid Rain Provisions of the 1990 Clean Air Act Amendments. *Journal of Air and Waste Management Association* 47:395-402.

Chestnut, L.G., and R.D. Rowe. 1990b. A New National Park Visibility Value Estimates. In *Visibility and Fine Particles*, Transactions of an AWMA/EPA International Specialty Conference, C.V. Mathai, ed. Air and Waste Management Association, Pittsburgh.

Chestnut, L.G. and R.D. Rowe. 1990a. *Preservation Values for Visibility Protection at the National Parks: Draft Final Report.* Prepared for Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park, NC and Air Quality Management Division, National Park Service, Denver, CO.

Crocker T. D. and R. L. Horst, Jr. 1981. “Hours of Work, Labor Productivity, and Environmental Conditions: a Case Study.” *The Review of Economics and Statistics* 63:361-368.

Delfino, R.J., R.S. Zeiger, J.M. Seltzer, and D.H. Street. 1998. Symptoms in Pediatric Asthmatics and Air Pollution: Differences in Effects by Symptom Severity, Anti-inflammatory Medication Use and Particulate Averaging Time. *Environmental Health Perspectives,* 106(11): 751-761.

Delfino, R.J., R.S. Zeiger, J.M. Seltzer, and D.H. Street, 1998. Symptoms in Pediatric Asthmatics and Air Pollution: Differences in Effects by Symptom Severity. Anti-inflammatory Medication Use and Particulate Averaging Time. *Environmental Health Perspectives,* 106(11): 751-761.

Dennis, R.L., 1997. "Using the Regional Acid Deposition Model to Determine the Nitrogen Deposition Airshed of the Chesapeake Bay Watershed." In: *Atmospheric Deposition to the Great Lakes and Coastal Waters*. Baker, J.E., ed. Society of Environmental Toxicology and Chemistry, Pensacola, FL. pp. 393-413. See EPA Air Docket A-96-56, Document No. VI-B-09.

Desvouges, W.H., F. R. Johnson, and H.S. Banzhaf. 1998. *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method*. Edward Elgar, Northhampton, MA.

Dickie, M. et al. 1991. Reconciling Averting Behavior and Contingent Valuation Benefit Estimates of Reducing Symptoms of Ozone Exposure (draft), as cited in Neumann, J.E., Dickie, M.T., and R.E. Unsworth. 1994. Industrial Economics, Incorporated. Memorandum to Jim DeMocker, US EPA, Office of Air and Radiation. March 31.

Dillman, D. 1992. Mail and Telephone Surveys. John Wiley Publishing. New York.

Dockery, D.W., C.A. Pope, X.P. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris and F.E. Speizer. 1993. "An association between air pollution and mortality in six U.S. cities." *New England Journal of Medicine* 329(24): 1753-1759.

Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne and F.E. Speizer. 1996. "Health Effects of Acid Aerosols On North American Children-Respiratory Symptoms." *Environmental Health Perspectives*. 104(5): 500-505.

Douglas, S.G. and R.K. Iwamiya, 1999. *Estimating the Effects of the Tier 2 Motor-Vehicle Standards on Air Quality: Ozone*. Prepared for Abt Associates, Inc. Prepared by Systems Applications International, Inc. SYSAPP-99-98/50. January.

Duffield, J.W., Neher, C. J. Winter 1998-99 Visitor Survey Yellowstone N.P., Grand Teton N.P., and the Greater Yellowstone Area Final Report. Report prepared for National Park Service, Denver, CO. May, 2000. This document is available in Docket A-2000-01, Document IV-A-114.

E.H. Pechan & Associates, 1996. R*egional Particulate Control Strategies Phase II*. Prepared for the US Environmental Protection Agency, Office of Policy, Planning, and Evaluation. Washington, DC. September.

E.H. Pechan & Associates, 1999. *Emissions and Air Quality Impacts of Proposed Motor Vehicle Tier 2 and Fuel Sulfur Standards*. Prepared by The Pechan-Avanti Group under EPA Contract No. 68-D9-8052. for US EPA, Office of Air Quality Planning and Standards, Innovative Strategies and Economics Group. Research Triangle Park, NC. January.

Elixhauser, A., R.M. Andrews, and S. Fox. 1993. Clinical Classifications for Health Policy Research: Discharge Statistics by Principal Diagnosis and Procedure. Agency for Health Care Policy and Research (AHCPR), Center for General Health Services Intramural Research, US Department of Health and Human Services.

Empire State Electric Energy Research Corporation (ESEERCO). 1994. *New York State Environmental Externalities Cost Study. Report 2: Methodology.* Prepared by: RCG/Hagler, Bailly, Inc., November.

EPA-SAB, Health and Ecological Effects Subcommittee of the Advisory Council on Clean Air Act Compliance Analysis. 1999. Summary Minutes of Public Meeting, April 21-22, 1999.

EPA-SAB-COUNCIL-ADV-99-05, 1999. An SAB Advisory on the Health and Ecological

Effects Initial Studies of the Section 812 Prospective Study: Report to Congress: Advisory by the Health and Ecological Effects Subcommittee, February.

EPA-SAB-COUNCIL-ADV-98-003, 1998. Advisory Council on Clean Air Compliance Analysis Advisory on the Clean Air Act Amendments (CAAA) of 1990 Section 812 Prospective Study: Overview of Air Quality and Emissions Estimates: Modeling, Health and Ecological Valuation Issues Initial Studies.

EPA-SAB-COUNCIL-ADV-99-012, 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 1. July. A copy of this document can be found in Docket A-2000-01, Document IV-A-204.

EPA-SAB-COUNCIL-ADV-00-001, 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 2. October, 1999.

EPA-SAB-COUNCIL-ADV-00-002, 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Advisory Council on Clean Air Compliance Analysis: Costs and Benefits of the CAAA. Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 2. October, 1999.

EPA-SAB-EEAC-00-013, 2000. An SAB Report on EPA's White Paper *Valuing the Benefits of Fatal Cancer Risk Reduction*.US Environmental Protection Agency, Science Advisory Board, Environmental Economics Advisory Committee, July 27, 2000. A copy of this document can be found in Docket A-99-06, Document IV-A-19.

Greenbaum, D., President, Health Effects Institute. "Dear Colleague" letter dated May 30, 2002. A copy of this letter can be found in Docket A-2000-01, Document IV-A-145, as an attachment to a letter from Lester D. Grant, PhD, to Dr. Philip K. Hopke, dated August 8, 2002.

Grosclaude, P. and N.C. Soguel. 1994. "Valuing Damage to Historic Buildings Using a Contingent Market: A Case Study of Road Traffic Externalities." *Journal of Environmental Planning and Management* 37: 279-287.

Holland, M., D. Forster, and M. Wenborn. 1999. Economic Evaluation of Proposals Under the UNECE Multi-effects and Multi-pollutant Protocol. Prepared for: European Commission, DGXI, Brussels and Luxembourg. January. Report no. AEAT-4587.

Hoskins, G., C. McCowan, R.G. Neville, G.E. Thomas, B. Smith, and S. Silverman. 2000. "Risk Factors and Costs Associated with and Asthma Attack." *Thorax*. 55: 19-24.

Hoskins, G., C. McCowan, R.G. Neville, G.E. Thomas, B. Smith, S. Silverman. 2000. Risk Factors and Costs Associated with an Asthma Attack. *Thorax*, 55: 19-24.

Hubbell, Bryan. 2002a. Senior Economist, OAQPS. Memorandum to Docket A-2000-01. Estimated NOx, SO2, and PM Emissions Health Damages for Heavy Duty Vehicle Emissions. April 22, 2002. A copy of this document can be found in Docket A-2000-01, Document IV-A-146.

Hubbell, Bryan. 2002b. Senior Economist, OAQPS. Memorandum to Trish Koman, OTAQ. Appendix to April 22 Memo "Estimated NOx, SO2, and PM Emissions Health Damages for Heavy Duty Vehicle Emissions": Alternative Estimates of Mortality and Chronic Bronchitis Impacts. A copy of this document can be found in Docket A-2000-01, Document IV-A-202.

Industrial Economics, Incorporated (IEc). 1994. Memorandum to Jim DeMocker, Office of Air and Radiation, Office of Policy Analysis and Review, US Environmental Protection Agency, March 31.

Jack, E., L.P. Boss, and W.M. Millington. 2000. Asthma - A Speaker's Kit for Public Health Professionals. Centers for Disease Control and Prevention, National Center for Health Statistics, Division of Environmental Hazards and Health Effects, Air Pollution and Respiratory Health Branch. Available at: http://www.cdc.gov/nceh/asthma/speakit/cover.htm.

Jones-Lee, M.W. 1989. *The Economics of Safety and Physical Risk*. Oxford: Basil Blackwell.

Jones-Lee, M.W., G. Loomes, D. O'Reilly, and P.R. Phillips. 1993. The Value of Preventing Non-fatal Road Injuries: Findings of a Willingness-to-pay National Sample Survey. TRY Working Paper, WP SRC2.

Krewski D, Burnett RT, Goldbert MS, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M, White WH. 2000. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality. Special Report to the Health Effects Institute, Cambridge MA, July 2000. A copy of this document can be found in Docket A-99-06, Document IV-G-75.

Krupnick, A.J., W. Harrington and B. Ostro. 1990. "Ambient Ozone and Acute Health Effects - Evidence From Daily Data." *Journal of Environmental Economics and Management* 18(1): 1-18.

Krupnick, A.J. and M.L. Cropper. 1992. "The Effect of Information on Health Risk Valuations." *Journal of Risk and Uncertainty* 5(2): 29-48.

Krupnick, A.J., A. Alberini, M. Cropper, N. Simon, B. O'Brien, R. Goeree, and M. Heintzelman. 2000. Age, Health, and the Willingness to Pay for Mortality Risk Reductions: A Contingent

Valuation Survey of Ontario Residents. Resources for the Future Discussion Paper 00-37.

Krupnick, A.J. 2000. Personal Communication, December 5.

Kunzli, N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horak Jr., V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J-C Vergnaud, and H. Sommer. 2000. Public-health Impact of Outdoor and Traffic-related Air Pollution: A European Assessment. *The Lancet*, 356: 795-801.

Lang, C., G. Yarwood, F. Lalonde, and R. Bloxam. 1995. *Environmental and Health Benefits of Cleaner Vehicles and Fuels*. Prepared for: Canadian Council of Ministers of the Environment Task Force on Cleaner Vehicles and Fuels, Winnipeg, Manitoba. October.

Laurence, J.A., W.A. Retzlaff, J.S. Kern, E.H.Lee, W.E. Hogsett, and D.A. Weinstein. 2000. Predicting the regional impact of ozone and precipitation on the growth of loblolly pine and yellow-poplar using linked TREGRO and ZELIG models. For Ecological Management. In press.

Loehman, E.T., S.V. Berg, A.A. Arroyo, R.A. Hedinger, J.M. Schwartz, M.E. Shaw, R.W. Fahien, V.H. De, R.P. Fishe, D.E. Rio, W.F. Rossley, and A.E.S. Green. 1979. “Distributional Analysis of Regional Benefits and Cost of Air Quality Control.” *Journal of Environmental Economics and Management* 6: 222-243.

Manuel, E.H., R.L. Horst, K.M. Brennan, W.N. Lanen, M.C. Duff and J.K. Tapiero. 1982. *Benefits Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates, Volumes I-IV*. Prepared for US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

McClelland, G., W. Schulze, D. Waldman, J. Irwin, D. Schenk, T. Stewart, L. Deck, and M. Thayer. 1993. *Valuing Eastern Visibility: A Field Test of the Contingent Valuation Method*. Prepared for Office of Policy, Planning and Evaluation, US Environmental Protection Agency. September.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, H. Vora, E. Avol, W.J. Gauderman, H.G. Margolis, F. Lurmann, D.C. Thomas, and J.M. Peters. 1999. Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. *Environmental Health Perspectives*, 107(9): 757-760.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, H. Vora, E. Avol, W.J. Gauderman, H.G. Margolis, F. Lurmann, D.C. Thomas, and J.M. Peters. 1999. Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. *Environmental Health Perspec*tives. 107(9): 757-760.

McDonnell, W.F., D.E. Abbey, N. Nishino and M.D. Lebowitz. 1999. “Long-term ambient ozone concentration and the incidence of asthma in nonsmoking adults: the ahsmog study.” *Environmental Research*. 80(2 Pt 1): 110-21.

Mitchell, RC and RT Carson, 1989. Using Surveys to Value Public Goods: the Contingent Valuation Method. Resources for the Future. Washing ton DC.

NCLAN. 1988. Assessment of Crop Loss from Air Pollutants. (Eds. Walter W. Heck, O. Clifton Taylor and David T. Tingey) Elsevier Science Publishing Co.: New York, Pp. 1-5. (ERL,GB 639).

O’Conor, Richard M. and Glenn C. Blomquist, 1997. “Measurement of Consumer-Patient Preferences Using a Hybrid Contingent Valuation Method.” *Journal of Health Economics* 16:667-683.

