EPA420-R-99-009

Exhaust Emission Factors for Nonroad Engine Modeling-- Spark Ignition

Report No. NR-010b
February 24, 1998
revised June 15, 1998
revised March 30, 1999

Megan Beardsley, Christian E. Lindhjem, and Craig Harvey
U.S. EPA Office of Mobile Sources, Assessment and Modeling Division

Purpose

This report describes and documents exhaust emission factors used for spark ignition (SI) engines in EPA's NONROAD emission inventory model. It covers emission factors for engines powered by gasoline, natural gas and liquefied petroleum gas.

EPA expects to recalculate most SI emission factors prior to release of the final version of the NONROAD model. This report describes the emission factors that will be used for the draft version of the model and lists the data sources that will be considered when calculating new emission factors for the final model. When complete, the final emission factors will be similarly documented and distributed for stakeholder review.

Additional EPA reports will describe other issues relating to emission factors including NONROAD emission factors for evaporative emissions, crankcase emissions, spillage and other non-exhaust emissions (NR-012), adjustments to emission rates due to variations in fuel and temperature (NR-001), speciation of hydrocarbon emissions (NR-002), and adjustments to emission rates as equipment deteriorates due to time and use (NR-011). Emission factors for compression ignition (diesel) engines are covered in a separate report (NR-009).

Introduction

The U.S. EPA's NONROAD model computes county-level emission inventories for nonroad engines. These calculations rely on emission factors -- estimates of the amount of pollution emitted by a particular type of equipment during a unit of use. Typically emission factors for nonroad sources are reported in grams per horsepower-hour, but they also may be reported in grams per mile, grams per hour, grams per gallon, etc.

This report begins by describing emission factors used in prior models. It then briefly describes our plans for pre-controlled and controlled SI exhaust emission factors in the draft and final versions of NONROAD.

Appendix A provides information on the sources of emission factors. Appendix B has two parts: (1) a large spreadsheet that lists the numerical value of emission factors that have been used in prior inventories and that we intend to use for the draft version of NONROAD, and (2) a guide to using the spreadsheet. Appendix C explains how NONROAD uses "technology groups" to account for changes in emisssion factors over time.

The pollutants covered by this report include exhaust total hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), total particulate matter (PM), and brake specific fuel consumption (BSFC). For nonroad engines all PM emissions are assumed to be smaller than 10 microns (PM10), and 92% of the PM from gasoline and diesel fueled engines is assumed to be smaller than 2.5 microns (PM2.5). For gaseous fueled engines (LPG/CNG) 100% of the PM emissions are assumed to be smaller than PM2.5. The NONROAD Reporting Utility allows the user to select the desired size range.

As explained in NR-006, spark-ignition engine equipment population under 25 horsepower will be combined into one SCC per application to handle expected shifts in market share between 2 and 4-stroke gasoline, LPG, and CNG engines. In the model, the distinction between two- and four-stroke spark-ignition engine emission factors will be maintained using the technology groups described in Appendix C of this report. In this current document, the SCC distinction between 2 and 4-stroke gasoline, LPG, and CNG engines is maintained, however, in the model, we will distinguish emission factors between them by using the technology group methodology.

Background

Prior to the NONROAD model, there have been three major efforts to estimate nonroad spark ignition emission inventories. We have relied heavily on these efforts in our work to select emission factors for the draft version of NONROAD. The three inventories/models are:

- EPA's Nonroad Engine and Vehicle Emission Study ("NEVES").[1] Published in November, 1991, this study was mandated by Congress to determine whether nonroad sources made a significant contribution to urban air pollution. The study covers emissions from all nonroad engines and includes hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), total particulates (PM), sulfur dioxide (SO_2) and other pollutants. It provides inventories for 19 ozone and 16 CO nonattainment areas.

- California Air Resources Board's nonroad model ("OFF-ROAD") [2], designed to estimate nonroad emissions for the state of California only. A draft version of this model was released August 1, 1997. The model covers HC, CO, NO_x, PM, sulfur dioxide (SO_2),

and carbon dioxide (CO_2) for all nonroad engines. ARB is currently revising much of its work on nonroad modeling and the emission factors reported here may not reflect ARB's most recent conclusions.

- EPA's "Small Engine Model"--designed as an internal tool for evaluating various control scenarios, EPA has used this model to estimate the effect of regulations on small spark-ignition (SI) engines under 19 kW (25 hp) This model has evolved over time, but the pre-control exhaust emission factors have not changed since the model was documented in 1995.[3] The model computes national-level inventories of nonroad HC, CO and NOx.

As detailed in Appendix A, the emission factors used in these prior efforts have been based on a very small number of engine studies, particularly when compared to the large body of data available for highway vehicles.

Emission Factor Categories

NEVES defines emission factors by the equipment use (i.e., by "application") but does not assign different emission factors to engines of different sizes within the same application. On the other hand, OFF-ROAD and the Small Engine Model define emission factors by engine size (by horsepower in OFF-ROAD and by displacement in the Small Engine Model), but do not assign different emission factors to engines used in different applications that are of the same size. Given the structure of emission control regulations and the design similarities between engines of the same horsepower used in various applications, we will likely define emission factors primarily by power level for the final release of NONROAD. The NONROAD model allows for the use of application-specific emission factors if there is sufficient information to justify their use by the time of the final release. We expect to use application-based emission factor categories only to distinguish handheld equipment, recreational marine engines and selected recreational vehicles.

Due to time and resource constraints, inputs for the draft version of NONROAD will retain some of the application-specific groupings given by NEVES and the Small Engine Model as detailed below. However, we intend to recalculate emission factors for the final version of the model based on the information given in Appendix A.

Accounting for In-Use Operation

Many nonroad engines operate under transient loads, but the engines are typically tested with steady-state tests. While clear and significant differences between in-use transient and steady-state emissions have been found for compression-ignition engines, such differences have not been found conclusively for SI engines. Three studies have compared transient and steady-state emissions in SI engines, but they have not found consistent results and in most cases

transient and steady-state have produced equivalent emission factors. [4-6] At present, EPA believes there is not sufficient information to justify an in-use transient adjustment factor for SI engines, so the NONROAD model will use emission factors based on unadjusted steady-state test results.

Emission Factors for Pre-control Engines–Draft Version

This section describes the emission factors that will be used for the draft version of NONROAD. Because we plan to recalculate the pre-control emission factors for the final version of the model, these emission factors should be considered placeholder values.

Gasoline Engines ≤25 hp

In general, for small gasoline engines, the draft version of the model will use emission factors based on those in the Small Engine Model.[7] Like the Small Engine Model, NONROAD will distinguish between handheld and non-handheld applications and distinguish engines by size. The draft version of NONROAD separates overhead valve and side-valve four-stroke engines and two-stroke engines through the use of technology types.

Gasoline engines > 25 hp

For larger gasoline engines, the draft version of the model will use emission factors from NEVES. However, to simplify the entry of these placeholder values, and to move toward the horsepower-based emission factors planned for the final version of the model, the draft version of the inputs will not distinguish emission factors for specific applications such as "rubber-tired dozer", but instead will use a single factor for all equipment in a general category such as "construction" or "agriculture". Table 1 lists the specific NEVES emission factors to be used for large engines in the draft version of NONROAD.

Table 1-- NEVES sources of NONROAD large engine emission factors

Emissions Category in NONROAD (Draft Version)	Based on NEVES Emission Factors for:
-All Construction > 25 hp	"Other Construction Equipment"
-All Industrial >25 hp -All Lawn & Garden > 25 hp -All Commercial >25 hp -All Logging > 25 hp -All Aircraft Support > 25 hp -All Underground Mining >25 hp -All Oil Field Equipment > 25 hp	"Other General Industrial Equipment"
-All Agricultural >25 hp	"Other Agricultural Equipment"

NEVES used one average power level and one average emission factor for each application. NEVES used emission factors from AP-42 which were calculated for the average power level of each specific application. The draft version of the NONROAD model will account for power level by using small and large engine emission factors for each application. We expect this approach will provide results similar to NEVES and will serve as an acceptable placeholder until new factors are calculated.

