Quality Assurance Issues Associated With Draft NONROAD2002a

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ABSTRACT

Nonroad sources have been estimated to be a significant portion of the mobile source emission inventory for many pollutants. The Draft NONROAD2002a model is currently the U.S. Environmental Protection Agency's (EPA) best available tool for estimating emissions from most nonroad source types; however, there are several key assumptions in the model that can have a significant effect on the results. This paper (1) provides a means of visualizing and understanding some of the model's key assumptions and sensitivities, and (2) illustrates that some quality assurance (QA) is possible with available data or limited surveys. For example, available data indicate that diesel fuel usage in construction equipment is being overestimated by at least a factor of two, and that growth rates may also be overstated by a factor of two. In addition, assumptions regarding the fuel types used in large spark-ignition (SI) engines are qualitative, and emission factors are significantly different from EPA's latest estimates.

INTRODUCTION

Nonroad sources are defined by EPA's Consolidated Emissions Reporting Rule (40 CFR 51, Subpart A) to include all internal combustion engines that are neither stationary nor installed in on-road or competition vehicles. The Draft NONROAD2002a model (hereafter referred to as "NONROAD") was released by the EPA in June 2003 for the purpose of estimating emissions from all nonroad sources other than commercial marine vessels, locomotives, and aircraft. EPA has stated it will not require that inventories developed using the Draft model be updated when the final version of the model is released.[1] However, EPA has not provided specific guidance for assuring the quality of the inventories that the model predicts. For localized activity data, survey-based approaches have been utilized in the past for purposes of quality-assuring data for specific source types, but these approaches can be labor intensive, and are usually not feasible for all source types incorporated into the model. The need for more generalized quality assurance (QA) is significant, because several assumptions are incorporated into the model.

MODEL OVERVIEW

Because EPA's technical documentation for NONROAD is voluminous, it is useful to summarize some of the key aspects here. NONROAD includes a wide array of engines ranging in size from less than 1 hp up to 3000 hp. There are approximately 100 specific nonroad engine application types in the model that are organized into the categories shown in Table 1; for each application, there are up to five fuel/engine types including oil-fueled compression-ignition (diesel) engines, 2-stroke gasoline fueled SI engines, and 4-stroke SI engines (fueled with gasoline, liquefied petroleum gas [LPG], or compressed natural gas [CNG]). (It is inferred that other types such as dual-fueled diesels and 2-stroke CNG-fueled SI engines were not believed to be significant.) EPA has developed a unique 10-digit Area and Mobile Source (AMS) code for each combination of engine application and fuel/engine cycle type. For each AMS code (c), annual exhaust emissions for each engine age (a) and size range (r) are calculated as follows:

Equation (1)

Exhaust Emissions (*c*,*a*,*r*) = Engine Population (*c*,*a*,*r*) * Average Horsepower Rating (*c*,*r*) * Load (*c*) * Operating Hours (*c*) * Emission Factor (*c*,*a*,*r*)

Table 1. Application types in the NONROAD model.

Application Category	Corresponding 10-digit EPA Area and Mobile Source (AMS) Codes[a]
Recreational Equipment	22-xx-001-yyy (Recreational)
Construction & Mining Equipment	22-xx-002-yyy (Construction & Mining) 22-xx-009-yyy (Underground Mining)
Industrial Equipment	22-xx-003-yyy (Industrial) 22-xx-010-yyy (Oil Field Equipment)
Lawn & Garden Equipment	22-xx-004-yyy (Lawn & Garden)
Agricultural Equipment	22-xx-005-yyy (Agricultural)
Commercial Equipment	22-xx-006-yyy (Commercial)
Logging Equipment	22-xx-007-yyy (Logging)
Airport Equipment[b]	22-xx-008-yyy (Aircraft Ground Support)
Pleasure Craft	22-82-xxx-yyy (Pleasure Craft)
Railroad Equipment[c]	22-85-xxx-yyy (Railroad Equipment)

[a]xx = The code for fuel/engine cycle type, yyy = The code for specific applications
[b]Specifically refers to airport ground support equipment only
[c]Specifically refers to railroad maintenance equipment only