Ostro, B.D., M.J. Lipsett, J.K. Mann, H. Braxton-Owens, M.C. White, 1995. Air Pollution and Asthma Exacerbations Among African-American Children in Los Angeles. *Inhalation Toxicology,* 7:711-722.

Ostro, B.D. 1987. Air Pollution and Morbidity Revisited: a Specification Test. *Journal of Environmental Economics Management.* 14: 87-98.

Ostro B.D. and S. Rothschild. 1989. “Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants.” *Environmental Research* 50:238-247.

Ostro, B.D., M.J. Lipsett, J.K. Mann, H. Braxton-Owens, M.C. White. 1995. Air Pollution and Asthma Exacerbations Among African-American Children in Los Angeles. *Inhalation Toxicology*, 7:711-722.

Pew Environmental Health Commission. 2000. *Attack Asthma: Why America Needs A Public Health Defense System to Battle Environmental Threats*. Johns Hopkins School of Public Health, Baltimore, MD.

Pew Environmental Health Commission. 2000. *Attack Asthma: Why America Needs A Public Health Defense System to Battle Environmental Threats.* John Hopkins School of Public Health, Baltimore, MD.

Pope, C.A., III, M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath, Jr. 1995. “Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults.” *American Journal of Respiratory Critical Care Medicine* 151: 669-674.

Pope, C.A., III, D.W. Dockery, J.D. Spengler, and M.E. Raizenne. 1991. “Respiratory Health and PM_{10} Pollution: a Daily Time Series Analysis" *American Review of Respiratory Diseases* 144: 668-674.

Rowe, R.D. and L.G. Chestnut. 1986. "Oxidants and Asthmatics in Los Angeles: A Benefits Analysis--Executive Summary." Prepared by Energy and Resource Consultants, Inc. Report to the US EPA, Office of Policy Analysis. EPA-230-09-86-018. Washington, DC March.

Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, Schwartz J, Zanobetti A. 2000. The National Morbidity, Mortality and Air Pollution Study: Part II: Morbidity, Mortality and Air Pollution in the United States. Research Report No. 94, Part II. Health Effects Institute, Cambridge MA, June 2000. Docket A-2000-01, Documents IV-A-205 and 206.

Schwartz, J., Dockery, D.W., Neas, L.M., Wypij, D., Ware, J.H., Spengler, J.D., Koutrakis, P., Speizer, F.E., and Ferris, Jr., B.G. 1994. "Acute Effects of Summer Air Pollution on Respiratory Symptom Reporting in Children" *American Journal of Respiratory Critical Care* Medicine 150: 1234-1242.

Schwartz, J. 1993. "Particulate Air Pollution and Chronic Respiratory Disease" *Environmental Research* 62: 7-13.

Sheppard, L., D. Levy, G. Norris, T.V. Larson and J.Q. Koenig. 1999. Effects of ambient air pollution on nonelderly asthma hospital admissions in Seattle, Washington, 1987-1994. *Epidemiology*. Vol. 10(1): 23-30.

Sisler, J.F. 1996. Spatial and Seasonal Patterns and Long Term Variability of the Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network. Cooperative Institute for Research in the Atmosphere, Colorado State University; Fort Collins, CO July.

Smith, D.H., D.C. Malone, K.A. Lawson, L. J. Okamoto, C. Battista, and W.B. Saunders, 1997. "A National Estimate of the Economic Costs of Asthma." *American Journal of Respiratory Critical Care Medicine* 156: 787-793.

Smith, V.K., G.Van Houtven, and S. Pattanayak. 1999. "Benefit Transfer as Preference Calibration" *Resources for the Future Discussion Paper* 99-36.

Taylor, C.R., K.H. Reichelderfer, and S.R. Johnson. 1993. Agricultural Sector Models for the United States: Descriptions and Selected Policy Applications. Iowa State University Press: Ames, IA.

Thurston, G.D., M.L. Lippman, M.B. Scott, and J.M. Fine. 1997. Summertime Haze Air Pollution and Children with Asthma. *American Journal of Respiratory Critical Care Medicine,* 155: 654-660.

Thurston, G.D., M.L. Lippman, M.B. Scott, and J.M. Fine. 1997. Summertime Haze Air Pollution and Children with Asthma. *American Journal of Respiratory Critical Care Medicine,* 155: 654-660.

Tolley, G.S. et al. 1986. Valuation of Reductions in Human Health Symptoms and Risks. University of Chicago. Final Report for the US Environmental Protection Agency. January.

US Department of Commerce, Economics and Statistics Administration. 1992. Statistical Abstract of the United States, 1992: The National Data Book. 112th Edition, Washington, DC.

US Department of Commerce, Bureau of Economic Analysis. 1995. BEA Regional Projections to 2045: Vol. 1, States. Washington, DC US Govt. Printing Office, July 1995.

US Department of Health and Human Services, Centers for Disease Control and Prevention. 1999. National Center for Environmental Health Web Site. Available at http://www.cdc.gov/nceh/asthma/factsheets/asthma.htm

US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. 1994. Vital Statistics of the United States, 1990. Volume II-Mortality. Hyattsville, MD.

US Department of Health and Human Services, Centers for Disease Control and Prevention. 1999. “Forecasted State-Specific Estimates of Self-Reported Asthma Prevalence -- United States, 1998.” *CDC-Morbidity and Mortality Weekly Report*, 47: 1022-1025.

US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. 1999. National Vital Statistics Reports, 47(19).

US Department of Interior, 1986. Natural Resources Damage Assessment Rules and Regulations. (51 FR 148: 27725-27753. August 1, 1986)

US Department of Interior, 1991. Natural Resource Damage Assessment: Notice of Proposed Rulemaking. 56 FR 82: 19752-19753 April 29, 1991).

US Environmental Protection Agency, 1996b. *Review of the National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information.* Office of Air Quality Planning and Standards, Research Triangle Park, NC EPA report no. EPA/4521R-96-013. A copy of this document can be found in Docket A-99-06, Document II-A-23.

US Environmental Protection Agency, 1997e. *Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule.* US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. July. See

EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1998a. *Regulatory Impact Analysis for the NOx SIP Call, FIP and Section 126 Petitions, Volume 2: Health and Welfare Benefits*. Prepared by: Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC December.

US Environmental Protection Agency, 1997a. *Regulatory Impact Analysis for Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed RH Rule.* Prepared by: Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC. July.

US Environmental Protection Agency, 1998a. *Regulatory Impact Analysis for the NOx SIP Call, FIP, and Section 126 Petitions*. US EPA, Office of Air and Radiation. Washington, DC. EPA-452/R-98-003. December. See EPA Air Docket A-96-56, VI-B-09.

US Environmental Protection Agency, 1998b. *The Regional NOx SIP Call & Reduced Atmospheric Deposition of Nitrogen: Benefits to Selected Estuaries*, September.

US Environmental Protection Agency, 1999a. *The Benefits and Costs of the Clean Air Act, 1990-2010.* Prepared for US Congress by US EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC, November; EPA report no. EPA-410-R-99-001.

US Environmental Protection Agency, 1999b. *Regulatory Impact Analysis: Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements*. Prepared by: Office of Mobile Sources, Office of Air and Radiation, December.

US Environmental Protection Agency, 1999c. *Regulatory Impact Analysis for the Final Regional Haze Rule.* Office of Air Quality Planning and Standards, Research Triangle Park, NC. April 22, 1999.

US Environmental Protection Agency, 1997f. "Response to Comments Made by AISI on EPA Methodology for Predicting PM2.5 from PM10." Memorandum to the docket from Terence Fitz-Simons (Office of Air Quality Planning and Standards, Air Quality Trends Analysis Group). February 6. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1996a. *Proposed Methodology for Predicting PM2.5 from PM10 Values to Assess the Impact of Alternative Forms and Levels of the PM NAAQS.* Prepared by Terence Fitz-Simons, David Mintz and Miki Wayland (US Environmental Protection Agency, Office of Air Quality Planning and Standard, Air Quality Trends Analysis Group). June 26. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1996b. *Review of the National Ambient Air Quality Standards for Ozone: Assessment of Scientific and Technical Information.* Office of Air Quality Planning and Standards, Research Triangle Park, NC EPA report no. EPA/4521R-96-007. Docket A-99-06, Document II-A-22.

US Environmental Protection Agency, 1994. Documentation for Oz-One Computer Model (Version 2.0). Prepared by Mathtech, Inc., under Contract No. 68D30030, WA 1-29. Prepared for US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. August

US Environmental Protection Agency, 1993. External Draft, Air Quality Criteria for Ozone and Related Photochemical Oxidants. Volume II. US EPA, Office of Health and Environmental Assessment. Research Triangle Park, NC, EPA/600/AP-93/004b.3v.

US Environmental Protection Agency, 1999b. *Regulatory Impact Analysis for the Final Regional Haze Rule*. Prepared by: Office of Air Quality Planning and Standards, Office of Air and Radiation, April.

US Environmental Protection Agency, 2000a. Technical Support Document for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements- Air Quality Modeling Analyses. December 2000.

US Environmental Protection Agency, 2000b. *Valuing Fatal Cancer Risk Reductions*. White Paper for Review by the EPA Science Advisory Board.

US Environmental Protection Agency,1997c. "Methodology Used to Create PM10 and PM2.5 Air Quality Databases for RIA Work." Memorandum from David Mintz, Air Quality Trends Analysis Group, Office of Air Quality Planning and Standards to Allyson Siwik, Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards. July 15. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1997b. *The Benefits and Costs of the Clean Air Act, 1970 to 1990*. Prepared for US Congress by US EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC

U.S. EPA Guidelines for the Health Risk Assessment of Chemical Mixtures. EPA Report No. 630/R-98/002. September 24, 1986. Federal Register 51(185) : 34014 - 34025. http://cfpub.epa.gov/ncea/

Valigura, Richard A., and W.T. Luke, R.S. Artz, B.B. Hicks. 1996. Atmospheric input to coastal areas: reducing the uncertainties. NOAA Coastal Ocean Program, Decision Analysis Series No. 9. NOAA Atmospheric Resources Laboratory, Silver Spring, MD.

Valiela, G. Collins, and J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, C.H. Sham. 1997. "Nitrogen loading from coastal watersheds to receiving estuaries: new method and application." *Ecological Applications* 7(2), pp. 358-380.

Viscusi, W.K. 1992. *Fatal Tradeoffs: Public and Private Responsibilities for Risk*. (New York: Oxford University Press).

Viscusi, W.K., W.A. Magat, and J. Huber. 1991. "Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis" *Journal of Environmental Economics and Management*, 21: 32-51.

Walsh, RG, DM Johnson and JR McKean, 1992. Benefits Transfer of Outdoor Recreation Demand Studies, 1968 - 1988. Water Resource Research. 28: 703-713.

White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

Whittemore, A.S. and E.L. Korn. 1980. Asthma and Air Pollution in the Los Angeles Area. *Am J Public Health*. Vol. 70: 687-696.

Yu, O., L. Sheppard, T. Lumley, J. Q. Koenig, and G.G. Shapiro. 2000. Effects of Ambient Air Pollution on Symptoms of Asthma in Seattle-Area Children Enrolled in the CAMP Study. *Environmental Health Perspectives*, 108(12): 1209-1214.

Chapter 11: Regulatory Alternatives

Adopting standards to reduce emissions requires consideration of a variety of alternative approaches. This rulemaking development effort includes consideration of the timing of emission standards, the level of stringency, the appropriate test procedures, among other things. In this chapter, we present a variety of alternatives that we considered in preparing this rulemaking. While these alternatives were not adopted as part of the final rule, they are discussed here with an analysis of the associated costs and emission reductions involved and our rationale for not adopting them.

11.1 Recreational Marine Diesel Engines

While developing the CI recreational marine engine standards we analyzed two alternative approaches. The first approach was to apply the draft European Commission recreational marine emission standards to CI recreational marine engines used in the United States. Another approach we considered was to implement the CI recreational marine engine standards on the same schedule as for commercial marine engines. These two alternative approaches are discussed below.

11.1.1 Harmonization with Draft EC Standards

Several manufacturers commented that we should finalize the emission standards proposed by the European Commission (EC) for CI recreational marine engines for our national standards. These emission levels are presented in Table 11.1-1. This table also presents the U.S. standards finalized today and average baseline emissions based on data presented earlier in Chapter 4 on engines for which we had data on both HC+NOx and PM.[yy] Based on this data, we believe that the proposed European emissions standards for recreational marine diesel engines may not result in a decrease in emissions, and may even allow an increase in emissions from engines operated in the U.S. because current engines are already performing better than the proposed EC limits. Also, because the Clean Air Act directs us to set standards that “achieve the greatest degree of emission reduction achievable” given appropriate considerations, we do not believe it would be appropriate to finalize emission standards at the levels proposed by the European Commission.

[yy] If we include HC+NOx data from engine tests that did not include PM measurement, the HC+NOx average decreases to 8.6 g/kW-hr.

Table 11.1-1
EPA and Proposed European Standards Compared to Average Baseline Levels for CI Recreational Marine Emissions

Pollutant	EPA Standards g/kW-hr	Proposed EC Standards g/kW-hr	Baseline Emissions g/kW-hr
HC+NOx	7.2-7.5	9.8 NOx, 1.5 HC*	9.2
PM	0.2-0.4	1.4	0.2
CO	5.0	5.0	1.3

* HC increases slightly with increasing power rating.