Recreational Marine Engines

Emission factors for recreational marine spark-ignition engines were taken from work accomplished in support of the 1996 rulemaking for new emission standards for these engines. [8] Table 2 shows how the outboard power level ranges used in the 1996 rulemaking analysis were matched to the power levels used in NONROAD. The subsequent tables show the emission rates by power range for precontrolled engines.

These emission factors have been changed from the sales-weighted averages used in the June 1998 draft version of NONROAD to be straight averages of the final M1 - M4 technology type data used in the 1996 rulemaking to be consistent with the method used for the controlled engine types (M5 - M15). For the final version of NONROAD we may return to using sales-weighted averages of the baseline data for tech types M1 - M4.

Table 2 Mapping of Recreational Marine Engine Power Ranges

	EPA-RIA	NONROAD Model
Outboard	<3.9 hp	0 - 3 hp
	3.9 - 9.9	3 - 11
	9.9 - 29.9	11 - 25
	29.9 - 49.9	25 - 50
	49.9 - 74.9	-------
	74.9 - 99.9	50 - 100
	99.9 - 149.9	-------
	149.9 - 199.9	100 - 175
PWC	30 - 50 hp	0 - 50 hp
	50 - 75	50 - 175

Inboard	100 - 150 hp	0 - 100 hp
	150 - 200	100 - 175
	>200	>175

Table 3 Two-Stroke Outboard (SCC - 2282005010) Emission Factors for Precontrolled Engines (M1 Tech Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	340.5	4.12	531.5
3 - 11	292.8	3.38	450.0
11 - 25	220.5	1.34	404.0
25 - 50	156.0	1.60	310.0
50 - 100	136.7	2.46	313.0
100 - 175	172.5	6.00	420.0
>175	172.5	6.00	420.0

Table 4 Four-Stroke Outboard (SCC - 2282005010) Emission Factors for Precontrolled Engines (M4 Tech Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	121.2	4.93	585.0
3 - 11	29.71	5.20	585.0
11 - 25	18.36	7.98	454.7
25 - 50	20.00	10.00	454.7
50 - 100	11.00	10.00	346.0
100 - 175	10.00	12.00	346.0
>175	10.00	12.00	346.0

Table 5 Personal Watercraft (SCC - 2282005015) Precontrolled Emission Factors (M2 Tech Type. For 4-stroke see Tech Type M13 in Table 20)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 50 hp	166.7	1.70	355.6
50 - 175	224.6	0.94	450.7

Table 6 Inboard (SCC - 2282010005) Precontrolled Emission Factors (M3 Tech Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 100 hp	7.2	7.6	175
100 - 175	7.0	7.6	175
>175	5.4	10.4	174

Motorcycles, All-Terrain Vehicles (ATVs), Snowmobiles, Specialty Vehicles, and Underground Mining Equipment

These engines differ significantly from other SI engines in their basic design, operating characteristics, and emission rates. For 2-stroke engines the June 1998 draft version of the model uses the emission factors from testing of two snowmobile engines by Southwest Research Institute. The two engines tested were a 1995 Suzuki 440cc and a 1997 Fudi HI 488cc 2-stroke engine yielding similar emissions levels.[9, 10] The average emissions for these two engines were 206 g/kW-hr THC, 523 g/kW-hr CO, 0.63 g/kW-hr NOx, 3.22 g/kW-hr PM, and 0.665 kg/kW-hr BSFC. The June 1998 draft release of NONROAD assumes that 2-stroke versions of all-terrain vehicles, motorcycles, and specialty vehicles all produce similar exhaust emission rates to these 2-stroke snowmobiles. However, for BSFC for all of these 2-stroke engines have been 0.79 kg/kW-hr (1.3 lb/hp-hr) based on the NEVES assumptions for all other 2-stroke equipment categories.[1] For the final release of NONROAD we plan to change the BSFC input to 0.665 kg/kW-hr (1.09 lb/hp-hr) mentioned above, unless even better data become available.

For 4-stroke recreational equipment engines NONROAD uses the same emission factors as the 4-stroke overhead valve nonhandheld Class 2 engines shown below. The NEVES emission factors for these applications are given in units of grams per hour which is problematic for determining SOx emissions and allows for no differences between the several power levels of these types of engines. The Small Engine Model used in the EPA Phase 1 rulemaking does not consider these applications because they are exempted from the rulemaking. [7]

Natural Gas/LPG Engines

For small engines (less than 25 hp) fueled by natural gas and Liquefied Petroleum Gas (LPG), we plan to use the emission factors from NEVES because these are the only estimates for which full documentation is available. For larger engines the June 1998 draft also used NEVES emission factors, but more recent test data from CARB testing done at Southwest Research Institute [14] allowed these model inputs to be updated in July 1998. The resulting emission factors are shown below.

Table 7 Emission Factors for LPG and CNG engines

Engine Type	THC (g/hp-hr)	CO (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)	BSFC (lb/hp-hr)
LPG < 25hp	3.19	84.27	5.25	0.06	0.693
LPG > 25hp	1.68	28.23	11.99	0.05	0.507
CNG < 25hp	3.19	84.27	5.25	0.06	0.693
CNG > 25hp	1.68	28.23	11.99	0.05	0.507

It should be noted that the above emission factors for under 25 hp engines appear to have been incorrectly translated from the NEVES values due to assuming g/kw-hr units when the NEVES values were in fact g/hp-hr. Thus, the draft final release of NONROAD will use the following values unless more recent test data becomes available.

Table 7a Emission Factors for LPG and CNG engines - Corrected (to be included in a future draft final release of NONROAD)

Engine Type	THC (g/hp-hr)	CO (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)	BSFC (lb/hp-hr)
LPG < 25hp	4.28	113	7.04	0.05	0.693
LPG > 25hp	1.68	28.23	11.99	0.05	0.507
CNG < 25hp	4.28	113	7.04	0.05	0.693
CNG > 25hp	1.68	28.23	11.99	0.05	0.507

Emission Factors for Pre-control Engines--Final Model

For the final version of the model, EPA plans to recompute emission factors for pre-control engines. The new factors will be based on data described in Appendix A. This data includes confidential data from manufacturers and baseline data from a number of small studies. EPA requests immediate assistance in identifying additional sources of pre-control emissions data and assistance in obtaining raw data for the studies listed. Raw data is needed to demonstrate that the emissions information is aggregated properly.

Controlled Emissions–Draft and Final

In addition to estimating emissions from pre-controlled engines, the NONROAD model is designed to account for the effect of federal emissions standards. The model does not cover California emission standards and federal standards that are not yet final. However, because EPA expects to finalize the proposed Phase 2 small engine rule before the release of the final NONROAD model, the proposed Phase 2 standards have been included in the draft version of the model. Thus, NONROAD will include emission factors under three regulations:

- Emissions for New Nonroad Spark Ignition Engines at or below 19 Kilowatts. ("Small Engine Rule, Phase I") [11]

- Phase 2: Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts "Small Engine Rule Phase II" [12]

- Final Rule for New Gasoline Spark-Ignition Marine Engines; Exemptions for New Nonroad Compression-Ignition engines at or Above 37 Kilowatts and New Nonroad Spark-Ignition Engines at or Below 19 Kilowatts ("Marine Rule") [13]

NONROAD will use the brake-specific fuel consumption (BSFC) and the HC, CO, and NO_x emission factors that are in the regulatory support documents for the rules listed above. The NONROAD input structure for handling the phase-in of new emission standards and technologies is explained in Appendix C. The control emission factors for marine engines are listed in the spreadsheet Tech1.wk4 and the technology fractions are listed in the workbook Techmix.wk4. The Phase 1 emission factors for small SI engines are from Appendix F of the Phase 2 regulatory support document, and are listed as "new engine exhaust" values in Table F-07. The Phase 2 emission factors are from the Phase 2 final rule. NONROAD's technology fractions for these engines will follow the sales mixes for Phase 1 and Phase 2 as listed in Tables F-03 and F-04 of the RSD appendix. The Phase 2 final rule did not include handheld engines, so if those standards are changed from what was assumed in this report, the final version of the model will reflect those changes.