In equation (1), the Average Horsepower Rating refers to engines of type *c* within the specified size range *r*; the Load is a fraction (between 0 and 1) that represents the average % load on the engine during operation; and the Emission Factor is in units of grams per horsepower-hour (g/hp-hr). The model's Graphical User Interface (GUI) only allows input parameters which affect the Emission Factor, specifically gasoline volatility and oxygen content, sulfur content for all fuels (used to calculate SO_2 and sulfate particulate emissions), and temperatures (which only affect emissions from spark-ignition engines, i.e., engines other than diesels). However, it is possible to adjust other aspects of equation (1) by editing auxiliary files provided with the program (in the DATA subdirectory), as described in the user's guide.[2]

Most engine population data incorporated into the model are based on sales data obtained by EPA from Power Systems Research (PSR). Although on-road mobile engines are clearly excluded from the PSR database, PSR does not track the extent to which the engines in the database are nonroad (mobile) or stationary. Engines that stay at the same site at a facility for an entire year (or season, for certain specific applications) are excluded from EPA's definition of "nonroad" (40 CFR 89.2). In NONROAD, EPA adjusted PSR populations of certain equipment downward, based on estimates of the extent to which the engines were mobile (nonroad) or stationary (see Table 2). Although EPA cited a 1992 study by Booz Allen Hamilton (BAH) as the source of the data, BAH based their estimates on interviews with just six engine and equipment manufacturers, only made estimates for engines rated between 25 and 500 hp, and only applied those estimates to compressors, pumps, and generator sets (gensets).

Table 2. NONROAD estimates of the extent to which engine populations for compressors, pumps, gensets, welders, agricultural hydraulic power sets, and agricultural irrigation sets are mobile versus stationary;[3] PSR engine populations for these applications were multiplied by the mobile percentage before being incorporated into the model.

Horsepower Range	Percentage of total engine population that is mobile	Percentage of total engine population that is stationary	Reference
0 – 25	90%	10%	(Undocumented)
25 – 40	90%	10%	Booz Allen Hamilton, Inc.[4, a]
40 – 100	70%	30%	Booz Allen Hamilton, Inc.[4, a]
100 – 175	20%	80%	Booz Allen Hamilton, Inc.[4, a]
175 – 300	15%	85%	Booz Allen Hamilton, Inc.[4, a]
300 – 500	10%	90%	Booz Allen Hamilton, Inc.[4, a]
500 – 600	10%	90%	(Undocumented)
600 +	0%	100%	(Undocumented)

[a]This reference only applied these percentages to compressors, pumps, and gensets.

In addition to exhaust emissions, NONROAD models evaporative VOC emissions from engines with open crankcases, diurnal losses, and refueling losses (for gasoline-fueled equipment only). For 4-stroke SI engines, open crankcase emissions are assumed to be 33% of exhaust emissions, based on estimates published for 1963 and older on-road vehicles.[5] Crankcase emissions for other engine types are estimated to be negligible relative to exhaust emissions. Diurnal losses and refueling losses are calculated based on somewhat more extensive data and would be difficult to quality-assure further. Hot soak losses, running losses and resting losses are not calculated, in part because they are believed to be minor compared to diurnal and refueling emissions.[6]