We are not presenting an analysis of the cost per ton of emission reduction for this approach because we do not believe that it would result in emission reductions. However, the engine manufacturers would still need to incur the certification and compliance costs presented in Chapter 5. Therefore, setting a standard equal to the draft EC standards would likely result in costs with few or no benefits.

11.1.2 Earlier Implementation Dates Consistent with Commercial Marine

We believe that the emission-reduction strategies expected for land-based nonroad diesel engines and commercial marine diesel engines will also be applied to recreational marine diesel engines. Marine diesel engines are generally derivatives of land-based nonroad and highway diesel engines. Marine engine manufacturers and marinizers make modifications to the engine to make it ready for use in a vessel. These modifications can range from basic engine mounting and cooling changes to a restructuring of the power assembly and fuel management system. Because we anticipate that the same or similar technology will be used to meet the recreational and commercial marine standards, we considered including recreational marine engines in the commercial marine program with the same implementation dates.

Engine manufacturers commented that recreational marine engines need at least two years of lead time after the commercial marine standards to transfer technology from commercial marine engines to recreational marine engines and to stagger the need for manufacturers' research and development costs. We agree that this is necessary. In current production practices, the recreational marine engines are designed to operate at a higher power to weight ratio than commercial engines which requires development efforts specific to these engines. Although we believe that the same technology can be applied to recreational and commercial marine engines to reduce emissions, we recognize that individual development efforts will be required. In current practices, manufacturers stagger their development schedules to effectively use resources which include engineering hours and test cell time. If we were to require that recreational marine engines meet the new standards in the same year as commercial marine engines, manufacturers would likely need to double their research and development resources. We do not consider it practical for a manufacturer to do this in time for earlier standards, especially if the resources are only needed for two years. By allowing an additional two years of lead time, manufacturers are better able to stagger their development efforts.

The advantage of the earlier implementation dates would be to achieve emission reductions two years earlier. This would not likely affect the hardware costs discussed in Chapter 5, but would significantly increase the research and development costs if new people had to be hired and new facilities constructed. In fact, manufacturers would not likely have enough time to increase their research and development resources in time to meet earlier implementation dates. Therefore we are giving two years of additional lead time for recreational marine engines beyond the commercial marine implementation dates.

11.2 Large Industrial Spark-Ignition Engines

Of the several possibilities for Large SI engines, we are choosing one alternative over several others. For example, we are not analyzing the alternative of adopting only 2004 standards. Given the California certification data showing that some manufacturers are already achieving 2007 emission levels (with steady-state testing). This alternative would therefore clearly not meet the Clean Air Act direction to adopt the most stringent standards achievable.

Second, we are not analyzing a scenario of more stringent emission standards. The 2007 standards follow directly from available emission test data showing what level of emission control is achievable in that time frame. Any significant emission reductions beyond the 2007 standards would be appropriate to consider for a third tier of emission standards. Once manufacturers gain experience with the new emission-control technologies and the measurement procedures, additional information will be available to help us evaluate the relative costs and benefits of more stringent standards. Such information is not available today.

Third, we are not considering the approach of requiring forklifts to convert to battery power. We don’t believe this would be an appropriate policy under Clean Air Act section 213, as described in the Summary and Analysis of Comments. An analysis comparing the life-cycle costs and benefits of the two alternative power sources for forklifts would provide useful information to consumers interested in evaluating their available choices. However, such an analysis is outside the scope of this rulemaking.

The alternative we have chosen to analyze captures a common input from those commenting on the proposal. Manufacturers generally questioned the need, value, or cost-effectiveness of adopting emission procedures requiring transient engine operation. To evaluate this more carefully, we analyzed the scenario of adopting the 2007 standards based only on steady-state emission measurement. To assess this alternative, we have calculated the costs and emission reductions associated with adding the transient controls to an engine already meeting the 2007 standards with steady-state testing.

Estimating the costs of controlling transient emissions is straightforward, with two simplifying assumptions. First, we need to assume that the technology and costs associated with the 2004 standards presented in Chapter 5 are sufficient to achieve the 2007 standards with steady-state testing. The existing California certification data support this. Second, even though the 2007 cost estimates include an allowance for meeting diagnostic requirements and field-testing standards, in this analysis we assign the full estimated cost of meeting the 2007 standards to upgrading for transient control. The resulting estimated first-year cost of $27 per engine therefore somewhat overestimates the actual cost . This includes engineering time to improve calibrations with the existing hardware, so there are no variable costs under this scenario.

To estimate the emission reductions associated with the transient test procedure, we rely primarily on the transient adjustment factors described in Chapter 6. Applying the transient adjustment factor leads to increased emissions of about 0.77 g/hp-hr HC+NOx and 3 g/hp-hr CO. Factoring in the lifetime operating parameters from the NONROAD model leads to a discounted lifetime emission reduction per engine of 0.22 tons for HC+NOx and 0.76 tons for CO. Comparing costs and emission reductions yields an estimated cost of about $200 per ton HC+NOx. Estimated nationwide emission reductions after fully phasing in the emission standards are 17,000 tons HC, 36,000 tons NOx, and 188,000 tons CO. These figures represent the incremental benefit of adding transient test procedures for the Tier 2 standards.

This analysis supports the decision to adopt emission standards requiring control of emissions during transient operation.

11.3 Recreational Vehicle Exhaust Emission Standards

11.3.1 Off-highway Motorcycles

We are presenting an analysis of two alternatives to the 2.0 g/km HC+NOx standard contained in the Final Rule, a less stringent and a more stringent alternative. The less stringent alternative we are presenting is a 4.0 g/km HC+NOx standard in the same time frame as the 2.0 g/km standard (50 and 100% phase-in for 2006 and 2007). We are finalizing this standard as an option to the 2.0 g/km standard with the provision that a manufacturer must certify all of their products, including machines that may otherwise meet the exemption for vehicles used solely for competition, to the 4.0 g/km standard. This alternative is numerically less stringent than the 2.0 g/km standard, but may actually result in more significant emission reductions than the final program since machines that may otherwise be exempt in the final program are included in the optional 4.0 g/km standard. Most competition off-highway motorcycles that could meet the competition exemption use high performance two-stroke engines that have HC levels significantly higher than the standard.

The second alternative we are presenting is the 2.0 g/km standard with an additional more stringent Phase 2 standard of 1.0 g/km phased in at 50 and 100% in 2009 and 2010. We proposed this alternative for ATVs, but not for off-highway motorcycles. It is clear from our analysis of technology, the current off-highway motorcycle market, and the comments received from manufacturers that four-stroke engines are technologically within reach for all off-highway motorcycle applications. While it is less clear, based on our analysis of technology and comments received from manufacturers and user groups it appears that direct fuel injection for two-stroke engines may also be within reach for some off-highway motorcycle applications. An analysis of the costs, emission reductions, costs per ton, and economic impacts of the alternatives are presented here. The methodology used for these analyses are the same as those described for the final program in the previous chapters.

11.3.1.1 Per Unit Costs

We have analyzed a less stringent standard of 4.0 g/km HC+NOx phased in at 50 and 100% in 2006 and 2007. The per unit average cost for this alternative is presented in Table 11.3.1-1 below. The average costs are based on a technology mix that includes the use of four-stroke engines and direct fuel injection for two-stroke engines. Because off-highway motorcycles have been using four-stroke engines for a many years and there is a significant number of these engines sold, the cost of using a four-stroke engine is less than the cost of using a direct fuel injection system with a two-stroke engine. Since we do not anticipate that any direct fuel injection two-stroke engines will be capable of meeting the final standard of 2.0 g/km HC+NOx, the resulting average cost for this alternative is somewhat higher than that of the final program, which we estimated at $158 per unit (see Chapter 5).

Table 11.3.1-1
Estimated Average Costs For Off-Highway Motorcycle Alternative 1 (4.0 g/km)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 125 cc (31%)	4-stroke engine	$219	($140)	55%	85%	$66	$42
	Direct injection	$375	($140)	0%	15%	$56	$21
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$129	$63
125 < 250 cc (27%)	4-stroke engine	$286	($140)	29%	85%	$160	$78
	Direct injection	$375	($140)	0%	15%	$56	$21
	compliance	$7	--	0%	100%	$7	--
	total	--	--	--	--	$223	$99
≥ 250 cc (42%)	4-stroke engine	$353	($140)	29%	85%	$198	$78
	Direct injection	$375	($140)	0%	15%	$56	$21
	compliance	$7	--	0%	100%	$7	--
	total					$71	$99
Near Term Composite Incremental Cost		--	--	--	--	$210	$88
Long Term Composite Incremental Cost		--	--	--	--	$127	$88

We have also analyzed an alternative that would include our final standard of 2.0 g/km plus a Phase 2 standard of 1.0 g/km that would be phased in at 50 and 100% in 2009 and 2010. This additional level of control would require R&D beyond that projected for the final 2.0 g/km standard and the incorporation of additional controls for four-stroke engines. We are projecting that at least half of off-highway motorcycle models would be equipped with catalysts in order to meet this level of stringency. The estimated average per unit costs for Phase 2 incremental to Phase 1 are provided in Table 11.3.1-2. We estimate that Phase 2 would cost about $70 incremental to Phase 1.

Table 11.3.1-2
Estimated Average Costs For Phase 2 Off-highway Motorcycles (Phase 2 = 1.0 g/km)
(Non-competition models only)

		Cost	Lifetime Fuel Savings (NPV)	Baseline	Control	Incremental Cost	Incremental Fuel Savings (NPV)
< 125 cc (37%)	4-stroke engine	$219	($140)	100%	100%	$0	$0
	pulse air	$39	$0	25%	75%	$19	$0
	R&D including recalibration	$15	$0	0%	100%	$15	$0
	Catalyst	$68	$0	0%	50%	$34	$0
	compliance	$1	--	0%	100%	$1	--
	total	--	--	--	--	$70	$0
125 < 250 cc (21%)	4-stroke engine	$286	($140)	100%	100%	$0	$0
	pulse air	$39	$0	0%	25%	$19	$0
	R&D including recalibration	$15	$0	0%	100%	$15	$0
	Catalyst	$68	$0	0%	50%	$34	$0
	compliance	$1	--	0%	100%	$1	--
	total	--	--	--	--	$70	$0
≥ 250 cc (42%)	4-stroke engine	$353	($140)	100%	100%	$0	$0
	pulse air	$39	$0	0%	25%	$19	$0
	R&D including recalibration	$15	$0	0%	100%	$15	$0
	Catalyst	$70	$0	0%	50%	$35	$0
	compliance	$1	--	0%	100%	$1	--
	total					$71	$0
Near Term Composite Incremental Cost		--	--	--	--	$70	$0
Long Term Composite Incremental Cost		--	--	--	--	$28	$0

11.3.1.2 Aggregate Cost Estimates

Based on the above per unit costs, we have estimated the aggregate costs for the two alternatives. The aggregate costs for Alternative 2 includes the costs for both phases of standards. The aggregate costs for the alternatives are provided in Table 11.3.1-3, along with the aggregate cost estimates for the final off-highway motorcycle program, which are estimated in Chapter 5. The fuel savings for both alternatives result from the switching of two-stroke to four-stroke engines. Alternative 1 also experiences fuel savings by the incorporation of competition machines into the program. Competition machines would either switch from two-stroke to four-stroke engines or use direct fuel injection with two-stroke engines. Direct fuel injection with two-stroke technology can result in similar fuel savings as converting from two-stroke to four-stroke engines.