Effect of the Federal Rulemaking on SI Recreational Marine Engines

To determine the effect of the Federal rulemaking for these types of engines, technical types were defined to reflect new technologies that would be employed to meet the emission levels required. These new technologies would be employed to various degrees to reflect the phase-in of the new emission standards. Technical types were defined to incorporate the emission reductions expected and the phase-in of the standards.

Outboard Engine (SCC - 2282005010) Emissions

The precontrolled outboard two-stroke and four-stroke engines were defined by the technical types M1 and M4. New engine technical types were defined to account for the new standards and allows for phase-in of the standards. The initial and the phase-in fleet fractions were estimated for all of the technical types.

Table 8 Two-Stroke Outboard (SCC - 2282005010) Emission Factors with Carburetor & Ignition Modifications (M5 Tech Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	340.50	4.12	650.0
3 - 11	292.80	3.38	650.0
11 - 25	216.50	1.34	577.5
25 - 50	156.00	1.60	566.0
50 - 100	136.67	2.46	370.0
100 - 175	155.00	11.00	388.0
>175	155.00	11.00	388.0

Table 9 Two-Stroke Outboard (SCC - 2282005010) Emission Factors with Modifications and Catalyst (M6 Technical Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	165.8	3.43	417.6
3 - 11	142.6	2.82	353.6
11 - 25	107.4	1.12	317.4
25 - 50	75..97	1.33	243.6
50 - 100	66.55	2.05	245.9
100 - 175	84.00	5.00	330.0
>175	84.00	5.00	330.0

Table 10 Two-Stroke Outboard (SCC - 2282005010) Emission Factors with Catalyst & Electronic Fuel Injection (M7 Technical Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	61.12	20.65	625.8
3 - 11	52.55	16.95	529.8
11 - 25	39.58	6.73	475.7
25 - 50	28.00	8.00	365.0
50 - 100	26.50	9.50	342
100 - 175	25.67	11.00	325.0
>175	25.00	11.00	325.0

Table 11 Two-Stroke Outboard (SCC - 2282005010) Emission Factors with Electronic Fuel Injections (M8 Technical Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	61.12	20.65	625.8
3 - 11	52.55	16.95	529.8
11 - 25	39.58	6.73	475.7
25 - 50	28.00	8.00	365.0
50 - 100	26.50	9.50	342.5
100 - 175	25.67	11.00	325.0
>175	25.00	11.00	325.0

Table 12 Direct-Injection Type A Outboard (SCC - 2282005010) Emission Factors (M9 Technical Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	77.21	15.34	577.5
3 - 11	66.39	12.59	489.0
11 - 25	50.00	5.00	439.0
25 - 50	38.00	5.00	261.0
50 - 100	43.00	5.00	256.0
100 - 175	54.00	5.00	409.5
>175	51.00	5.00	381.0

Table 13 Direct-Injection Type B Air Assisted Outboard (SCC - 2282005010) Emission Factors (M15 Technical Type)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 3 hp	77.21	15.34	577.5
3 - 11	66.39	12.59	489.0
11 - 25	50.00	5.00	439.0
25 - 50	38.00	5.00	261.0
50 - 100	43.00	5.00	256.0
100 - 175	54.00	5.00	409.5
>175	51.00	5.00	381.0

The technical types were used to allow the phase-in of the new engines. This phase-in was estimated to be unique by the following power levels, 0-3 hp, 3-11, 11-25, 25-50, 50-100, 100-175, and greater than 175 hp. No changes from the initial 90% two-stroke and 10% four-stroke outboard fleet fractions is estimated to occur for the less than 3 horsepower outboard engines. The other fleet fraction estimates are shown below derived from information generated for the rulemaking.

Table 14 Technical Type Fleet Fractions for 3 - 11 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	0.957	0.043	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.870	0.130	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.537	0.463	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.276	0.724	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.260	0.724	0.016	0.000	0.000	0.000	0.000	0.000

Table 15 Technical Type Fleet Fractions for 11 - 25 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	0.989	0.011	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.962	0.038	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.780	0.216	0.004	0.000	0.000	0.000	0.000	0.000
2004	0.640	0.349	0.011	0.000	0.000	0.000	0.000	0.000
2005	0.633	0.356	0.011	0.000	0.000	0.000	0.000	0.000
2006	0.091	0.620	0.011	0.000	0.000	0.000	0.277	0.000

Table 16 Technical Type Fleet Fractions for 25 - 50 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.972	0.028	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.683	0.049	0.000	0.000	0.000	0.268	0.000	0.000
2002	0.105	0.049	0.000	0.000	0.000	0.268	0.578	0.000
2003	0.098	0.049	0.007	0.000	0.000	0.268	0.578	0.000
2005	0.085	0.063	0.007	0.000	0.000	0.268	0.578	0.000

Table 17 Technical Type Fleet Fractions for 50 - 100 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.950	0.050	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.917	0.050	0.033	0.000	0.000	0.000	0.000	0.000

Table 18 Technical Type Fleet Fractions for 100- 175 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.988	0.000	0.000	0.000	0.000	0.012	0.000	0.000
1998	0.954	0.000	0.034	0.000	0.000	0.012	0.000	0.000
1999	0.575	0.000	0.034	0.000	0.000	0.012	0.379	0.000
2003	0.302	0.000	0.035	0.267	0.000	0.012	0.384	0.000
2004	0.000	0.000	0.035	0.267	0.000	0.314	0.384	0.000

Table 19 Technical Type Fleet Fractions for >175 hp Outboard Engines

Year	M1	M4	M5	M6	M7	M8	M9	M15
1900	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.967	0.000	0.000	0.000	0.000	0.033	0.000	0.000
1998	0.234	0.000	0.000	0.000	0.000	0.033	0.733	0.000
2004	0.000	0.000	0.000	0.000	0.000	0.290	0.710	0.000

Personal Water Craft (SCC - 2282005015) Emissions

Personal Water Craft (PWC) emissions are characterized by three technical types, 2-stroke (labeled M2), 4-stroke (M13), and 2-stroke with major modifications (M14). Type M2 has the emission factors given above in Table 4.

Table 20 Personal Watercraft (SCC - 2282005015) 4-Stroke Emission Factors (M13)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 50 hp	16.13	6.33	354.0
50 - 175	16.98	7.00	326.2

Table 21 Personal Watercraft (SCC - 2282005015) 2-Stroke with Major Modifications Emission Factors (M14)

NONROAD power range	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
0 - 50 hp	166.70	1.70	355.6
50 - 175	224.55	0.94	450.7

The first two tables below show the PWC technology phase-in fractions that are in the draft NONROAD model as of December 1998. The 25-50hp phase-in fractions come directly from the spreadsheets used in the June 1996 Regulatory Impact Analysis, except for 2002 for which the RIA had fractions of 0.680, 0.320, and 0.000 for M2, M13, and M14. The 0-25hp table requires some explanation because the RIA assumed there were no engines under 30hp. As described in technical report NR-006a, "Nonroad Engine Population Estimates," the PSR data that NONROAD uses as a basis for most of the engine population inputs does indicate some engines in that lower power range, including some 4-strokes. The table below for 0-25hp PWC engines takes into account those PSR population fractions.