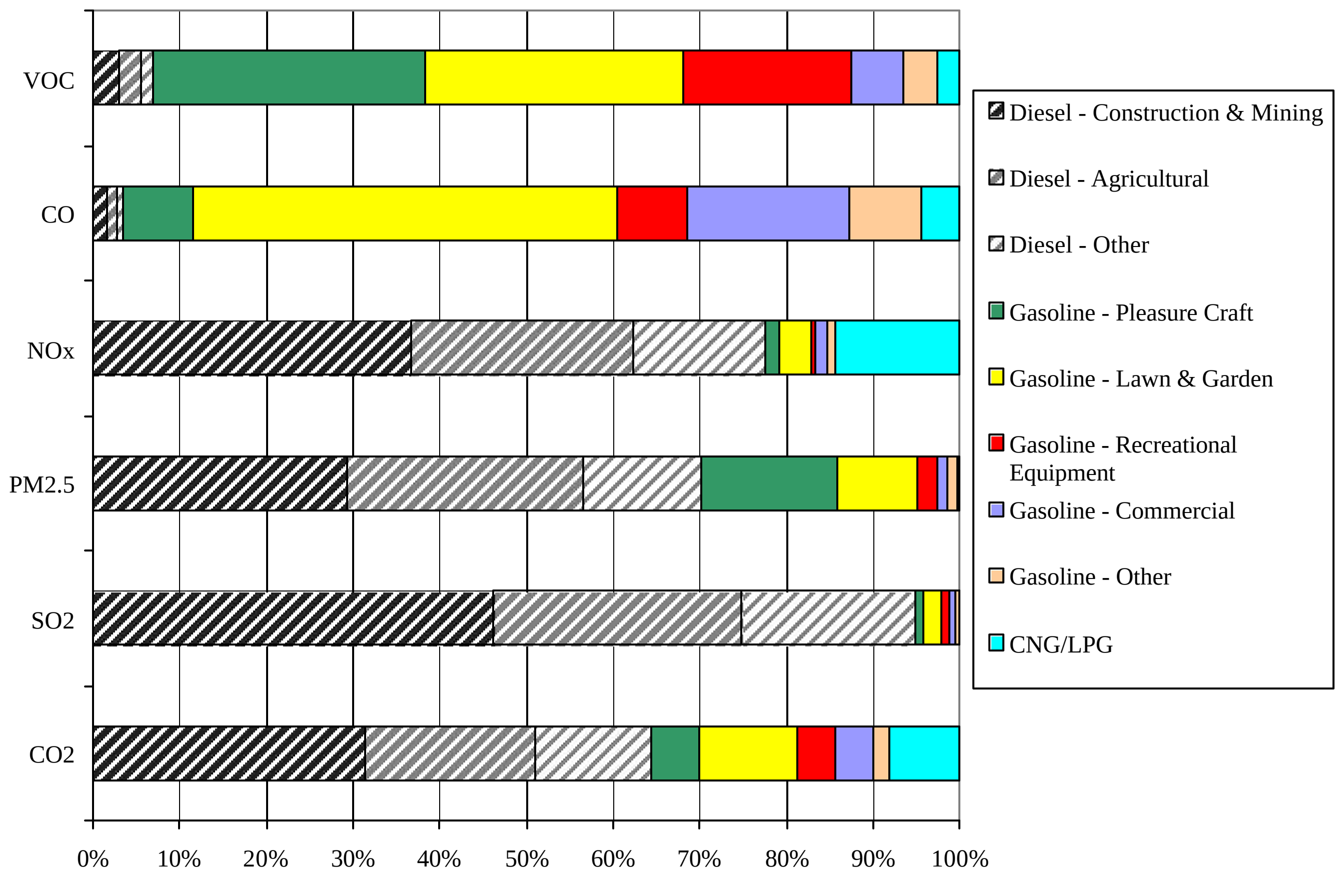
The model's data files include engine populations by state. To estimate emissions at the county level, the model utilizes surrogates (county-specific statistics for population, business types, etc.) to apportion statewide engine populations to counties.[7] To estimate emissions for time periods of less than a year, the model estimates the extent to which activity in different applications occurs in each month with monthly activity distribution dependent on region of the country,[8] and includes information regarding the extent to which each engine application activity occurs during weekdays or weekends.[9] Emissions on shorter timescales (e.g., hourly) are not estimated by NONROAD.

QA of all inputs to and outputs from NONROAD is not likely to be feasible. It is therefore useful to recognize which fuels and applications are most significant in the overall inventory, and therefore which assumptions are the most significant to the overall inventory of nonroad sources.