Table 11.3.1-3
Summary of Annual Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
OHMC Final Program	$16.27	$24.24	$21.53	$22.63	$23.79
Alternative 1	$30.68	$46.56	$42.90	$45.09	$47.39
Alternative 2	$16.27	$34.25	$28.53	$29.99	$31.52
Fuel Savings (Alt 1)	$1.32	$14.13	$30.62	$39.05	$41.98
Fuel Savings (Alt 2)	$0.63	$7.23	$16.19	$21.03	$22.65

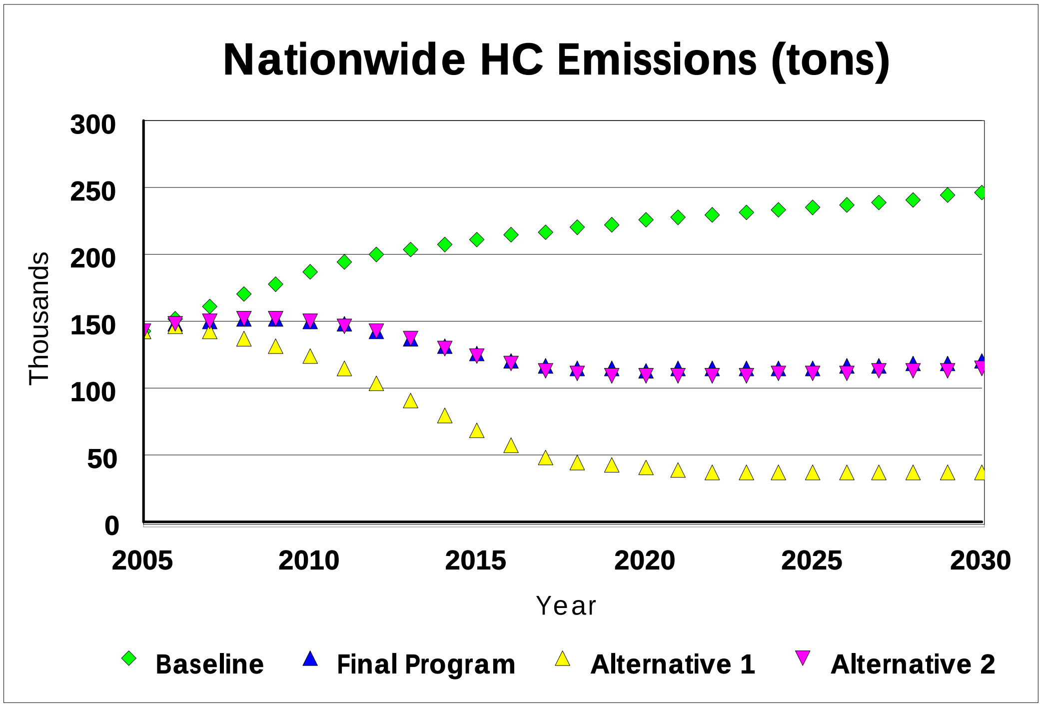
11.3.1.3 Emissions Reductions

In Chapter 6, we estimated the emissions reductions for the final program. We have estimated the emissions reductions from both alternatives using the same methodology. We would expect NOx and CO to be similar under the various alternatives. The results for HC are shown in Table 11.3.1-4 and in the Figure 11.3.1-1. The majority of the HC emissions reductions occur due to switching those remaining two-stroke off-highway motorcycles over to four-stroke technology. We expect this to occur in each of the alternatives we have analyzed. Alternative 1 has significantly greater reductions than alternative 2 or the final program, even though the numerical standard is less stringent. This is due to the fact that alternative 1 includes all off-highway motorcycles. Machines that may otherwise qualify for the competition exemption make up 29-percent of off-highway motorcycle sales, and they tend to use high-performance two-stroke engines that emit very high levels of HC emissions. Controlling HC emissions from these machines to the alternative 1 standard of 4.0 g/km would result in significant reductions.

Table 11.3.1-4
Summary of HC Reductions (thousands of tons)

	2006	2010	2015	2020	2025
OHMC Final Program	3.1	36.3	84.1	111.1	120.0
Alternative 1	5.7	63.4	142.6	184.9	199.2
Alternative 2	3.1	36.8	86.6	115.4	124.8

Figure 11.3.1-1
Off-Highway Motorcycle HC Emissions Inventory



11.3.1.4 Cost Per Ton

Chapter 7 provides the cost per ton estimate for the final program. Using the same methodology, we have estimated the cost per ton of HC+NOx reduced for the two alternatives. The results are provided in Table 11.3.1-5. The results of Alternative 2 Phase 2 are based on the incremental change from 2.0 g/km to 1.0 g/km.

Table 11.3.1-5
Estimated Off-Highway Motorcycle Average
Cost Per Ton of HC + NOx Reduced (7 percent discount rate)

	Lifetime Reductions per Vehicle (NPV tons)	Discounted Per Vehicle Costs Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Costs Per Ton with Fuel Savings ($/ton)
Final Program	0.38	$410	$280
Alternative 1	0.50	$420	$210
Alternative 2 Phase 1	0.38	$410	$280
Alternative 2 Phase 2*	0.02	$3,590	$3,590

* Phase 2 standards incremental to Phase 1

11.3.1.5 Economic Impacts Analysis

The human health and environmental benefits and economic costs of the regulatory alternatives for off-highway motorcycles are presented. The methodologies used to estimate the economic costs of these alternatives are discussed extensively in Chapter 9. We are presenting two alternatives to the 2.0 g/km HC+NOx standard contained in the Final Rule, a less stringent and a more stringent alternative.

Table 11.3.1-6
Economic Costs of Alternative
Off-Highway Motorcycle Standards—Values in 2030 (millions of 2001$)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
OHM Final Program	$25.9	$25.0	$25.2	$0.2
Alternative 1	$33.1	$31.7	$46.4	$14.7
Alternative 2	$49.8	$46.6	$25.2	($21.5)

1 Economic costs or net economic costs shown in parenthesis. Additional important considerations, such as potential safety impacts discussed below, are not reflected in these cost estimates.

Table 11.3.1-7a
Economic Costs of Alternative Off-Highway Motorcycle Standards—Net Present Value 2002 through 2030 (millions of 2001$, using 3 percent discount rate)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
OHM Final Program	$372.6	$358.9	$242.4	($116.5)
Alternative 1	$461.4	$441.1	$467.8	26.7
Alternative 2	$712.0	$663.1	$242.4	($420.7)

1 Economic costs or net economic costs shown in parenthesis.

Table 11.3.1-7b
Economic Costs of Alternative Off-Highway Motorcycle Standards—Net Present Value 2002 through 2030 (millions of 2001$, using 7 percent discount rate)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
OHM Final Program	$214.3	$206.3	$120.6	($85.6)
Alternative 1	$261.6	$249.9	$232.5	($17.4)
Alternative 2	$408.6	$379.9	$120.6	($259.3)

1 Economic costs or net economic costs shown in parenthesis.

11.3.1.6 Discussion

Although alternative 1 is numerically less stringent than the final standard of 2.0 g/km HC+NOx, it would result in significant additional emissions reductions from the final program. These reductions are gained by the inclusion of machines that could otherwise qualify as vehicles used solely for competition into the program. The CAA requires that competition vehicles be exempt from emission regulations. Moreover, the 4.0 g/km standard would not otherwise meet the CAA requirements that standards achieve the greatest degree of emissions reduction achievable through use of available technology, taking cost, noise, energy, and safety into account. Therefore, this alternative cannot be considered as a replacement to the final program. However, the potential for significant emission reductions resulting from the control of competition machines is very desirable. That is why we are finalizing alternative 1 as an option to the 2.0 g/km HC+NOx standard in the final program. This option would result in the use of four-stroke engines and two-stroke engines equipped with direct fuel injection.

Alternative 2 would require manufacturers to achieve reductions beyond those required by the California off-highway motorcycle program. We believe that manufacturers would be required to use high levels of pulse air and would also need to use catalysts on some models. As discussed in Chapter 4, there are still concerns over the safety, durability and feasibility of the widespread use of catalysts on off-highway motorcycles. We are concerned that catalysts could pose safety threats from burns to individual riders as well as the potential for setting fires in the riding environment, which is frequently forests and grassy fields. There are also concerns over the ability of a catalyst to be able to physically survive in the very harsh environment that off-highway motorcycles frequently operate in. In general, we have concerns about the feasibility of many advanced emission control technologies with off-highway motorcycle applications. Off-highway motorcycles are exposed to dirt, dust, mud, water, rocks, etc. All of which make the use of relatively fragile technology such as electronic fuel injection and secondary air injection questionable. This alternative is based on the standards we proposed for ATVs but are not finalizing. As discussed in detail in the preamble for the Final Rule, we are not finalizing this level of control for ATVs due to concerns about the ability of manufacturers to meet the standards within the time frame proposed. These same concerns apply to off-highway motorcycles. We believe additional testing and analysis is needed before we can affirm the feasibility of Phase 2 standards.

11.3.2 All-terrain Vehicles

We are presenting an analysis of two alternatives to the 1.5 g/km HC+NOx standard contained in the Final Rule, a less stringent and a more stringent alternative. The less stringent alternative we are presenting is a 2.0 g/km HC+NOx standard in the same time frame as the 1.5 g/km standard (50 and 100 % phase-in for 2006 and 2007). The second alternative we are presenting is the 2.0 g/km alternative with an additional more stringent Phase 2 standard of 1.0 g/km phased in at 50/100% in 2009/2010. We proposed but did not finalize two phases of standards for ATVs and the second alternative analyzed below is based on the proposed standards. It is clear from our analysis of technology, the current ATV market, and the comments received from manufacturers that 4-stroke engines are technologically within reach for all ATV applications. Therefore, the focus of the alternatives analysis is on what level of control to require from 4-stroke ATVs. An analysis of the costs, emissions reductions, costs per ton, and economic impacts of the alternatives are presented here. The methodology used for these analyses are the same as those described for the final program in the previous chapters. Also, the costs for the various technologies is presented in Chapter 5. Finally, a discussion of why these alternatives were not chosen for the Final Rule is provided in Section 11.3.2.6.

11.3.2.1 Per unit Costs

We have analyzed a less stringent standard of 2.0 g/km HC+NOx phased in at 50 and 100% in 2006 and 2007. The per unit average cost for this alternative is presented in Table 11.3.2-1 below. The average costs are based on a technology mix similar to that of the final 1.5 g/km standard, but with less reliance on reducing emissions from the 4-stroke engines through the use of recalibration and secondary air. This results in an average cost that is somewhat lower than that of the final program, which we estimated would cost $87 per unit (see Chapter 5).

Alternative 2 would require manufacturers to achieve reductions beyond those required by the California off-highway motorcycle program. We believe that manufacturers would be required to use high levels of pulse air and would also need to use catalysts on some models. As discussed in Chapter 4, there are still concerns over the safety, durability and feasibility of the widespread use of catalysts on off-highway motorcycles. We are concerned that catalysts could pose safety threats from burns to individual riders as well as the potential for setting fires in the riding environment, which is frequently forests and grassy fields. There are also concerns over the ability of a catalyst to be able to physically survive in the very harsh environment that off-highway motorcycles frequently operate in. In general, we have concerns about the feasibility of many advanced emission control technologies with off-highway motorcycle applications. Off-highway motorcycles are exposed to dirt, dust, mud, water, rocks, etc. All of which make the use of relatively fragile technology such as electronic fuel injection and secondary air injection questionable. This alternative is based on the standards we proposed for ATVs but are not finalizing. As discussed in detail in the preamble for the Final Rule, we are not finalizing this level of control for ATVs due to concerns about the ability of manufacturers to meet the standards within the time frame proposed. These same concerns apply to off-highway motorcycles. We believe additional testing and analysis is needed before we can affirm the feasibility of Phase 2 standards.

Table 11.3.2-1
Estimated Average Costs For a ATV Alternative 1 (2.0 g/km)

		Cost	Lifetime Fuel Savings (NPV)	% of use Baseline	% of use Control	Incrementa l Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$219	($124)	8%	100%	$202	($114)
	pulse air	$33	$0	0%	25%	$8	$0
	R&D for exhaust including recalibration	$16	$0	0%	50%	$8	$0
	permeation control	$3	($5)	0%	100%	$3	($5)
	compliance	$13	--	0%	100%	$13	--
	total	--	--	--	--	$234	($119)
> 200 cc (85%)	4-stroke engine	$349	($124)	93%	100%	$24	($9)
	pulse air	$27	$0	0%	25%	$7	$0
	R&D for exhaust including recalibration	$5	$0	0%	50%	$2	$0
	permeation control	$3	($5)	0%	100%	$3	($5)
	compliance	$12	--	0%	100%	$12	--
	total	--	--	--	--	$49	($13)
Near Term Composite Incremental Cost		--	--	--	--	$76	($29)
Long Term Composite Incremental Cost		--	--	--	--	$36	($29)

Table 11.3.2-2
Estimated Average Costs For ATV Alternative 2 (Phase 2 =1.0 g/km)

		Cost	Lifetime Fuel Savings (NPV)	% of use, Phase 1 = 2.0 g/km	% of use, Phase 2 = 1.0 g/km	Incremental Cost	Incremental Fuel Savings (NPV)
< 200 cc (15%)	4-stroke engine	$219	($124)	100%	100%	$0	$0
	pulse air	$33	$0	0%	50%	$16	$0
	R&D for exhaust including recalibration for Phase 2	$16	$0	0%	100%	$16	$0
	Catalyst	$68	$0	50%	100%	$34	$0
	compliance	$2	--	0%	100%	$2	--
	total	--	--	--	--	$68	$0
> 200 cc (85%)	4-stroke engine	$349	($124)	100%	100%	$0	$0
	pulse air	$27	$0	0%	50%	$14	$0
	R&D for exhaust including recalibration for Phase 2	$5	$0	0%	100%	$5	$0
	Catalyst	$70	$0	50%	100%	$35	$0
	compliance	$2	--	0%	100%	$2	--
	total	--	--	--	--	$54	$0
Near Term Composite Incremental Cost		--	--	--	--	$56	$0
Long Term Composite Incremental Cost		--	--	--	--	$30	$0

11.3.2.2 Aggregate Cost Estimates

Based on the above per unit costs, we have estimated the aggregate costs for the two alternatives. The aggregate costs for Alternative 2 includes the costs for both phases of standards. The aggregate costs for the alternatives are provided in Table 11.3.2-3, along with the aggregate cost estimates for the final ATV program, which are estimated in Chapter 5. The fuel savings result from switching from 2-stroke to 4-stroke engines and are the same for each alternative.