Table 22 Estimate Phase-in of New Personal Water Craft Engines 0-25 hp

Year	M2	M13	M14
1900	0.218	0.782	0.000
2005	0.075	0.925	0.000

Table 23 Estimate Phase-in of New Personal Water Craft Engines 25-50 hp

Year	M2	M13	M14
1900	1.000	0.000	0.000
1999	0.680	0.000	0.320
2002	0.680	0.136	0.184
2003	0.496	0.320	0.184
2004	0.496	0.504	0.000
2005	0.075	0.925	0.000

Table 24 Estimate Phase-in of New Personal Water Craft Engines >50 hp

Year	M2	M13	M14
1900	1.000	0.000	0.000
1999	0.177	0.092	0.731
2000	0.177	0.259	0.564
2001	0.177	0.533	0.291
2002	0.177	0.823	0.000
2004	0.038	0.962	0.000

Inboard Engines (SCC - 2282010005) Emissions

There are no assumed improvements in emissions from this application as a result of the Federal rulemaking.

Effect of Federal Rulemaking on Small (<19kW) SI Engines

New Federal regulations will be in place for most categories of small spark-ignition engines. Phase 1 of the regulations starts with 1997 regulatory model year which begins September,1996 and provides allowances for special circumstances and manufacturers. The NONROAD model accounts for this by assuming that some of the engines produced in the calendar year 1996 meet the Phase 1 standard. The Phase 2 standard phases-in over 4 years for handheld (Class III-V), 1 year for Class I, and 5 years for Class II new engines built in 2001 or later. These new standards are considered in NONROAD through the use of technology types. The technology types meeting the new standards (with appropriately lower emission factors) then gain market share during the appropriate model years which represent the start year of the regulations.

Engine standards are determined by the class of the engine (I - V) which is determined by the use of the engine, handheld or nonhandheld, and engine displacement. The five classes were associated with application and power level in NONROAD as described in another report (NR-006) to closely simulate the expected effect of this rulemaking.

In order to account for the effect of the rulemaking and the phase-in of the new standards, engines meeting the new standards were defined by technical types as described below. Handheld engines (Classes III-V) are not expected to include any 4-stroke engines (but emission factors are supplied for users) but are expected to include a small fraction of catalyst equipped engines. Nonhandheld engines include both 2 and 4-stroke engines, but manufacturers are expected to build only 4-stroke engines with the advent of the new regulations. Nonhandheld 4-

stroke engine production is split between two technical types, side-valve and overhead valve systems, which have been shown to exhibit significantly different emission characteristics.

New Engine Emission Factors

Emission rates from these engines are determined as a function of new engine emissions. The emission rates for new engines have been determined from testing and the expected effects of new emission standards, and the estimates for NONROAD are shown below.

Table 25; Class III Engine Emissions for New Engines (g/kW-hr)

Engine Tech Type	**HC**	**CO**	**NOx**	**PM**	**BSFC**
G2H3 (gas 2-stroke handheld Class III, baseline)	350	964	1.3	7.7	830
G2H31 (Phase 1)	295	644	1.05	7.7	720
G2H3C1 (Phase 1 with catalyst)	295	644	1.05	7.7	720
G2H32 (Phase 2)	63.7	644	1.97	7.7	500
G2H3C2 (Phase 2 with catalysts)	42.5	644	5.0	7.7	500

Table 26; Class IV Handheld New Engine Emissions (g/kW-hr)

Engine Tech Type	**HC**	**CO**	**NOx**	**PM**	**BSFC**
G2H4 (gas 2-stroke handheld Class IV, baseline)	350	964	1.26	7.7	830
G2H41 (Phase 1)	241	546.5	0.688	7.7	720
G2H4C1 (Phase 1 with catalyst)	241	546.5	0.688	7.7	720
G4H41 (Phase 1 4-stroke)	30	715.6	2.40	0.06	515
G2H42 (Phase 2)	63.7	546.5	1.97	7.7	500
G2H4C2 (Phase 2 with catalysts)	42.5	546.5	5.00	7.7	500
G4H42 (Phase 2 4-stroke)	30	715.6	2.40	0.06	515

Table 27; Class V Handheld New Engine Emissions (g/kW-hr)

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H5 (gas 2-stroke handheld Class V, baseline)	214	696	1.3	7.7	560
G2H51 (Phase 1)	161	470.9	2.436	7.7	529
G2H5C1 (Phase 1 with catalyst)	161	470.9	2.436	7.7	529
G2H52 (Phase 2)	76.93	470.9	2.38	7.7	500
G2H5C2 (Phase 2 with catalysts)	56.14	470.9	5.00	7.7	500

Table 28; Class I Nonhandheld New Engine Emissions (g/kW-hr)

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2N1 (gas 2-stroke nonhandheld Class I, baseline)	278.8	651.5	0.39	7.7	529
G4N1S (gas, side-valved, 4-stroke nonhandheld Class I, baseline)	52.3	577.8	2.68	0.06	830
G4N1O (gas, overhead-valved, 4-stroke nonhandheld Class I, baseline)	17.96	548.3	2.41	0.06	603
G2N11 (2-stroke, Phase 1)	161	603	5.36	7.7	529
G4N1S1 (Phase 1 side-valved, 4-stroke)	11.27	474.3	4.83	0.06	560
G4N1O1 (Phase 1 overhead valved 4-stroke)	11.27	470.9	4.34	0.06	475
G4N1SC1 (Phase 1 side-valved, 4-stroke with catalyst)	11.27	474.3	4.83	0.06	560
G4N1S2 (Phase 2 side-valved)	10.63	474.3	3.17	0.06	560
G4N1O2 (Phase 2 overhead valved)	8.22	470.9	2.46	0.06	475

Table 29; Class II Nonhandheld New Engine Emissions (g/kW-hr)

Engine Tech Type	**HC**	**CO**	**NOx**	**PM**	**BSFC**
G2N2 (gas 2-stroke nonhandheld Class II, baseline)	278.8	651.5	0.39	7.7	529
G4N2S (gas, side-valved, 4-stroke nonhandheld Class II, baseline)	12.96	578	2.76	0.06	570
G4N2O (gas, overhead-valved, 4-stroke nonhandheld Class II, baseline)	6.97	548.3	4.69	0.06	570
G4N2S1 (Phase 1 side-valved, 4-stroke)	7.37	519	6.03	0.06	528
G4N2O1 (Phase 1 overhead valved 4-stroke)	6.97	472.8	4.69	0.06	450
G4N2S2 (Phase 2 side-valved)	7.37	519	6.03	0.06	528
G4N2O2 (Phase 2 overhead valved)	5.58	472.8	3.72	0.06	450

References

[1] "Nonroad Engine and Vehicle Emission Study" (NEVES), U.S. EPA, Office of Air and Radiation, 21A-2001. November, 1991.

[2] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," ("Inputs...") Energy and Environmental Analysis, Inc. for California Air Resources Board. February, 1997.

[3] "Documentation of the OMS Small Gasoline Engine Spreadsheet System, Final Technical Memorandum," Dan Bowman, TRC Environmental Corporation. August 1995.

[4] "Emissions Analysis of Small Utility Engines." Sun, X., et al. SAE paper 952080. 1995.

[5] "Emissions from 4-Cycle Walk-Behind-Mower Engines: Test Cycle Effects." Gabele, Peter. SAE Paper 972793. 1997

[6] "Transient versus steady-state test procedure evaluation of 4-cycle utility engines," Carpenter, T., Buszkiewicz, T., Trimble, T. EPA regulation negotiation test procedure task group, November, 1994. EPA Air Docket A-93-29, Docket Item II-M-27 and "Final Report - Handheld Subgroup of the Test Procedure Task Group", EPA Air Docket A-93-29, Docket Item II-M-40.

[7] "Regulatory Support Document, Control of Air Pollution, Emission Standards for New Nonroad Spark-ignition Engines at or below 19 Kilowatts," U.S. EPA, May 1995, EPA Air Docket, Docket Item # V-B-01.

[8] "Regulatory Impact Analysis: Control of Air Pollution Emission Standards for New Spark-Ignition Marine Engines," U.S. EPA, October, 1996.