Most Significant Fuels and Applications

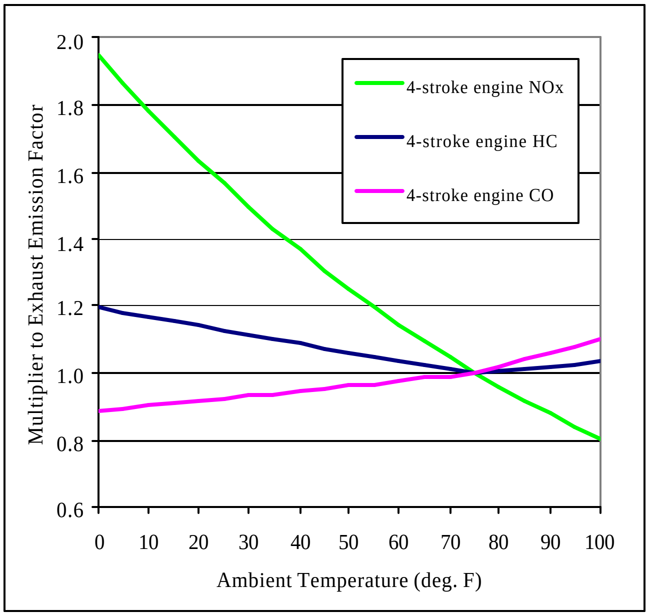
Although inventories for different areas of the country will vary in different ways, certain qualitative characteristics of the NONROAD inventories are likely to hold in many (if not all) areas. Figure 1 illustrates the results of a NONROAD run for the entire United States, using default inputs to the NONROAD model.

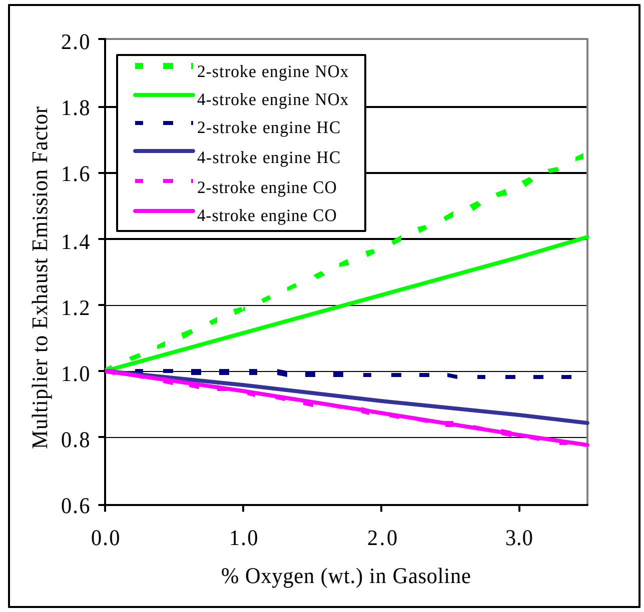
Figure 1. Relative contributions of different fuels and application types to the annual 2002 U.S. NONROAD emission inventory, at default temperatures (average = 75°F, diurnal range 60-84°F), default sulfur contents (0.3% S = 300 ppmw S gasoline, 0.23% S diesel, 0.003% S LPG/CNG), and a gasoline Reid Vapor Pressure of 9.0 psi.



Some regional variabilities can be anticipated: for example, engines in the Agricultural application will contribute significantly more to inventories for rural areas than to those for urban areas, and Pleasure Craft emissions will be negligible in areas where recreational boating is not possible. Ambient temperatures and gasoline volatilities will also vary both temporally and spatially, although NONROAD assumes that these affect only diurnal and refueling VOC emissions (approximately 12% of the total VOC in Figure 1) and exhaust emissions from 4-stroke SI engines (as shown in Figure 2a). The use of oxygenate in gasoline can also have an effect on exhaust emissions from gasoline-fueled equipment (see Figure 2b). However, Figure 1 is a useful benchmark, and in most (if not all) cases, changes to input parameters will not alter the qualitative result that gasoline-fueled SI engines emit an overwhelming majority of the total VOC and CO emissions from the NONROAD sources, and diesel engines emit a majority of the NO_x and $PM_{2.5}$ emissions. Estimates of SO_2 emissions depend primarily on the accuracy of the fuel sulfur input data, and will be significantly affected by the extent to which nonroad engines utilize diesel fuel meeting EPA's 2006 low-sulfur standards for on-road vehicle diesel fuel (15 ppmw = 0.0015%), or gasoline meeting EPA's 2005 low-sulfur standards for on-road vehicle gasoline (30 ppmw = 0.0030%). Sulfates account for approximately 6% of the $PM_{2.5}$ mass emissions in Figure 1; thus, the fuel sulfur content changes will have little effect on the $PM_{2.5}$ emissions.