Table 11.3.2-3
Summary of Annual Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
ATV Final Program	$42.46	$65.30	$52.44	$47.56	$47.56
Alternative 1	$37.43	$57.11	$48.18	$43.29	$43.29
Alternative 2	$37.43	$102.58	$77.28	$72.39	$72.39
Fuel Savings	$0.93	$15.14	$36.22	$48.84	$51.00

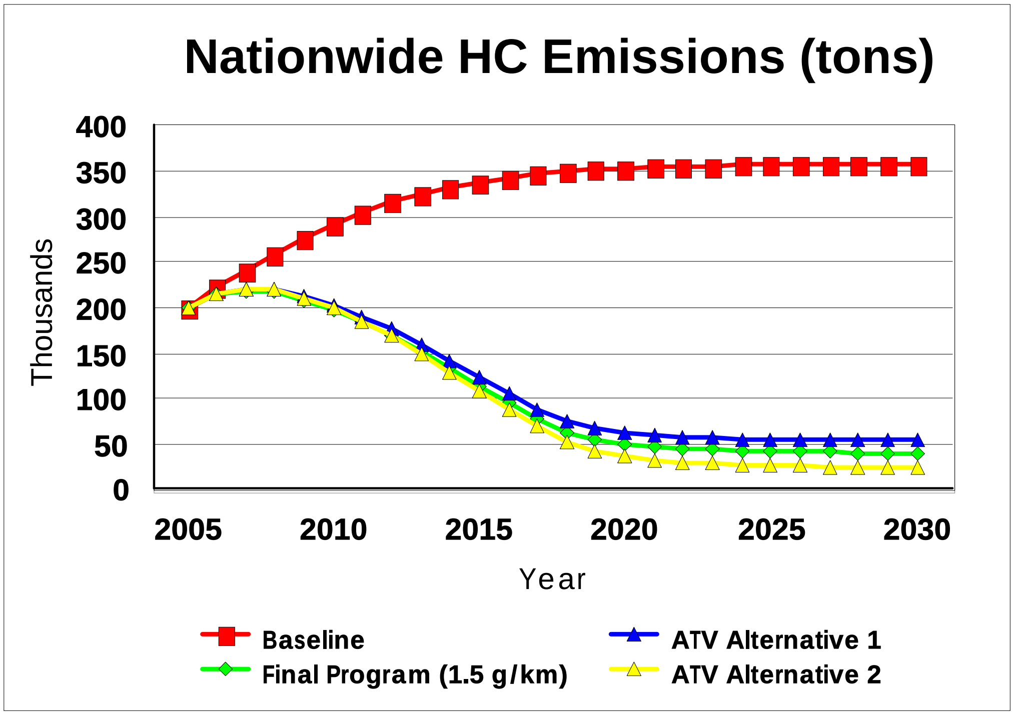
11.3.2.3 Emissions Reductions

In Chapter 6, we estimated the emissions reductions for the final program. We have estimated the emissions reductions for both alternatives using the same methodology. We would expect NOx and CO to be similar under the various alternatives. The results for HC are shown in Table 11.3.2-4 and in the following figure. The majority of the HC emissions reductions occur due to switching those remaining 2-stroke ATVs over to 4-stroke technology. The base emission factor is about 34 g/km for that 20 percent of the ATV fleet which is two-stroke and 1.8 g/km for the remaining 80 percent which are four stroke. Thus, even though eliminating the four strokes is significant the reductions from the four strokes is large as well. We expect this to occur in each of the alternatives we have analyzed.

Table 11.3.2-4
Summary of HC Reductions (thousands of tons)

	2006	2010	2015	2020	2025
ATV Final Program	6.2	92.4	225.0	304.1	315.5
Alternative 1	5.9	88.0	214.9	291.0	302.0
Alternative 2	5.9	91.1	230.4	317.0	331.0

Figure 11.3.2-1: ATV HC Emissions Inventory



11.3.2.4 Cost Per Ton

Chapter 7 provides the cost per ton estimates for the final program. Using the same methodology, we have estimated the cost per ton of HC+NOx reduced for the two alternatives. The results are provided in table 11.3.2-5. The results for Alternative 2 Phase 2 are based on the incremental change from 2.0 g/km to 1.0 g/km.

Table 11.3.2-5
Estimated ATV Average
Cost Per Ton of HC + NOx Reduced (7 percent discount rate)

	Lifetime Reductions per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Final Program	0.21	$400	$290
Alternative 1	0.20	$370	$250
Alternative 2 Phase 1	0.20	$370	$250
Alternative 2 Phase 2*	0.02	$2,700	$2,700

* Phase 2 standards incremental to Phase 1

11.3.2.5 Economic Impacts Analysis

The economic costs of the regulatory alternatives for ATVs are presented. The methodologies used to estimate economic costs of these alternatives are discussed extensively in Chapter 9. We are presenting two alternatives to the 1.5 g/km HC+NOx standard contained in the Final Rule, a less stringent and a more stringent alternative.

Table 11.3.2-6
Economic Costs of Alternative ATV Standards—Values in 2030 (millions of 2001$)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
ATV Final Program	$496.3	$491.9	$253.0	($238.9)
Alternative 1	$445.2	$441.7	$253.0	($188.6)
Alternative 2	$662.0	$654.1	$253.0	($401.0)

1 Economic costs or net economic costs shown in parenthesis.

Table 11.3.2-7a
Economic Costs of Alternative ATV Standards
Net Present Value 2002 through 2030
(millions of 2001$, using 3 percent discount rate)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
ATV Final Program	$836.3	$829.2	$510.5	($318.7)
Alternative 1	$752.9	$747.0	$510.5	($236.5)
Alternative 2	$1,154.1	$1,140.5	$510.5	($630.0)

1 Economic costs or net economic costs shown in parenthesis.

Table 11.3.2-7b
Economic Costs of Alternative ATV Standards
Net Present Value 2002 through 2030
(millions of 2001$, using 7 percent discount rate)

Standard (HC/CO Reductions)	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[1]
ATV Final Program	$836.3	$829.2	$510.5	($318.7)
Alternative 1	$752.9	$747.0	$510.5	($236.5)
Alternative 2	$1,154.1	$1,140.5	$510.5	($630.0)

1 Economic costs or net economic costs shown in parenthesis.

11.3.2.6 Discussion

Alternative 1 would require only modest additional emissions reductions from 4-strokes, in general, and many models would meet the standard in their base configuration. In addition, this alternative is less stringent than the current California standard for ATVs. Most, if not all 4-stroke ATV models are certified to the California requirements. We received support for harmonizing standards with California and this level of control is feasible for 4-stroke equipped ATVs. Therefore, we do not believe that a standard less stringent than that contained in the California program would meet the basic criteria of the Clean Air Act which requires us to set a standard based on the greatest degree of emission reduction achievable. Our consideration of costs and economic impacts did not change our view that a 1.5 g/km standard was appropriate for ATVs.

Alternative 2 would require manufacturers to achieve reductions beyond those required in by the California program. We believe that manufacturers would be required to use a high level of pulse air and would also need to use catalyst on some ATV models. For our cost analysis above, we projected that catalysts would be used on half of all ATV models. This alternative is based on the standards we proposed for ATVs but are not finalizing. As discussed in detail in the preamble for the Final Rule, we are not finalizing this level of control due to concerns about the ability of manufacturers to meet the standards within time frame proposed. We believe additional testing and analysis is needed before we can affirm the feasibility of the Phase 2 standards.

11.3.3 Snowmobiles

While developing the final snowmobile emissions standards we analyzed four alternative sets of emissions standards, including options both less stringent and more stringent than the final standards. These alternatives are as follows:

Alternative 1 - keeping the Phase 1 standards indefinitely (i.e., not adopting Phase 2 or Phase 3 standards)

Alternative 2 - adopting the snowmobile manufacturers' recommended phase 2 standards in 2010 (which provide a 50% reduction in HC but keep the CO standard at the phase 1 level), with no Phase 3 standards

Alternative 3 - adopting Phase 2 standards in 2010 based on a large percentage of four-stroke engines; (70% HC/30% CO) reduction

Alternative 4 - adopting more stringent Phase 2 in 2010 which would require optimized advanced technology on every snowmobile; (85% HC/50% CO) reduction.

All of these alternatives were modeled assuming 100 percent compliance with the Phase 1 standards in 2006, whereas the final program includes a phase in with 50 percent compliance in 2006 and 100 percent compliance in 2007.

In addition to these alternative standards scenarios, we looked at what would happen if four-stroke engine technology cost 25 percent more than we originally projected in order to assess the sensitivity to four-stroke technology costs. This sensitivity analysis was done on Alternative 4. This scenario will be referred to as Alternative 5 for the remainder of this snowmobile section.

11.3.3.1 Per unit Costs

The per unit costs for the various alternatives are shown in Tables 11.3.3-1 through 11.3.3-5. Also included in these tables are the technology mixes we used for each of the alternatives. The per unit costs for alternative 1 (Phase 1 standards only) shown in Table 11.3.3-1 are identical to the per unit costs for Phase 1 of the final program. The near term composite incremental costs of all of the other alternatives can be compared to the near term incremental cost of $89 for Phase 3 of the final program, as shown in Table 5.2.3-22 in Chapter 5.

Table 11.3.3-1
Estimated Average Costs For Snowmobiles (Alternative 1 - Phase 1 only)

		Cost	Lifetime Fuel Savings	Baseline	Phase 1	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	engine modifications	$18	$0	0%	60%	$11	$0
	modified carburetor	$18	$0	0%	60%	$11	$0
	direct injection*	$328	($512)	7%	10%	$10	($15)
	electronic fuel injection	$175	$0	12%	15%	$5	$0
	4-stroke engine	$455	($512)	7%	10%	$14	($15)
	permeation control	$7	($10)	0%	100%	$7	($10)
	compliance	$12	--	0%	100%	$12	$0
	total	--	--	--	--	$69	($40)
≥ 500 cc (70%)	engine modifications	$25	$0	0%	60%	$15	$0
	modified carburetor	$24	$0	0%	60%	$14	$0
	direct injection*	$295	($1,139)	7%	10%	$9	($34)
	electronic fuel injection	$119	$0	12%	15%	$4	$0
	4-stroke engine	$770	($1,139)	7%	10%	$23	($34)
	permeation control	$7	($10)	0%	100%	$7	($10)
	compliance	$12	$0	0%	100%	$12	$0
	total	--	--	--	--	$84	($78)
Near Term Composite Incremental Cost		--	--	--	--	$80	($67)
Long Term Composite Incremental Cost		--	--	--	--	$47	($67)

Table 11.3.3-2
Estimated Average Costs For Snowmobiles (Alternative 2 - Phase 2 HC standards with Phase 1 CO standards)

		Cost	Lifetime Fuel Savings	Phase 1	Phase 2	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	0%	30%	$12	$0
	direct injection*	$328	($512)	10%	35%	$82	($128)
	electronic fuel injection	$175	$0	15%	20%	$9	$0
	4-stroke engine	$455	($512)	10%	15%	$23	($26)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$128	($154)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	0%	30%	$12	$0
	direct injection*	$295	($1,139)	10%	35%	$74	($285)
	electronic fuel injection	$119	$0	15%	20%	$6	$0
	4-stroke engine	$770	($1,139)	10%	15%	$39	($57)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$132	($342)
Near Term Composite Incremental Cost		--	--	--	--	$131	($286)
Long Term Composite Incremental Cost		--	--	--	--	$77	($286)

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 11.3.3-3
Estimated Average Costs For Snowmobiles (Alternative 3 - Four-stroke based Phase 2 Standards)

		Cost	Lifetime Fuel Savings	Phase 1	Phase 2	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	0%	25%	$10	$0
	direct injection*	$328	($512)	10%	10%	$0	$0
	electronic fuel injection	$175	$0	15%	65%	$87	$0
	4-stroke engine	$455	($512)	10%	60%	$228	($256)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$327	($256)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	0%	25%	$10	$0
	direct injection*	$295	($1,139)	10%	10%	$0	$0
	electronic fuel injection	$119	$0	15%	65%	$60	$0
	4-stroke engine	$770	($1,139)	10%	60%	$385	($570)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$457	($570)
Near Term Composite Incremental Cost		--	--	--	--	$418	($476)
Long Term Composite Incremental Cost		--	--	--	--	$260	($476)

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 11.3.3-4
Estimated Average Costs For Snowmobiles
(Alternative 4 - Phase 2 Standards based on broad application of advanced technology)

		Cost	Lifetime Fuel Savings	Phase 1	Phase 2	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	0%	0%	$12	$0
	direct injection*	$328	($512)	10%	10%	$0	$0
	electronic fuel injection	$175	$0	15%	90%	$131	$0
	4-stroke engine	$455	($512)	10%	90%	$364	($410)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$497	($410)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	0%	0%	$	$0
	direct injection*	$295	($1,139)	10%	10%	$0	$0
	electronic fuel injection	$119	$0	15%	90%	$90	$0
	4-stroke engine	$770	($1,139)	10%	90%	$616	($911)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$718	($911)
Near Term Composite Incremental Cost		--	--	--	--	$652	($760)
Long Term Composite Incremental Cost		--	--	--	--	$410	($760)

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

Table 11.3.3-5
Estimated Average Costs For Snowmobiles (Alternative 4 with 25% higher 4-stroke costs)

		Cost	Lifetime Fuel Savings	Phase 1	Phase 2	Incremental Cost	Incremental Fuel Savings
< 500 cc (30%)	pulse air/recalibration	$41	$0	0%	0%	$12	$0
	direct injection*	$328	($512)	10%	10%	$0	$0
	electronic fuel injection	$218	$0	15%	90%	$164	$0
	4-stroke engine	$569	($512)	10%	90%	$455	($410)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$621	($410)
≥ 500 cc (70%)	pulse air/recalibration	$41	$0	0%	0%	$	$0
	direct injection*	$295	($1,139)	10%	10%	$0	$0
	electronic fuel injection	$149	$0	15%	90%	$112	$0
	4-stroke engine	$963	($1,139)	10%	90%	$770	($911)
	certification	$2	--	0%	100%	$2	$0
	total	--	--	--	--	$894	($911)
Near Term Composite Incremental Cost		--	--	--	--	$812	($760)
Long Term Composite Incremental Cost		--	--	--	--	$512	($760)

* Direct injection costs are an average of the air-assisted and pump assisted system costs.