[9] "Emissions from snowmobile engines using bio-based fuels and lubricants - draft final report" by Jeff J. White and James N. Carroll, SwRI report #7383, August 1997, prepared for State of Montana Department of Environmental Quality.

[10] "Development of Snowmobile Test Cycle - Final Report", SwRI report # 7574, by Janet P. Buckingham, Jeff J. White, and James N. Carroll, March 1996, prepared for the International Snowmobile Manufacturers Association

[11] 60 FR 34581, July 3, 1995.

[12] “Regulatory Support Document, Phase 2: Emission Standards for New Nonroad Spark Ignition Engines At or Below 19 Kilowatts”. U.S. EPA, Office of Air and Radiation, December 1997.

[13] 61 FR 52087, October 4, 1996.

[14] "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines; Volume 2, Cost-Effectiveness Analysis," Jeff J. White, Melvin N. Ingalls, Lit-Mian Chan, Southwest Research Institute, May 1998.

Appendix A
Detailed Discussion of Pre-Control Emission Factors for Spark Ignition Engines

This appendix provides a detailed description of the data sources used for pre-control emission factors for spark ignition (SI) engines in previous nonroad emission inventories. The Appendix also describes the pre-control emission factors that will be used in the draft version of NONROAD and it lists additional studies that EPA will consider when recalculating pre-control emissions factors for the final version of NONROAD. The appendix is divided into four sections:

- Emission Factors that Apply to All Spark Ignition Engines
- Emission Factors for 2-stroke Gasoline Engines
- Emission Factors for 4-stroke Gasoline Engines
- Emission Factors for Natural Gas/Petroleum Gas Engines

Note: This appendix uses the following abbreviations:

ARB	(California) Air Resources Board
ATV	All-Terrain Vehicle
BSFC	brake-specific fuel consumption
CO	carbon monoxide
CO_2	carbon dioxide
EEA	Energy and Environmental Analysis, Inc.
EMA	Engine Manufacturers Association
EPA	U.S. Environmental Protection Agency
FC	fuel consumption
HC	hydrocarbons
man.	manufacturers
na	not available
NEVES	(U.S. EPA) Nonroad Engine and Vehicle Emission Study
NMHC	non-methane hydrocarbons
NO_x	nitrogen oxides
OHV	overhead valve
OPEI	Outdoor Power Equipment Institute
PPEMA	Portable Power Equipment Manufacturers Association.
PM	particulate matter
rpm	revolutions per minute
TSD	technical support document
SwRI	Southwest Research Institute

SO_2 sulfur dioxide
UM University of Michigan
WBM walk-behind (lawn) mower

All Spark Ignition Engines

Sulfur Dioxide Emission Factors

Sulfur dioxide emissions are rarely measured. Instead, they typically are calculated from fuel consumption and fuel sulfur content. We have retained this approach for the NONROAD inputs. Sulfur dioxide emission factors for gasoline engines are calculated using the following equation:

$$SO_2 = (BSFC * 453.6 - HC) * Sulfur\ Level * 2$$

where

SO_2 is in g/hp-hr
BSFC is in lb/hp-hr
453.6 is the conversion factor from lbs to g
HC is hydrocarbon emissions in g/hp-hr
Sulfur Level for gasoline is 0.00034 weight fraction
2 is the grams of SO_2 formed from a gram of sulfur

The calculation for CNG/LPG engines is similar, with an average fuel sulfur content of 0.00003. This equation differs from the equation used for diesel engines in that all the sulfur is assumed to become sulfur dioxide. This may be a simplification because a relatively small fraction of sulfur (roughly 2%) can be converted in the engine to sulfur trioxide. Sulfur trioxide or the particulate derived from sulfur trioxide is not measured from gasoline engines, so there is no basis upon which to determine a sulfur related particulate emission rate. Therefore we ignore the small effect of particulate sulfur for the sulfur dioxide calculation.

The SO_2 emission factors are calculated for NONROAD's input data files based on the default fuel sulfur content listed here. NONROAD users may use the model interface to adjust the fuel sulfur content without changing the input files.

Carbon Dioxide

The NONROAD model does not require emission factor inputs for carbon dioxide. CO_2 emissions are estimated by the model based on fuel consumption using the equation below. Note that there is currently no subtraction of the carbon in exhaust HC emissions, since this is a negligible portion of the carbon for most engines. However, for 2-stoke engines a substantial

portion of the fuel (up to one third) goes into exhaust HC instead of CO_2. We plan to address this in the final release of the model. The most likely approach is to simply subtract exhaust THC from BSFC in the following equation.

$$CO_2 = BSFC * 453.6 * 0.87 * (44/12)$$

where

CO_2 is in g/hp-hr
BSFC is in lb/hp-hr
453.6 is the conversion factor from lbs to grams
0.87 is the carbon mass fraction of gasoline
44/12 is the ratio of CO_2 mass to carbon mass

Fuel Consumption

There are few studies that also measured fuel consumption in nonroad engines. NEVES does not explicitly report fuel consumption, but fuel consumption is reported for selected sources in the NEVES Appendix I. ARB reports fuel consumption and cites two studies: (1) ARB's 4-stroke factors for overhead valve (OHV) engines less than 25 horsepower and for side-valve engines of all horsepower are from an SwRI report.[1] (2)ARB's fuel consumption factors for OHV 4-stroke gasoline engines greater than 25 horsepower were based on pre-control on-road engine BSFC.[2] The small engine model lists fuel consumption for engines <25 hp, but the source of this estimate is not clear.

EPA intends to improve fuel consumption factors in the final version of the model; however, due to time constraints, the draft version of the model will use BSFC data adapted from that available in NEVES.

Two Stroke Gasoline Engines

Table A1 lists the sources of data used for emission factors of two-stroke engines in previous inventories and planned for the NONROAD draft model. The table also lists studies that provide additional data that EPA will consider when recalculating emission factors for the final version of the model. The references listed in the table are described below.

---

[1] White, Carroll, Hare and Lourenco. Emission Factors for Small Utility Engines. Southwest Research Institute and California Air Resources Board. 1991. (SAE Paper 910560).

[2] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model", Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.

Table A1–Data Sources for Baseline Emission Factors for Two-Stroke Gasoline Engines

Equipment Description	Emission Factor Data Sources given in Table A2 and Used by:				Notes	Additional Data Sources
	NEVES	ARB	Small Engine Model	Nonroad Draft Version		
General non-handheld (>=3 hp)	A	A,B	A	A	ARB includes a deteriorated engine (B) in PM estimate.	1,2
Offroad Motorcycles ATVs (all hp)	C, ?	C	na	C, ?	It is not clear where NEVES PM estimates are from, but we will use them for draft.	3
Golf carts, Minibikes and Specialty Carts (>3 hp)	C	A,B	A	A	Operating at lower rpm, these engines are more like lawnmowers than motorcycles.	
(≤3 hp)	C	G	A	G		
Snowmobiles (all hp)	D	D	na	D		4,5
Outboard marine engines (all hp)	A,E,F	A,E	na	A,E,F	NEVES and ARB use (A) for PM. NEVES uses (F) for SO_2	6,7
Personal Watercraft (all hp)	na	na	na	9	For draft, calculate HC, CO, NO_x and SO_x from new data. Use BSFC and PM from outboards.	8
Non-handheld (≤3 hp)	A	G	A	G		9, 10, 11
Handheld	G	G	G (modified)*	G (modified)*		12-18

* The small engine model documentation states that the emission factors for handheld engines were modified based on manufacturers data.