Figure 2a. (left) Effect of ambient temperature on exhaust emissions from 4-stroke gasoline engines. (Temperature effects are not included for other fuels/engine cycles.)[11] **Figure 2b.** (right) Effect of gasoline oxygen content on exhaust emissions.[12]





The most important source types to focus on may not be those that contribute most to the overall inventory, but those that are being considered for emission reductions. Although it is often considered desirable to estimate emissions conservatively—i.e., to err on the high side—such estimates can result in an overly optimistic estimate of the amount of reductions achieved by a subsequent control measure, which could in turn result in reducing the number of additional control measures pursued.

QA CONSIDERATIONS

Initial Considerations

Clearly, QA should be applied to the model GUI inputs. For example, fuels data should incorporate the fact that fuels utilized in nonroad engines do not necessarily meet requirements for on-road vehicle fuels. Areas with Stage II vapor recovery equipment requirements should probably use efficiencies substantially lower than 95%, to account for both rule effectiveness[10] and the fact that many nonroad vehicles may be fueled at centralized fueling locations that are exempt from Stage II requirements (because of low throughputs). However, given that model results are more dependent on a large number of assumptions that have been incorporated into the model itself, this paper is focusing on the evaluation of these assumptions rather than the GUI inputs.

Overall, the model incorporates several estimates based on relatively little information (some of which are identified above) and some broad assumptions based upon essentially no data (e.g., the assumption that for a given AMS code, the activity data for engines varying in size by three orders of magnitude can be approximated with a single estimate of load factor and operating hours and does not depend upon engine age; and the assumption that fuel sulfur content has no effect upon emissions of NO_x, VOC, or CO due to the limited use of catalysts). This paper focuses on three areas: (1) fuel usage estimates, (2) age distribution information, and (3) emissions assumptions for large SI engines.

Quality Assurance Based on Fuel Usage

Although some survey-based approaches to QA have focused on engine populations and/or the number of hours of operation, it is unlikely that survey respondents will be able to accurately estimate the average load on their engines. QA based on fuel usage eliminates this problem, since fuel usage reflects total engine usage, taking into account the horsepower, load, and other operational parameters. For example, pleasure craft owners may find it easier to estimate the number of times they fueled up their pleasure craft than to estimate hours of operation or engine loads (which are variable). NONROAD calculates fuel consumption in the same manner that it calculates emissions:

Equation (2)

$$\text{Fuel Consumption } (c,a,r) = \text{Engine Population } (c,a,r) * \text{Average Horsepower Rating } (c,r) * \text{Load } (c) * \text{Operating Hours } (c) * \text{BSFC } (c,a,r)$$

where BSFC is the brake-specific fuel consumption (gallons per horsepower-hour). If survey results do not agree with the calculated fuel consumption, NONROAD results may be scaled by the ratio of the surveyed and calculated fuel consumptions. Although this implies an assumption that BSFC data are accurate, this is justifiable given that variations in BSFC data are relatively small. BSFCs for different gasoline-fueled engine technologies may differ by up to a factor of two, but a given engine's BSFC is relatively constant (e.g., EPA determined that available data did not justify the need to adjust BSFC data for SI engines to account for transient operation or age).[13] The variation in BSFCs between all of the diesel engine technologies included in NONROAD vary on the order of only ±10%, and are not affected by engine age; although transient adjustment factors are applied for some applications, these increase fuel consumption by no more than 18%.

For distillate oil (including diesel fuel and other light oils such as those burned in boilers), the U.S. Department of Energy's Energy Information Administration (EIA) tabulates sales information as a function of the application. Although the application categories are defined differently from those in NONROAD, comparisons are possible by combining categories (see Table 3).

Because the EIA fuel include sales to all types of combustion sources including boilers and stationary engines, the EIA values should be higher than NONROAD values. Therefore, if the EIA data are higher than the NONROAD data, nothing can be determined without further data. As shown in Table 3, this is the case for the industrial equipment (which EIA describes as primarily stationary, "largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting").[14]

NONROAD estimates of oil usage by agricultural nonroad engines are essentially identical to the total oil usage identified by the EIA data. NONROAD assumes that a fraction of the agricultural engines were stationary; however, based on the factors in Table 2, the back-calculated fuel usage in stationary agricultural engines (under 600 hp) was only 0.1 billion gallons. Therefore, the agricultural category may be estimated reasonably well overall.