11.3.3.2 Aggregate Cost Estimates

Based on the above per unit costs, we have estimated the aggregate costs for the alternatives. The aggregate costs for the alternatives are presented in Table 11.3.3-6, along with the aggregate cost estimates for the final snowmobile program, which are estimated in Chapter 5. The fuel savings result in varying degrees of switching from current two-stroke technology to direct injection two-stroke and four-stroke technology.

Table 11.3.3-6
Summary of Annual Snowmobile Aggregate Costs and Fuel Savings (millions of dollars)

	2006	2010	2015	2020	2025
Final program	$6.58	$37.55	$41.91	$41.56	$41.56
Alternative 1	$13.17	$12.07	$11.08	$11.73	$11.73
Alternative 2	$13.17	$38.99	$28.65	$30.32	$30.32
Alternative 3	$13.17	$98.99	$70.03	$74.13	$74.13
Alternative 4	$13.17	$148.68	$104.08	$110.17	$110.17
Alternative 5	$13.17	$182.23	$127.25	$134.69	$134.69
Fuel savings (Final program)	$0.78	$11.81	$58.23	$103.00	$123.66
Fuel Savings (Alt 1)	$0.78	$4.31	$9.13	$12.33	$13.51
Fuel Savings (Alt 2)	$0.78	$8.81	$38.59	$66.73	$79.60
Fuel Savings (Alt 3)	$0.78	$11.81	$58.23	$103.00	$123.66
Fuel Savings (Alt 4)	$0.78	$16.31	$87.68	$157.40	$189.75
Fuel Savings (Alt 5)	$0.78	$16.31	$87.68	$157.40	$189.75

11.3.3.3 Emissions Reductions

In Chapter 6, we estimated the emissions reductions for the final program. We have estimated the emissions reductions for the alternatives using the same methodology. The results for HC are shown in Table 11.3.3-7 and in Figure 11.3.3-1, while the results for CO are shown in Table 11.3.3-8 and in Figure 11.3.3-2.

As can be seen in Tables 11.3.3-7 and 11.3.3-8, there are cases where the emissions reductions for a given pollutant are different for different alternatives even though the numerical limits for that pollutant are the same for those alternatives. For example, the final program and

Alternative 2 would both require 50 percent reductions in HC, but the HC reductions shown in Table 11.3.3-7 are different for these two options. The reason for this difference in HC reductions is that under these two options the CO limits are different. Under the final program the CO limit would require a 50 percent reduction in CO, while in Alternative 2 the CO reductions would only be 30 percent. This difference in CO limits results in the need for a different technology mix being needed under the two alternatives. The more aggressive application of technology needed under the final program to meet the CO limit has the effect of producing somewhat higher HC reductions. Similarly, the different HC limits for Alternatives 1 through 3 result in different technology mixes for the these alternatives. These different technology mixes result in different CO reductions for each alternative even though the CO limits are the same for all three alternatives. This can be seen in Tale 11.3.3-8.

Table 11.3.3-7
Summary of Snowmobile HC Reductions (thousands of tons)

	2006	2010	2015	2020	2025
Final Program	4.0	42.9	123.3	196.1	230.4
Alternative 1	7.9	44.9	98.4	135.1	148.5
Alternative 2	7.9	47.3	114.2	165.2	185.6
Alternative 3	7.9	52.1	146.8	227.6	262.4
Alternatives 4 and 5	7.9	55.8	172.4	276.4	322.4

Table 11.3.3-8
Summary of Snowmobile CO Reductions (thousands of tons)

	2006	2010	2015	2020	2025
Final Program	9.9	105.3	285.0	442.2	513.4
Alternative 1	19.9	112.7	246.6	338.7	372.3
Alternative 2	19.9	116.2	270.1	383.6	427.7
Alternative 3	19.9	120.1	296.6	436.8	493.1
Alternatives 4 and 5	19.9	123.1	317.4	476.8	544.0

Figure 11.3.3-1 Snowmobile HC Emissions Inventory

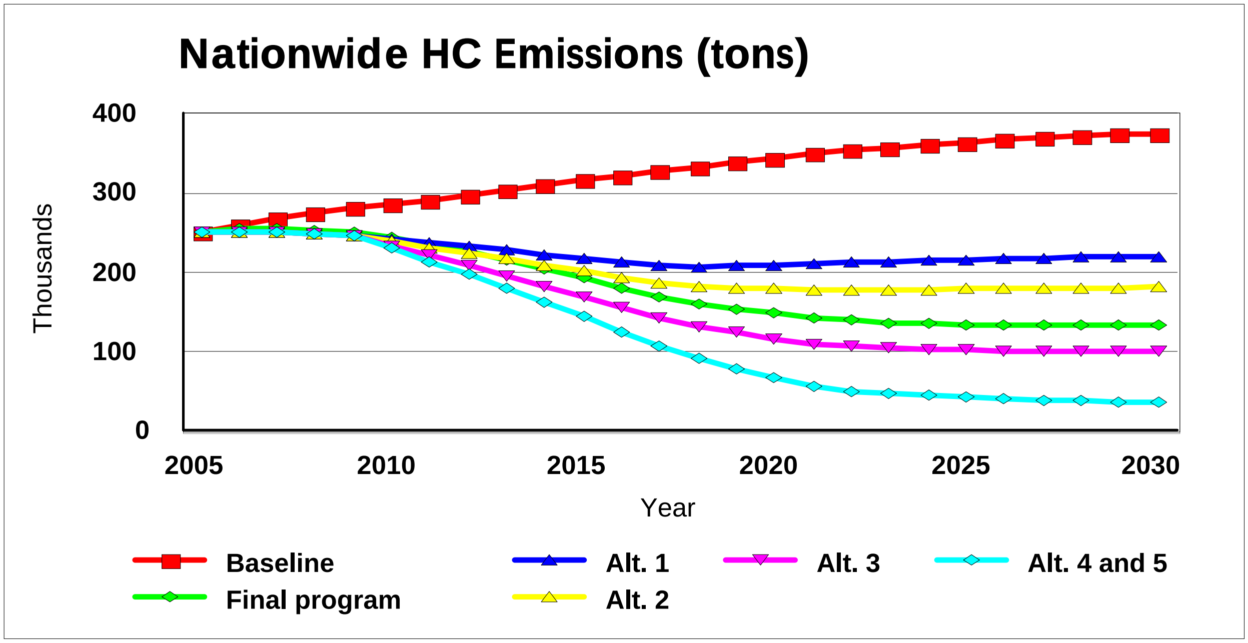
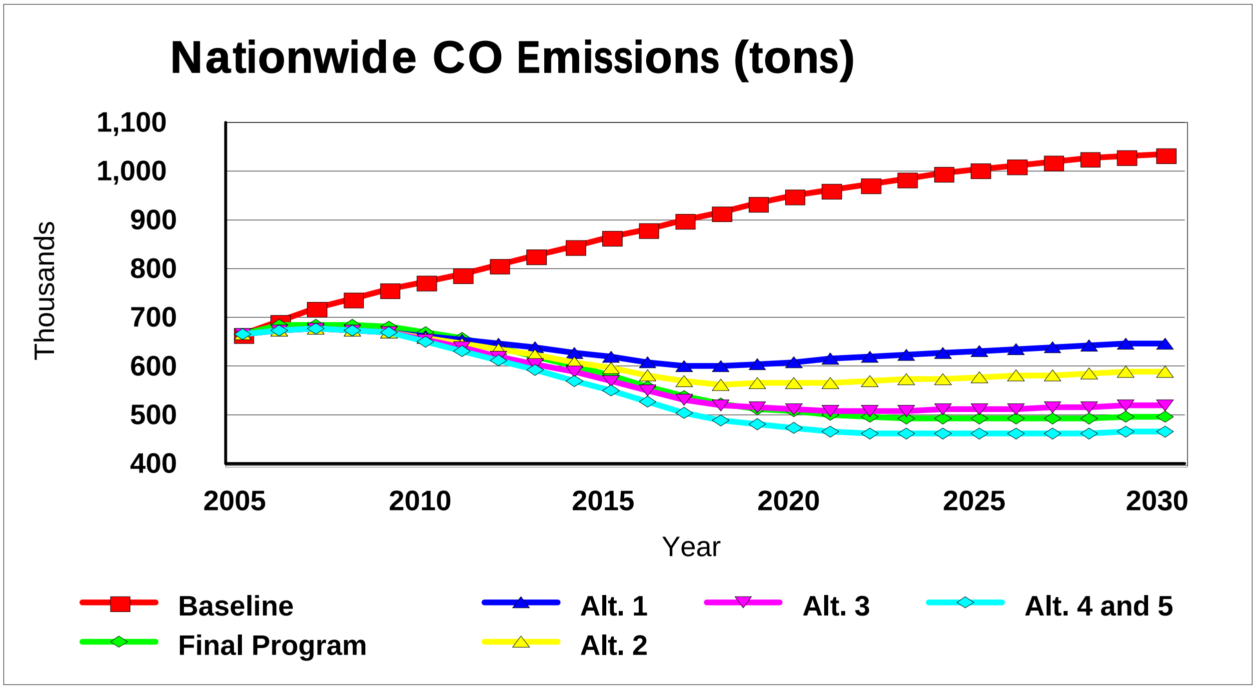


Figure 11.3.3-2 Snowmobile CO Emissions Inventory



11.3.3.4 Cost Per Ton

Chapter 7 provides the cost per ton estimates for the final program. Using the same methodology, we have estimated the cost per ton of HC and CO reduced for the alternatives, as shown in Table 11.3.3-9. The results for alternative 1 (Phase 1 standards only) are shown first. All other scenarios, including the final program, are base on the incremental change from the Phase 1 standards to whatever Phase 2 standards are considered in the particular scenario.

Table 11.3.3-9
Estimated Snowmobile Average Cost per Ton of HC and CO Reduced
(7 percent discount rate)

	Lifetime Reductions per Vehicle (NPV tons)		Discounted per Vehicle Cost Per Ton without Fuel Savings ($/ton)		Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)	
	HC	CO	HC	CO	HC	CO
Alternative 1	0.40	1.02	$90	$40	$20	$10
Final Program[c]	n/a	0.25	n/a	$360	n/a	($410)
Alternative 2[a]	0.10	n/a	$1,370	n/a	($1,610)	n/a
Alternative 3[a]	0.28	n/a	$1,480	n/a	($210)	n/a
Alternative 4[a]	0.49	0.50	$670	650	($110)	($110)
Alternative 5[a,b]	0.49	0.50	$840	$810	($50)	($50)

a. Shown based on incremental change from Phase 1 standards.
b. Alternative 4 with 25% higher 4-stroke cost.
c. Shown based on incremental change from Phase 2 standards

11.3.3.5 Economic Impacts Discussion

The economic costs of the regulatory alternatives for snowmobiles are presented. Net social costs (or gains) of the alternatives in the year 2030 are shown on Table 11.3.3-10, while the net present value of these costs through 2030 are reflected on Tables 11.3.3-11a and 11.3.3-11b. The methodologies used to estimate the economic costs of these alternatives are discussed extensively in Chapter 9. Each of the alternatives, is modeled based on a 30 percent reduction in HC and CO, respectively during Phase 1 of the regulation.

Table 11.3.3-10
Economic Costs of Alternative Snowmobile Standards—Values in 2030[1,3] (millions of 2001$)

Scenario	**Engineering Costs**	**Economic Costs (Surplus Losses)**	**Fuel Efficiency Cost Savings**	**Economic Gains or Costs[2]**
Alternative 1	$11.7	$11.6	$18.2	$6.6
Alternative 2	$30.3	$29.8	$88.0	$58.2
Final Program	$43.1	$41.9	$135.0	$93.1
Alternative 3	$74.1	$70.5	$134.5	$64.0
Alternative 4	$111.2	$102.1	$204.3	$102.2
Alternative 5[4]	$134.7	$122.7	$204.3	$81.6

1. Assumes the final program Phase 1 standards as the first phase in each alternative
2. Economic costs or net economic costs shown in parenthesis.
3. Dollar values are rounded to the nearest 10 million.
4. Same standards as Alternative 4, but assumes a 25% increase in the cost of a 4-stroke engine.