Table A2–Emission Factor Data Sources Listed in Table A1 for Two-Stroke Gasoline Engines

Reference Code	Number of Engines. Tested	Age and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
A	1	WBM	5 hp	SwRI	HC, CO, NO_x, PM, FC	"Technical Support Document for California Exhaust Emission Standards and Test Procedures for 1994 and Subsequent Model-Year Utility and Lawn and Garden Equipment Engines." (ARB TSD) California Air Resources Board. Attachment C to ARB Mailout #90-64. December 1990. p. 31. Some of this data also is reported in SAE 910560.
B	1	11-year-old WBM	2.4 hp	SwRI	HC, CO, NO_x, CO_2, PM, FC	Carroll, James N. Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors SwRI 3426-006 for EPA, September 1991.
C	?	?	?	?	HC, CO, NO_x	ARB Mailout #90-58, "Proposal to control emissions from Off-Road Motorcycles," September 7, 1990. The mail-out does not describe the source of the emission factors. According to Ingalls, M. "Nonroad Emission Factors, Interim Report" SwRI 08-3426-005. February 1991, for NEVES, the mailout factors were converted to g/hr based on average speed of 25 mph.

D	3	snow-mobiles	?	SwRI	HC, CO, NO_x, PM, FC	AP-42, 4th Edition, Sept. 1985. II-8. Data is based on: C.T. Hare, K.J. Springer, T.A. Huls, "Snowmobile Engine Emissions and Their Impact", SAE 740735, 1974. Converted to g/hp-hr by dividing by an average hp of 5.8.
E	25	outboard engines	?	EMMA	HC, CO, NO_x, BSFC	NEVES
F	4	outboard engines	?	SwRI	HC, CO, NO_x, SO_x	Hare C.T. and K.J. Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part II, Outboard Motors. Final Report." Southwest Research Institute. January 1973.
G	50 including legible data on: 8 11 2	 chainsaws chainsaws trimmers	 1-3 hp 3-6 hp 0-1 hp	PPEMA	HC, CO, NO_x	Heiden Report cited in "ARB TSD". The closest in EPA dockets is Untitled, A-93-25 II-D-23. Only part of this data is legible. **EPA requests assistance locating this report.**

Table A3--Known Additional Data Sources Listed in Table A1 for Gasoline Two-Stroke Engines

Reference Code	Number of Engines. Tested	Age and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	2	?	3, 4.5	UM	HC, CO, NO_x, CO_2	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.
2	2	7- and 10-year-old mower*	?	UM	HC, CO, NO_x	Charmley, William. "Memorandum: U/M data on in-use two strokes" 1993. (Docket A-93-25/II-B-03)
3	1	moped/ATV	6	SwRI	NMHC, CO, NO_x, PM	Hare, C.T., and J.J. White. "Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues," 1991. SAE 911222 in SAE P-254.
4	8	snowmobile	?	man.	HC+ NO_x, CO	"Regulatory Strategies for Off-Highway Equipment. Addendum: Potential Emission Control Regulations for Snowmobiles, Preliminary Draft" EEA for ARB, February 1992, p. A-12. Data from International Snowmobile Industry Association.
5	1	snowmobile	50 hp	SwRI	HC, CO, NO_x, PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541, (SwRI/ARB 1993) December, 1993.
6	1	outboard marine	9.9 hp	EPA	HC, CO, NO_x, FC	"Memorandum: Exhaust Emission Testing of a Two-Stroke and a Four-Stroke Marine Engine; Results and Procedures," Mike Samulski to Docket #A-92-28.
7	?	outboard marine	?	man.	HC, CO, NO_x	Manufacturer testing of 56 engine families. (Confidential business data.)

8	?	PWC	?	man.	HC, CO, NO_x	Manufacturer testing of 10 engine families (Confidential business data)
9	1	non-handheld	2 hp	SwRI	HC, CO, NO_x, PM	Hare, C.T., K.J. Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment using Internal Combustion Engines, Final Report Part 4, Small Air-Cooled Spark Ignition Utility Engines." May 1973. Table 19.
10	3	?	1.2, 2.2, 2.3 hp	UM	HC, CO, NO_x, CO_2	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.
11	1	11-year-old WBM*	2.4 hp	SwRI	HC, CO, NO_x, CO_2, PM, FC	Carroll, James N. Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors SwRI 3426-006 for EPA, September 1991.
12	1	?	1.25 hp	UM	HC, CO, NO_x, CO_2	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.

13	24 including 3 3 6 3 9	handheld blowers blowers trimmers chainsaws chainsaws	 0-1 hp 1-3 hp 0-1 hp 0-1 hp 1-3 hp	Poulan/ Weed Eater	HC, CO, NO_x, FC	Liechty, Kim. "Investigation of In-Use Deterioration of Exhaust Emissions from Small Single-Cylinder Two Stroke-Cycle Engines," SAE 952137.
14	5	1-7-year-old handheld engines*	?	SwRI	HC, CO, NO_x	Carroll, J.N., J.J. White. "Emission Testing of In-Use Handheld Engines" SwRI 08-4855--211. (EPA Docket A-93-25//II-A-06).
15	3	string trimmers	0-1 hp	PPEMA	HC, CO, NO_x	"PPEMA/AQC In-Use Emissions Test Report: 25 cc String Trimmers." 1993. (Docket A-93-25/II-D-23, attach 2)
16	3	chainsaws	1.4 hp	PPEMA	HC, CO	EPA/PPEMA "In-Use" Emissions Test Report. (Docket A-93-25/II-D-23, attach. 3)
17	1	4-year-old string trimmer*	0.5 hp	SwRI	HC, CO, NO_x, CO_2, PM, FC	Carroll, James N. "Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors" SwRI 3426-006 for EPA, September 1991.
18	1	string-trimmer	?	SwRI	HC, CO, NO_x, FC	J.P. Latusek and R.W. Burrahm, "Conversion of Two Small Utility Engines to LPG Fuel", 1993, SAE 932447. Note, data is from a 2-mode test.

*In-use testing listed for reference only. EPA does not plan to include this data when calculating emission factors for new engines.

4-Stroke Gasoline Engines

Table A4 lists references for data used for four-stroke gasoline engines in previous inventories and planned for the NONROAD draft model. The table also lists studies that provide additional data that EPA will consider when recalculating emission factors for the final version of the model.

Tables A5 and A6 describe the studies referenced in Table A4.

Table A4–Data Sources for Baseline Emission Factors for Four-Stroke Gasoline Engines

Equipment Description	Emission Factor Data Sources Used for:				Notes	Additional Data Sources
	NEVES	ARB	Small Engine Model	Nonroad Draft Version		
Off-Road Motorcycles, ATVs	A?	A	na	A	It is not clear where NEVES PM estimates are from, but we will use them for draft.	
Golf carts, Minibikes and Specialty Carts (>3 hp)	A	B	C	C	Operating at lower RPM, these are more like lawnmowers than motorcycles.	1
Snowmobiles	na	na	na	A	A few exist. We will use motorcycle factors.	
General (>25 hp)	D	C,E	na	D	See Table 1 in the main report.	2-5
General (<25 hp)	D	B	C	C		6-15
Lawn & Gard., Commercial, Logging, Airport Support (<25 hp)	C	B	C	C		6-15
Rec. Marine--Outboards	F	F	na	F		16
Rec Marine--Sterndrive/ Inboards	G	G*	na	G		17-18
Rec Marine--PWC	na	na	na	na	No 4-strokes in baseline years	

* There may be a typographic error in ARB's emission factor for 4-stroke inboards.