For the category labeled "Construction, Logging, Generators, Compressors, and Other," NONROAD predicts significantly higher oil usage (6.6 billion gallons per year) than the EIA data would indicate (2.4 billion gallons per year), and based on the factors in Table 2, the NONROAD simulation indicates that an additional 1.1 billion gallons of oil are being used by stationary "commercial" engines (pumps, gensets, compressors, etc.) under 600 hp. Of the 6.6 billion gallons of oil usage estimated by

NONROAD, 5.5 billion gallons are attributed to construction. It appears likely that NONROAD is significantly overestimating the amount of oil burned by the construction industry.

Table 3. National distillate oil usage (in billions of gallons) predicted by NONROAD for calendar year 2002 compared to EIA data.[14]

Source Type	NONROAD (fuel used by nonroad engines only)	EIA (fuel used by all combustion sources, including boilers, stationary engines, and nonroad engines)
Agricultural/Farm Equipment	3.4	3.4
Industrial Equipment (including Mining and Oil Field equipment)[a]	1.1	3.2
Construction, Logging, Generators, Compressors, and Other[b]	6.6	2.4
Total[c]	11.1	8.9

[a] NONROAD categories: Industrial Equipment and Other Underground Mining Equipment; EIA sectors: the sum of Industrial and Oil Company

[b] NONROAD categories: Construction and Mining Equipment (minus Other Underground Mining Equipment), Airport Equipment, Commercial Equipment (which consists primarily of generators, pumps, and compressors), Lawn and Garden Equipment, Logging Equipment, and Recreational Equipment; EIA sectors: Off-Highway sector, which specifically includes construction, logging, generators, and compressors.

[c] Excludes Pleasure Craft and Railroad Equipment categories from NONROAD; excludes Residential, Commercial (primarily stationary), Electric Power, Railroad, Vessel Bunkering, On-Highway Diesel, and Military sectors of EIA data.

Because EIA provides sales information by state, this type of QA exercise can be conducted at a localized level. If the EIA data are lower than the NONROAD predictions, it may be desirable to determine the ratio of the two and scale down the NONROAD emissions estimates accordingly. Although this would still be an overestimate—to the extent that the EIA data include information for sources other than nonroad engines—this adjustment would bring NONROAD'S estimates closer to the true values.