Table 11.3.3-11a
Economic Costs of Alternative Snowmobile Standards—Net Present Value 2002 through 2030[1] (millions of 2001$, using 3 percent discount rate)

Scenario	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[2]
Alternative 1	$183.7	$182.1	$174.7	($7.4)
Alternative 2	$426.9	$418.9	$697.7	$278.8
Final Program	$569.6	$553.1	$999.6	$446.5
Alternative 3	$987.6	$885.0	$1,046.3	$161.3
Alternative 4	$1,450.1	$1,335.0	$1,569.3	$234.3
Alternative 5[3]	$1,763.8	$1,591.8	$1,569.3	($22.5)

1. Assumes the final program Phase 1 standards as the first phase in each alternative
2. Economic costs or net economic costs shown in parenthesis.
3. Same standards as Alternative 4, but assumes a 25% increase in the cost of a 4-stroke engine.

Table 11.3.3-11b
Economic Costs of Alternative Snowmobile Standards— Net Present Value 2002 through 2030[1]
(millions of 2001$, using 7 percent discount rate)

Scenario	Engineering Costs	Economic Costs (Surplus Losses)	Fuel Efficiency Cost Savings	Economic Gains or Costs[2]
Alternative 1	$106.6	$105.7	$86.8	($18.9)
Alternative 2	$235.7	$231.1	$327.2	$96.1
Final Program	$305.7	$296.9	$459.7	$162.8
Alternative 3	$531.5	$470.0	$487.4	$17.4
Alternative 4	$775.7	$713.1	$727.8	$14.7
Alternative 5[3]	$941.1	$847.6	$727.8	($119.8)

1. Assumes the final program Phase 1 standards as the first phase in each alternative
2. Economic costs or net economic costs shown in parenthesis.
3. Same standards as Alternative 4, but assumes a 25% increase in the cost of a 4-stroke engine.

11.3.3.6 Discussion

Alternative 1 (Phase 1 standards only) would require relatively minimal additional use of advanced technologies beyond what we project as a baseline. These advanced technologies (direct injection two-stroke, and four-stroke technologies) have been shown to be both feasible and capable of emissions reductions well below those required of the Phase 1 standards. Thus, we do not believe that this alternative would meet the basic criteria of the Clean Air Act which requires us to set standards based on the greatest degree of emissions reductions achievable.

Alternative 2 (Phase 2 HC standards with Phase 1 CO standards) would require roughly half of new snowmobiles to have advanced technology beginning with the 2010 model year, with the emphasis on direct injection two-stroke technology. The remaining snowmobiles would have a combination of engine modifications, recalibration and electronic fuel injection. We believe that a higher level of advanced technology than 50 percent penetration is certainly feasible beyond 2010 and therefore do not believe that in the absence of more stringent Phase 3 standards this alternative would meet the basic criteria of the Clean Air Act which requires us to set standards based on the greatest degree of emissions reductions achievable.

Alternative 3 (more stringent Phase 2 HC standards than final program in conjunction with Phase 1 CO standards) would require more advanced technology. We modeled 60 percent of the snowmobiles produced would be powered by four-stroke engines in 2010 and an additional ten percent would utilize direct injection two-stroke technology. The remainder would require some other technologies such as recalibrations and electronic fuel injection. We believe that these alternative standards strike a reasonable balance for allowing four stroke engines to be a primary Phase 2 technology, and have adopted these standards as an alternative to our primary Phase 2 standards on an engine family by engine family basis. Further discussion of our reasons for offering these standards as a Phase 2 option can be found in the preamble to the final rule.

Alternative 4 would require advanced technologies on all snowmobiles, beginning in 2010. We modeled 90 percent requiring four-stroke engines and the remaining ten percent requiring direct injection two-stroke technology. As discussed in detail in the preamble, given the number of snowmobile models and engine model offerings for each snowmobile model, and the fact that snowmobiles have not previously been regulated or used these advanced technologies in large numbers, we do not believe that it is feasible to apply and optimize advanced technology to every snowmobile by the 2010 model year. Thus we are not confident that this option is would be feasible in the time frame provided. We will, however, monitor the development and application of advanced technology and will in the future consider the adoption of snowmobile standards that would require advanced technology on every snowmobile.

Alternative 5 is simply a sensitivity analysis to look at how the cost of four-stroke engines might impact the consideration of Phase 2 standards which are based largely on four-stroke technology. This alternative has the same standards as Alternative 4, but with 25 percent higher costs for four-stroke engines.

11.4 Recreational Vehicle Permeation Emission Standards

While developing the fuel tank and hose permeation standards, we analyzed alternative approaches both more and less stringent than the final standards. These alternative approaches are discussed below.

11.4.1 Fuel Tanks

The final permeation standard for fuel tanks is 1.5 g/m^2/day when tested at 23°C on a test fuel with 90 percent gasoline and 10 percent ethanol. This standard represents approximately an 85 percent reduction from baseline HDPE fuel tanks. We considered an alternative standard equivalent to about a 60 percent reduction from baseline. This could be met by fuel tanks molded out of nylon. We also considered requiring metal fuel tanks which would essentially eliminate permeation emissions from fuel tanks.

11.4.1.1 60 Percent Reduction (Nylon Fuel Tanks)

One manufacturer commented that we should relax the fuel tank standard to a 55-60 percent reduction so that other technologies could be used. Specifically, they point to injection-molded nylon. Therefore, for this analysis, we consider the costs and emissions reductions associated with molding the fuel tank out of nylon.

As discussed in Chapter 5, nylon costs about $2.00 per pound while HDPE costs about $0.50 per pound. Depending on the shape of the fuel tank and the wall thickness, recreational vehicle fuel tanks weigh about 1-1.3 pounds per gallon. Including a 29% markup for overhead and profit, the increased cost for using nylon fuel tanks would be about $21 for snowmobiles (11 gallons), $10 for ATVs (4 gallons), and $8 for off-highway motorcycles (3 gallons). This is actually 5-10 times higher than our projected costs for using sulfonation to meet the final standard which represents about an 85 percent reduction.

Based on the data presented in Chapter 4, the use of nylon could achieve more than a 95 percent reduction in permeation compared to HDPE when gasoline is used. However, if a 10 percent ethanol blend is considered, then the reduction is only 40-60 percent depending on the nylon composition. On a 15 percent methanol blend, the permeation rate through nylon can actually be several times higher than through HDPE.

About one third of the gasoline sold in the U.S. today is blended with ethanol or some other oxygenate. In addition, the trend in the U.S. is towards using more renewable fuel and ethanol may be the leading choice. Therefore, it is important that the permeation control strategy used for recreational vehicles be effective on ethanol fuel blends. For this analysis, we consider a

10 percent ethanol blend when calculating emissions reductions.

Table 11.4-1 presents the projected national emission reductions for this approach. These figures can be compared to the anticipated reductions presented in Chapter 6 for the final standards (Table 6.2.6-3). Table 11.4-2 presents the cost per ton of permeation emissions reduced per fuel tank, using a 7 percent discount rate, with and without fuel savings. These figures can be compared to the cost per ton presented in Chapter 7 (Table 7.1.5-1).

Table 11.4-1
Projected Fuel Tank Permeation Emissions from Recreational Vehicles for the Alternative Approach of a 60 Percent Reduction [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	3,389	4,181	5,032	6,456	7,061
	control	3,389	4,181	4,106	2,737	2,824
	reduction	0	0	92	3,719	4,236
ATVs	baseline	3,985	6,751	9,275	11,109	11,231
	control	3,985	6,751	8,072	5,455	4,539
	reduction	0	0	1,202	5,654	6,692
OHMCs	baseline	882	1,303	1,710	2,061	2,248
	control	882	1,303	1,492	1,239	1,315
	reduction	0	0	218	821	933
Total	baseline	8,255	12,234	16,016	19,626	20,539
	control	8,255	12,234	13,671	9,431	8,678
	reduction	0	0	2,345	10,194	11,862

Table 11.4-2
Estimated Cost Per Ton of HC Reduced (7 percent discount rate) for the Alternative Approach of a 60 Percent Reduction from Fuel Tanks

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles	$21	$3	0.0084	$2,541	$2,178
ATVs	$10	$2	0.0047	$2,065	$1,702
OHMC	$8	$1	0.0027	$2,819	$2,456

Constructing fuel tanks out of nylon would be significantly more expensive than constructing them out of HDPE and applying a barrier treatment such as sulfonation to control permeation. Therefore, we believe that most manufacturers would choose the lower cost option of applying a barrier treatment even if we were to set a standard based on a 60 percent reduction. In addition, we believe that they would target the maximum effectiveness of the barrier treatment. Designing for a 60 percent reduction would not have meaningful cost savings over designing for a 95 percent reduction. As a result, while this option could result in less emission control than the standard, we do not believe that it would lower costs for manufacturers.

11.4.1.2 Metal Fuel Tanks

One commenter pointed out that essentially a 100 percent reduction in fuel tank permeation emissions could be achieved by replacing plastic fuel tanks with metal fuel tanks. However, they stated that a performance standard approaching this amount of emission reduction would be appropriate because it would allow industry flexibility on how to meet the standard. For this scenario we consider the use of metal fuel tanks in recreational vehicles.

Today, most if not all recreational vehicles use plastic fuel tanks. According to manufacturers plastic fuel tanks are desirable because they weigh less than metal fuel tanks, are more durable, can be formed into more complex shapes, are non-corrosive, and cost less. In recreational vehicle applications, weight is an issue because the vehicles must be light enough to be manipulated by the rider. However, more importantly, durability is an issue because of the rough use of these vehicles and because many of the fuel tanks are exposed. For example, if a dirt bike were to fall over, a metal tank could be dented on a rock which would damage the integrity of the fuel tank. A plastic tank, however, would likely be undamaged. In addition metal fuel tanks have seams due to the manufacturing process which are weak point and could result in leaking. Fuel tanks on recreational vehicles, are designed to maximize the fuel stored in a limited space. Current plastic fuel tank designs are molded with contours that match the vehicle chassis. Manufacturers have stated that these complex shapes cannot be stamped into metal parts and that using metal tanks could cause them to need to redesign the fuel tank geometry and could require modifications to the chassis in order to maintain the same fuel capacity.

For the purposes of this analysis we use a cost increase of 30 percent for metal tanks versus plastic fuel tanks. This is based on pricing seen for marine applications which use metal fuel tanks in some cases. Because metal fuel tanks are not used in recreational vehicle applications, direct costs cannot be used. This cost does not include research and design costs that would be required for developing metal tanks or costs of modifying production practices. Dealer prices for plastic fuel tanks, of the size used in recreational vehicles, range from 3 to 9 dollars per gallon of capacity.[1] Using an average cost of 6 dollars per gallon and a typical dealer markup, we get a cost of about 2 dollars per gallon for plastic fuel tanks. This cost estimate for plastic fuel tanks was confirmed in conversations with recreational vehicle manufacturers. Based on this analysis and a markup of 29%, we estimate a cost increase of about $9 for snowmobiles, $3 for ATVs, and $2 for non-competition off-highway motorcycles.

Table 11.4-3 presents the projected national emission reductions for this approach. These figures can be compared to the anticipated reductions presented in Chapter 6 for the final standards (Table 6.2.6-3). Table 11.4-4 presents the cost per ton of permeation emissions reduced per fuel tank, using a 7 percent discount rate, with and without fuel savings. These figures can be compared to the cost per ton presented in Chapter 7 (Table 7.1.5-1).

Table 11.4-3
Projected Fuel Tank Permeation Emissions from Recreational Vehicles for the Alternative Approach of a 100 Percent Reduction [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	3,389	4,181	5,032	6,456	7,061
	control	3,389	4,181	3,489	258	0
	reduction	0	0	1,542	6,198	7,061
ATVs	baseline	3,985	6,751	9,275	11,109	11,231
	control	3,985	6,751	7,271	1,685	78
	reduction	0	0	2,004	9,424	11,153
OHMCs	baseline	882	1,303	1,710	2,061	2,248
	control	882	1,303	1,347	692	692
	reduction	0	0	363	1,369	1,556
Total	baseline	8,255	12,234	16,016	19,626	20,539
	control	8,255	12,234	12,107	2,635	770
	reduction	0	0	3,909	16,991	19,769

Table 11.4-4
Estimated Cost Per Ton of HC Reduced (7 percent discount rate) for the Alternative Approach of a 100 Percent Reduction

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles	$9	$5	0.0140	$668	$305
ATVs	$3	$3	0.0078	$435	$72
OHMC	$2	$2	0.0046	$509	$146

Although this approach appears to be cost effective, we did not chose to set standards that would require manufacturers to use metal fuel tanks. We believe that there may be safety concerns with metal fuel tanks on recreational vehicles because of the rough use and likelihood of damage to the fuel tanks. Because some applications may be able to use metal fuel tanks, we will accept a metal tank for design-based certification to our standard. In addition, we believe that the final tank permeation standard can achieve nearly the same level of reduction as metal tanks while providing manufacturers very important flexibility in their design and manufacturing.