Table A5–Emission Factors Data Sources Listed in Table A4 for Four-stroke Gasoline Engines

Reference Code	Number of Engines. Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
A	?	?	?	?	HC, CO, NO_x	ARB Mailout #90-58, "Proposal to control emissions from Off-Road Motorcycles," September 7, 1990. (For NEVES, converted to g/hr based on an average speed of 25 mph).
B	"more than 500"	?	?	man.	HC, CO, NO_x	Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model, Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.
C	29 including 7 9 4 6 3	 side-valve OHV side-valve OHV side-valve	 3.5-5 hp 4-5 hp 8-12 hp 11-12.5 hp 16-18 hp	SwRI	HC, CO, NO_x (PM and FC for 6 engines)	Technical Support Document for California Exhaust Emission Standards and Test Procedures for 1994 and Subsequent Model-Year Utility and Lawn and Garden Equipment Engines. (ARB TSD) California Air Resources Board. Attachment C to ARB Mailout #90-64. December 1990. p. 31. Six of these engines are reported in SAE 910560, which lists PM and FC. *(Note that both NEVES and the Small Engine model use this data, but the emission factors are different because the calculations use different groupings. The Draft version of NONROAD will start with the emission factors from the small engine model, but will combine them into NONROAD categories using the sales fractions for OHV and Side Valve engines listed for "All Other Equipment" in Table B3 of Appendix B.*)

D	4	?	30-85	SwRI	HC, CO, NO_x, PM, FC	Hare, C.T and K.J. Springer. Exhaust Emission from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Final Report, Part 5, Heavy Duty Farm, Construction and Agricultural Engines. San Antonio TX: Southwest Research Institute, October 1973. (SwRI provided differently-weighted averages for various applications, creating a large number of emission factors from a few data points.)
C	2	?	53.5 and ?	?	HC, CO, NO_x	Cited in Regulatory Strategies for Off-Highway Equipment." EEA for ARB, August 1992.
F	3	outboard engines	10-45 hp	NMMA	HC, CO, NO_x, BSFC	NEVES Table I-11b
G	3	sterndrive/ inboard engines	120-200 hp	NMMA	HC, CO, NO_x, BSFC	NEVES Table I-11c

Table A6--Known Additional Data Sources Listed in Table A4 for Four-Stroke Gasoline Engines

Reference Code	Number of Engines. Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	1	OHV golf cart	8.4 hp	SwRI	HC, CO, NO_x, PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB), December 1993.
2	3		106, 107, 109 hp	SwRI	HC, NO_x	Carroll, J.N. "Emission Tests of a 4.9 Liter Ford Utility Engine in Twelve Configurations", SwRI for Geometric Results, April 1994.
3	2	lift-trucks	41.4, 85 hp	SwRI	HC, CO, NO_x, PM, CO_2, FC	Carroll, James N. and J. J. White. "Final Letter Report "Emission Tests of Three Lift-Truck Engines". SwRI 08-53L to William Montweiler, Industrial Truck Association. February 10, 1993.
4	2	utility engines	60, 100 hp	SwRI	HC, CO, NO_x, PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB) December, 1993.
5	5 (planned)	various applications	37-205 hp	SwRI	HC, CO, NO_x, BSFC	White, Jeff J. et al. "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines, Interim Report" SwRI 8778 for CA ARB, December 1997.

6	3	side-valve WBMs, 1-10 years old*	3.5-5 hp	EPA	HC, CO, NO_x, CO_2, other toxics and HC fractions	Gabele, Peter. "Emissions from 4-Cycle Walk-Behind-Mower Engines: Test Cycle Effects. SAE 972793.
7	8 including 6 2		 1-5 hp 8-12.5 hp	UM	HC, CO, CO_2, NO_x	Sun, X., et al. "Emissions Analysis of Small Utility Engines" SAE paper 952080. Data on same engines reported in "Small Engine Emissions" in Off Highway Engineering, Dec. 1995.
8	45	1-16 year-old lawnmowers*	3-5 hp	Ctr. for Em. Res. Anal.	HC, CO, NO_x, CO_2	Assessment of In-Use Emissions of Gasoline Engine Powered Lawnmowers, Final Report" The Center for Emissions Research and Analysis, Project #92-002 for EPA, etc., March 17, 1995
9	1	utility engine	8 hp	SwRI	HC, CO, NO_x, CO_2, FC	Burrahm, Robert W., Jeff J. White and James N. Carroll. "Small Utility Engine Emissions Reduction Using Automotive Technology." SAE paper 911805 in Two Stroke Engines, Small Engines and Emissions Reductions, SAE SP-883. Table 3.
10	1	riding mower	?	?	CO, HC+ NO_x	Swanson, Mark. "An Emission Comparison Between a Carburetor and an Electronic Fuel Injection System for Utility Engines." SAE paper 911806 in SAE SP-883. Table 2.
11	3	2 lawnmowers, 1 utility engine	4.5, 5, 11 hp	SwRI	HC, CO, NO_x, CO_2, FC	White, Jeff J. et al. "Emission Control Strategies for Small Utility Engines," SAE paper 911807 in SAE SP-883. Table 7, 9,10.

12	4	?	3.5, 4, 12.5, 18 hp	SwRI	HC, CO, NO_x, PM	Hare, C.T., and Karl Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Final Report, Part 4, Small Air-Cooled Spark Ignition Utility Engines." May 1973.
13	?	?*	?	Onan		Fax from Onan Corporation: "OPEI In-Use Emissions Testing." Docket A-93-25/II-D-46.
14	1	OHV WBM	3.5 hp	SwRI	NMHC, CO, NO_x, PM	Hare, C.T., and J.J. White. "Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues," 1991. SAE 911222.
15	1	OHV	(435 cc)	SwRI	?	Energy and Environmental Analysis, Inc. "Regulatory Strategies for Off-Highway Equipment," August, 1992.
16	1	outboard marine engine	8 hp	EPA	HC, CO, NO_x, FC	"Memorandum: Exhaust Emission Testing of a Two-Stroke and a Four-Stroke Marine Engine; Results and Procedures," Mike Samulski to Docket #A-92-28, May 30, 1996.
17	4	inboard marine engines	?	EPA	HC, CO, NO_x, FC	"Memorandum: Effects of Transience on Emissions from Inboard Marine Engines," from Michael Samulski, to Docket #A-92-28. May 30, 1996. (Note: includes data from Samulski, M., "Sensitivity of Test Cycle and Fuel Type on a Spark-Ignition Four-Stroke Inboard Marine Engine," 1994. SAE 941782.)
18	1	sterndrive marine engine	?	Mich. Auto. Res. Corp.	HC, CO, NO_x, FC	"A Comparison of Exhaust Emissions on a Marine Engine Run on Steady State and Simulated Transient Cycles," Michigan Automotive Research Corporation for National Marine Manufacturers Association, October 8, 1992.

*In-use data listed for reference only. EPA does not plan to include this data when calculating emission factors for new engines.

Other Spark Ignition Engines

Table A7–Data Sources for Baseline Emission Factors for CNG/LPG engines

Equipment Description	Emission Factor Data Sources Used for:			Notes	Additional Data Sources
	NEVES	ARB	Nonroad Draft Version		
All CNG/LPG Equipment	A,B	C,D	A**,**B	NEVES created emission factors by multiplying the relevant gasoline factor by an adjustment factor. The draft version of NONROAD will use the NEVE emission factor.	1-5

Table A8–Emission Factors Data Sources Listed in Table A7 for Natural Gas/LPG Engines

Reference Code	Number of Engines Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
A	1			SwRI	HC, CO, NO_x, PM	J.J. White, et. al. "Emission Factors for Small Utility Engines," 1991. SAE 910560
B	1			Onan	HC, CO, NO_x	Williamson, Dale E. Onan Corporation. Letter to California Air Resources Board, July 20, 1990.
C	?	?	?	man.	HC, CO, NO_x	Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model, Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.
D	1	utility engine	? (400 cc)	Walbro	HC, CO, NO_x, BSFC	"A Study of the Potential of Propane Fuel to Reduce Utility Engine Exhaust Emissions," Kenneth J. Cotton, Walbro Engine Management Corp. SAE 921696, September, 1992.