11.4.2 Hoses

The hose standard is 15 g/m^2/day when tested at 23°C on a test fuel with 90 percent gasoline and 10 percent ethanol (E10). For hoses we considered basing the standard on testing with an alcohol-free test fuel. We also considered a standard that would require the use of fuel tubing, such as used in automotive applications, which is fairly rigid in comparison to fuel hoses because tubing is generally constructed out of fluorothermoplastics while hoses are primarily constructed out of rubber.

11.4.2.1 Alcohol-Free Test Fuel

Manufacturers commented that we should specify ASTM Fuel C (50% toluene, 50% iso-octane) for the hose permeation testing, stating that this is the fuel used for measuring permeation under the SAE J30 recommended practice for R9 hose. Under SAE J30, R9 hose must meet a permeation rate of 15 g/m^2/day when tested at 23°C. Manufacturers noted that fuels with ethanol-gasolines blends would have a higher permeation rate than if they were tested on gasoline. Therefore, R9 hose would not necessarily meet the hose permeation standards. As noted in Chapter 4, barrier materials typically used in R9 hose today may have permeation rates 3 to 5 times higher on a 10 percent ethanol blend than on straight gasoline. In this section, we analyze the alternative of basing our hose permeation standard on testing using an alcohol-free test fuel.

For the purposes of our benefits analysis, as described in Chapter 6, we estimated that a hose designed to meet 15 g/m^2/day on E10 fuel would permeate at half of that rate when tested on gasoline. This estimate considers the entire hose construction and not just the effect of alcohol on the barrier materials. To model this alternative, we doubled the estimated permeation rates for hoses meeting the permeation standards. Based on costs of hose available today, R9 hose would cost about \$0.75/ft which represents a \$0.50/ft increase from R7 hose used in most applications today. For the same reasons as discussed in Chapter 5, we are conservatively adding a cost of hose clamps (\$0.20 each). As with the analysis in Chapter 5, we include a 29 percent markup in costs for profit and overhead.

Table 11.4.1-5 presents the projected national emission reductions for this approach. These figures can be compared to the anticipated reductions presented in Chapter 6 for the final standards (Table 6.2.6-4). Table 11.4-6 presents the cost per ton of permeation emissions reduced per fuel tank, using a 7 percent discount rate, with and without fuel savings. These figures can be compared to the cost per ton presented in Chapter 7 (Table 7.1.5-1).

Table 11.4-5
Projected Fuel Hose Permeation Emissions from Recreational Vehicles for the Alternative Approach of Using an Alcohol-Free Test Fuel [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	4,471	5,516	6,638	8,517	9,315
	control	4,471	5,516	4,659	564	254
	reduction	0	0	1,979	8,074	9,061
ATVs	baseline	4,243	7,189	9,876	11,829	11,959
	control	4,243	7,189	7,800	2,068	407
	reduction	0	0	2,076	9,761	11,552
OHMCs	baseline	1,878	2,774	3,642	4,389	4,787
	control	1,878	2,774	2,890	1,553	1,565
	reduction	0	0	751	2,836	3,222
Total	baseline	10,592	15,478	20,156	24,735	26,061
	control	10,592	15,478	15,349	4,184	2,225
	reduction	0	0	4,806	20,550	23,835

Table 11.4-6
Estimated Cost Per Ton of HC Reduced (7 percent discount rate) for the Alternative Approach of Using an Alcohol-Free Test Fuel [short tons]

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles	$4	$7	0.0179	$212	($151)
ATVs	$1	$3	0.0081	$144	($219)
OHMC	$2	$3	0.0095	$157	($206)

We also received comment that we should use the most permeable fuel blend on the market for testing the permeation rates through hoses. As discussed above, we believe that the use of ethanol-blended gasoline is too significant today to ignore and could increase in the future. For this reason, we believe that it is appropriate to base the standards on testing using E10 fuel. We do not believe it is necessary to relax the standards to allow R9 hose to be able to pass on E10 fuel. Several materials are available today that could be used as a low permeation barrier in rubber hoses that are resistant to permeation on alcohol fuel blends. In fact, SAE J30 specifies R11 and R12 hose which are low permeability hoses tested on 15 percent methanol blend. Chapter 4 presents data on low permeation hoses developed for automotive applications that easily meet the final hose permeation standards that we believe could be used on recreational applications. Finally, the incremental cost is small ($0.10/ft) between hose that would meet 15 g/m^2/day on straight gasoline versus gasoline with a 10 percent ethanol blend.

11.4.2.2 Automotive Plastic Fuel Tubing

In developing emission standards for nonroad vehicles, the Clean Air Act requires us to first consider standards for comparable on-highway applications. In automotive applications, manufacturers generally use very low permeation plastic fuel tubing to meet our evaporative emission requirements. Recommended practice specified by SAE J2260 defines a Category 1 fuel line which must meet a permeation requirement of 25 g/m^2/day at 60°C on a test fuel with 85 percent gasoline and 15 percent methanol (M15). This is roughly equivalent to meeting a limit of 2 g/m^2/day at 23°C. In addition, based on the data in Chapter 4, permeation rates for most materials used in hoses tend to be at least twice as high for M15 than E10 fuel. This plastic tubing is generally made of fluoropolymers such as ETFE or PVDF.

Manufacturers commented that fuel hose standards based on automotive fuel lines such as specified in SAE J2260[2] as Category 1 would be inappropriate for recreational vehicles. Although this technology can achieve more than an order of magnitude lower permeation than barrier hoses, it is relatively inflexible and may need to be molded in specific shapes for each recreational vehicle design. Manufacturers have commented that they would need flexible hose to fit their many designs, resist vibration, and to simplify the hose connections and fittings.

Plastic fuel tubing would likely cost less than multilayer barrier fuel hoses, but we estimate that it would cost about $0.50 per foot more than the rubber hoses currently used on recreational vehicles. This additional cost includes a markup to form the tubing to the tight bends that would be required for recreational applications. Although the fluoroplastics are more expensive than the materials used in hoses on a per pound basis, plastic automotive tubing is constructed with thin walls (approximately 1 mm on average). An additional cost associated with automotive fuel tubing would be for more sophisticated connectors for the plastic tubing. On recreational vehicles using rubber fuel hose, the hose is generally just pushed on to connectors formed into the fuel tank and carburetor. In some cases, these are push on fittings without the use of a clamp. In automotive applications, quick connects are generally used which cost about $0.50 each.[3] For ATVs and OHMCs, we include the costs of two quick connects for each vehicle. Snowmobiles can require 4 to 8 quick connects depending on the fuel pump configuration, number of carburetors, and if a fuel return line is included. We include the cost of six quick connects in this analysis.

Table 11.4-7 presents the projected national emission reductions for this approach. These figures can be compared to the anticipated reductions presented in Chapter 6 for the final standards (Table 6.2.6-4). Table 11.4-8 presents the cost per ton of permeation emissions reduced per fuel tank, using a 7 percent discount rate and a 29 percent markup for overhead and profit, with and without fuel savings. These figures can be compared to the cost per ton presented in Chapter 7 (Table 7.1.5-1).

Table 11.4-7
Projected Fuel Hose Permeation Emissions from Recreational Vehicles for the Alternative Approach of Basing the Standard on Automotive Fuel Tubing [short tons]

Vehicle	Scenario	2000	2005	2010	2020	2030
Snow-mobiles	baseline	4,471	5,516	6,638	8,517	9,315
	control	4,471	5,516	4,605	348	8
	reduction	0	0	2,033	8,169	9,306
ATVs	baseline	4,243	7,189	9,876	11,829	11,959
	control	4,243	7,189	7,744	1,804	93
	reduction	0	0	2,132	10,026	11,865
OHMCs	baseline	1,878	2,774	3,642	4,389	4,787
	control	1,878	2,774	2,870	1,476	1,478
	reduction	0	0	772	2,913	3,310
Total	baseline	10,592	15,478	20,156	24,735	26,061
	control	10,592	15,478	15,219	3,627	1,579
	reduction	0	0	4,936	21,107	24,481

Table 11.4-8
Estimated Cost Per Ton of HC Reduced (7 percent discount rate) for the Alternative Approach of Basing the Standard on Automotive Fuel Tubing

	Total Cost Per Vehicle	Lifetime Fuel Savings Per Vehicle (NPV)	Lifetime Reductions Per Vehicle (NPV tons)	Discounted Per Vehicle Cost Per Ton without Fuel Savings ($/ton)	Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton)
Snowmobiles	$6	$7	0.0184	$333	($30)
ATVs	$2	$3	0.0083	$233	($130)
OHMC	$2	$4	0.0097	$232	($131)

Although this approach appears to be cost effective, we did not choose to set standards that would require manufacturers to automotive type fuel tubing. We are concerned that the tubing is too rigid for the tight installation spaces and radii in recreational vehicle applications. Hoses on these vehicles today often have tight bends and are subject to high amounts of shock and vibration The above analysis does not include costs of adding additional length that may be required for molding in spirals or other bends for vibration resistance. Because some applications may be able to automotive fuel tubing, we will accept fuel lines conforming to SAE J2260 Category 1 for design-based certification to our standard. In addition, we believe that the final hose permeation standard can achieve nearly the same level of reduction as metal tanks while providing manufacturers flexibility in their design.

11.5 Incremental Cost Per Ton Analysis

The above discussion analyzes several options for the different engine categories. For completeness, we have also examined the cost per ton associated with the incremental steps in standards changes. The table below provides a summary of the incremental cost per ton for the differences in the alternatives analyzed above. Details of the alternative are provided above for each program.

Table 11.5-1: Incremental Cost Per Ton Estimates

Change in Standards	Average Cost		Lifetime Reductions per Vehicle (NPV tons) [a]		Discounted per Vehicle Cost Per Ton without Fuel Savings ($/ton) [a]		Discounted Per Vehicle Cost Per Ton with Fuel Savings ($/ton) [a]	
Off-highway Motorcycles (change in g/km HC+NOX standard)	w/o fuel savings	w/fuel saving	HC+NOx		HC+NOx		HC+NOx	
Baseline –> 4.0 g/km [b]	$210	$122	0.50		$420		$210	
Baseline –> 2.0 g/km	$158	$105	0.38		$410		$280	
2.0 g/km –> 1.0 g/km	$70	$70	0.02		$3,590		$3,590	
ATVs (change in g/km HC+NOX standard)	w/o fuel savings	w/fuel saving	HC+NOx		HC+NOx		HC+NOx	
Baseline –> 2.0 g/km	$73	$50	0.20		$370		$250	
2.0 –> 1.5 g/km	$11	$11	0.01		$1,010		$1,010	
1.5 –> 1.0 g/km	$48	$48	0.01		$4,740		$4,740	
Snowmobiles (HC/CO percent reduction)	w/o fuel savings	w/fuel saving	HC	CO	HC	CO	HC	CO
Baseline –> 30/30	$80	$13	0.40	1.02	$90	$40	$20	$10
30/30 –> 50/30	$131	($155)	0.10	0.16	$1,370	n/a	($1,610)	n/a
50/30 –> 50/50	$89	($102)	n/a	0.25	n/a	$330	n/a	($430)
50/30 –> 70/30	$287	$97	0.19	n/a	$1,540	n/a	$520	n/a
70/30 –> 85/50	$234	($50)	0.14	0.15	$820	$780	$180	($170)
Large SI	w/o fuel savings	w/fuel saving	HC+NOx		HC+NOx		HC+NOx	
Baseline –> Phase 1	$611	($3,370)	3.07		$240		($1,150)	
Phase 1 –> Phase 2	$55	$55	0.80		$80		$80	

a. Calculated using a discount rate of 7 percent.

b. The 4.0 g/km alternative requires manufacturers to certify competition off-highway motorcycles whereas the other alternative does not.

Chapter 11 References

1.White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

2.U.S. EPA Guidelines for the Health Risk Assessment of Chemical Mixtures. EPA Report No. 630/R-98/002. September 24, 1986. Federal Register 51(185) : 34014 - 34025. http://cfpub.epa.gov/ncea/

3.White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

Buckingham, JP; White, JJ; and Carroll, JN. (1996) Development of snowmobile test cycle – final report. Southwest Research Institute report #7574.

4.Benignus, V, W Boyes, and P. Bushnell, US Environmental Protection Agency. National Health and Environmental Effects Research Laboratory. Memorandum to the Docket. Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust. September 2002.

1. www.marinepart.com/fuetmold, A copy of this has been placed in the Docket A-2000-01, Document IV-A-87.

2. SAE Recommended Practice J2260, “Nonmetallic Fuel System Tubing with One or More Layers,”1996, Docket A-2000-01, Document IV-A-18.

3. Denbow, R., Browning, L., Coleman, D., “Report Submitted for WA 2-9, Evaluation of the Costs and Capabilities of Vehicle Evaporative Emission Control Technologies,” ICF, ARCADIS Geraghty & Miller, March 22, 1999, Docket A-2000-01, Document No. IV-B-05.