Table A9--Known Additional Data Sources Listed in Table A7 for Natural Gas/LPG Engines

Reference Code	Number of Engines Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	2	lift truck, utility engine	40, 60 hp	SwRI	HC, CO, NO_x, PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB 1993) December 1993. (Note, while ARB sponsored these tests, they chose not to use the data because the engines were tested at very lean calibrations.)
2	1	2s trimmer 4s side-valve	?	SwRI	HC, CO, BSFC	J.P. Latusek and R.W. Burrahm, "Conversion of Two Small Utility Engines to LPG Fuel," 1993, SAE 932447.
3	1	lift truck	85 hp	SwRI	HC, CO, NO_x, CO_2, BSFC	Carroll, James N. and J. J. White. "Final Letter Report: Emission Tests of Three Lift-Truck Engines". SwRI 08-53L to William Montweiler, Industrial Truck Association. February 10, 1993.
4	1		102 hp	SwRI	HC, NO_x	Carroll, J.N. "Emission Tests of a 4.9 Liter Ford Utility Engine in Twelve Configurations", SwRI for Geometric Results, April 1994.
5	4 (planned)	various	37-53 hp	SwRI	HC, NO_x, CO, BSFC	White, Jeff J. et al. "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines, Interim Report" SwRI 8778 for ARB, December 1997.

Appendix B
Cross-Inventory Comparison of SI Emission Factors

The body of Appendix B is the large Microsoft Excel™ spreadsheet ***compare.xls***. This document explains how the spreadsheet was created and explains how to use the spreadsheet, which compares emission factors from NEVES, OFF-ROAD, EPA's Small Engine Model and the draft version of NONROAD.

To make it possible to compare emission factors for specific equipment types, the rows in the spreadsheet ***compare.xls*** are a list of every combination of Source Classification Code (SCC) and horsepower group for spark ignition engines. The rows include SCCs (including 2266xxxxx and airport service equipment) that are not used in NONROAD but are used by California Air Resources Board (ARB). The columns in the spreadsheet are emission factors from NEVES, from ARB's draft OFF ROAD model, and from the Small Engine model. These are followed by some notes on differences between the factors and by a list of the emission factors used in the Draft version of NONROAD. Various subsets of the spreadsheet's columns can be selected by choosing"View Manager"™ in Excel's "View" menu.

Comparing emission factors between inventory models is not straightforward because the different models and inventories use different units and different categories in distinguishing emission factors. To compare the factors, all factors were converted to list emission factors in g/hp-hr by engine type, application and horsepower. This conversion required mapping both the ARB horsepower groups and the Small Engine Model's displacement classes to the horsepower groups used by the NONROAD model (see Tables B-1 and B-2). It was also necessary to combine the Small Engine Model's overhead-valve and side-valve categories into a single category by using a sales-weighted average, using the sales mix listed in Table B-3.

Note that the BSFC column labeled as NEVES BSFC is not directly from NEVES, but is based on NEVES information. Also note that the input files for NONROAD will have fewer entries because, without the need to compare across models and inventories, emission factors will be grouped by global SCCs and larger horsepower ranges.

Table B1--Mapping of small engine groupings used in the Small Engine Model and ARB's OFF-ROAD model to the small engine groupings used in the NONROAD model

Small Engine Model Class/Displacement	ARB Power Range	NONROAD Power Range	NONROAD source classification
Non-Handheld, I <225 cc	2-5 hp	3-6 hp	All engines except 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers
Non-Handheld, II >225 cc	5-15 hp 15-25 hp	6-16 hp 16-25 hp	All engines except 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers
Handheld, III 0-20 cc	≤ 2 hp	0-1 hp	All engines
Handheld, IV 20-50 cc	≤ 2 hp	1-3 hp	All engines
Handheld, V >50 cc	2-15 hp	3-6 hp	All 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers

Table B2-- Mapping of large engine groupings used in ARB's OFF-ROAD model to the large engine groupings used in the NONROAD model.

ARB hp range	NONROAD hp Range
5-15	6-11 & 11-16
15-25	16-25
25-50	25-50
50-120	50-100
120-175	100-175
175-250	175-250
250-500	250-500
500-750	500-750
750-9999	750-3000+

Table B3--Sales Mix for Small Engine Model, Pre-control [1]

Application	Sales Mix								
	2-stroke handheld			2-stroke non-handheld		4-stroke non-handheld, overhead- and side-valve			
	Class 3	Class 4	Class 5	Class 1	Class 2	Class 1 OHV	Class 1 SV	Class 2 OHV	Class 2 SV
Lawn Mowers				0.1		0.065	0.835		0.0014
Trimmers/ Edgers/ Cutters	0.0501	0.9173	0.0077			0.0016	0.0231		0.0002
Chain Saws	0.0035	0.6426	0.3539						
Leaf Blowers/ Vacuums	0.0528	0.6299	0.2086			0.0007	0.0721	0.0001	0.0359
Generator Sets				0.0017		0.0057	0.2853	0.0551	0.6522
Tillers		0.0101	0				0.7938	0.0001	0.196
Snowblowers			0.3205				0.3732		0.3063
Commercial Turf Equipment				0.0099		0.04	0.0647	0.3658	0.5196
Rear Engine Riding Mowers							0.0499	0.1563	0.7939
Lawn & Garden Tractors						0.0222	0.804	0.0013	0.1725
Pumps							0.0049	0.1421	0.8531
All Other Equipment				0.0974	0.0024	0.0375	0.4064	0.0081	0.4482

[1]“Documentation of the OMS Small Gasoline Engine Spreadsheet System, Final Technical Memorandum” TRC Environmental Corporation for U.S. EPA Air and Energy Research Laboratory. August 1995.

Appendix C
Technology Groups

NONROAD accounts for changes in sales fractions and emissions from the advent of emission standards or other changes by assigning technology groups to each Source Classification Code (SCC). Each technology group has its own emission factor and the fraction of the population assigned to each group can change over time. These "technology fractions" are contained in an input file in NONROAD called ***tech.dat***. A sample record for 4-stroke lawnmowers might show a shift in engine sales from side-valve engines (Tech Group 1) to overhead valve engines (Tech Group 2) as illustrated in Table C1, which shows side-valve engines declining from 90% of sales in 1991 to 50% of sales in 1997.

Table C1: Sample Technology Fractions

SCC/Year	Horsepower Range	Tech group/fraction	Tech group/fraction
2260004010	3-6 hp	1	2
1990		0.90	0.10
1997		0.50	0.50

Each technology group has an associated emission factor given in the emission factor input file for that pollutant. This emission factor can change with time. For example, CO emissions from Technology Group 1 (side-valve engines) might decrease from 819 g/hp-hr for model year engines 1990 through 1996 to 387 g/hp-hr for model years 1997 and later as shown in Table C2. The year listed in the emission factor input file is the first year in which the new emission factor applies.

Table C2: Sample Emission Factors

SCC/Year	Horsepower Range	Technology group/emissions	Units	Pollutant
2265004010	3-6 hp	1	g/hp-hr	CO
1990		819		
2265004010	3-6 hp	1	g/hp-hr	CO
1997		387		

For pre-controlled engines the only technology groups currently identified are those used to combine SCCs for spark-ignition engines <25 hp as described in NR-006. Technology groups primarily will be used for engines subject to emissions regulations. The regulations discussed in the main body of this report are expected to influence the sales fraction of various technology

types and the emission rates of those technologies. These anticipated changes are described in EPA's rulemakings and set forth in the spreadsheets ***Tech1.wk4***, ***Techmix.wk4***, and Appendix F of the small engine Phase II regulatory support document. The emission factors for Phase I and Phase II engines are listed as "new engine exhaust" values in Table F-07. The expected sales mixes for Phase I and Phase II as listed in Tables F-03 and F-04 of the RSD appendix.[1] For both the draft and final versions of NONROAD, EPA will simply format this information for the NONROAD input files.

If new emission factors are developed for other parts of the inventory (e.g., larger SI engines) to reflect distinctions between different engine technologies with different emission levels, then appropriate technology groups, technology fractions, and emission factors will be added to the model. Similarly, appropriate emission factors will be added to the model if new emission standards are implemented.

References

[1] "Regulatory Support Document, Phase 2: Emission Standards for New Nonroad Spark Ignition Engines At or Below 19 Kilowatts". U.S. EPA, Office of Air and Radiation, December 1997.