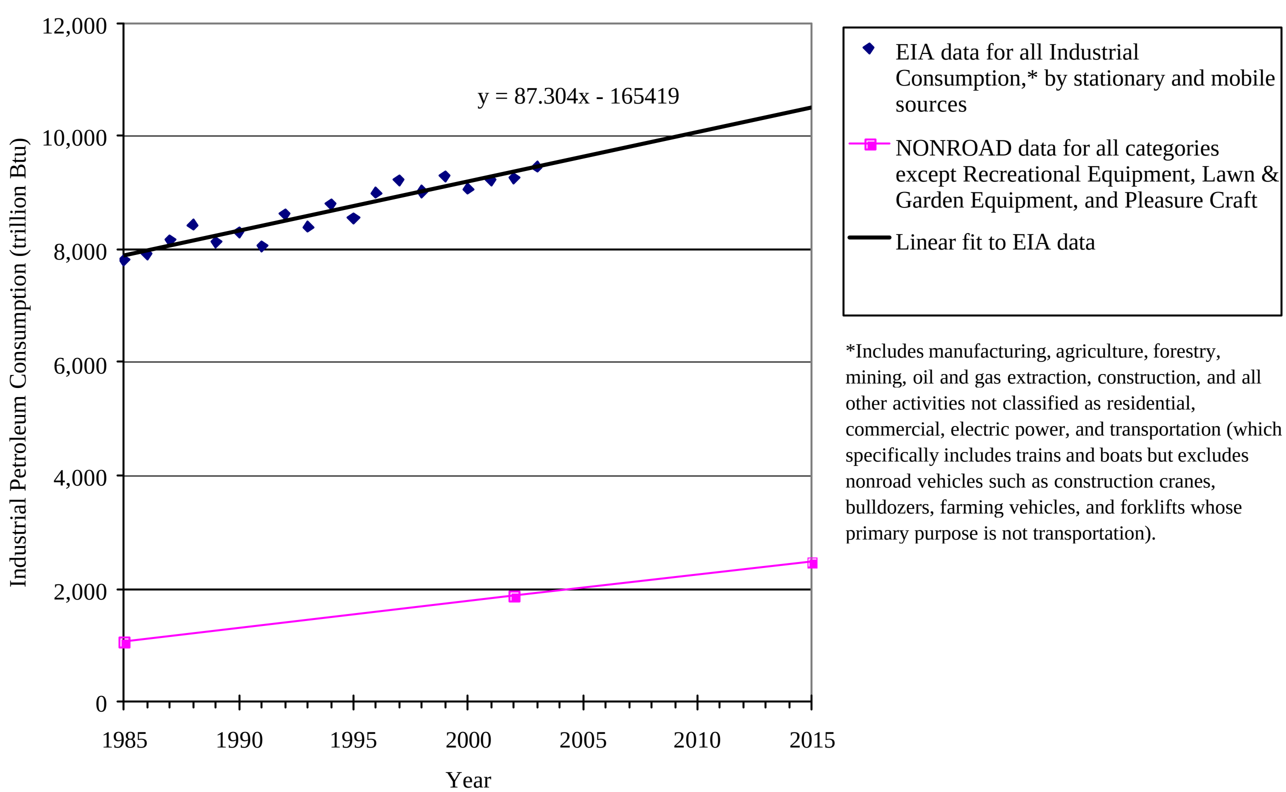
Fuel Usage for QA of Future-Year Projections

For State Implementation Plans (SIPs), the methodology for projecting future emissions can be more important than the methodology used for base-year emissions, given that required emission reductions are typically only a small percentage of base-year emissions. For example, consider a case where the base-year emissions of a pollutant are 200 tons per day (tpd), and assume that it has been estimated that total emissions need to be reduced by 10% by a future date. This emissions reduction target (20 tpd) is affected relatively little by an error of 10 tpd in the base-year emission estimates: i.e., the amount of reductions needed would only change by ±1 tpd. However, if the projected change in emissions between the base year and future year (which should reflect growth and any control strategies) is in error by 10 tpd, that full amount applies directly to the emissions reduction target. If the change in emissions is overestimated by 10 tpd, an additional 10 tpd of emission reductions will be required.

Growth rates vary for different areas, and growth rates derived for a local area are likely to be more accurate for that area than are national growth estimates. However, growth rates are often either not readily available or not sufficiently applicable to emission inventory projections, and EPA guidance regarding the modification of growth rates for nonroad engines is largely unspecific.[15] NONROAD incorporates growth estimates based on national sales data between 1988 and 1996 obtained from PSR, although EPA acknowledges that these growth rates were significantly higher than U.S. Department of Commerce estimates.[16]

Methods of forecasting growth vary (e.g., Chinkin et al.[17]). A relatively simple means of forecasting long-term growth is based on EIA data showing that industrial petroleum consumption has increased approximately linearly since the mid-1980s (see Figure 3). In this case, EIA is defining the "Industrial" sector more broadly than it is defined in Table 3 by including manufacturing, agriculture (including tractors), forestry, mining, oil and gas extraction, construction (including cranes and bulldozers), generators, and anything else that does not fall into the categories of Residential, Commercial, Transportation, or Electric Power. Since the mid-1980s, Industrial petroleum consumption has increased by approximately 87 trillion Btu per year. Using 2002 as a base year, the growth rate is approximately 0.9% per year. For the nonroad subset of industrial sources—all sources except Recreational Equipment, Lawn and Garden Equipment, and Pleasure Craft—NONROAD predicts growth of approximately 48 trillion Btu per year, or, 2.5% of 2002 fuel usage. This discrepancy could be a result of a reduction in activity levels for the nonroad equipment by such circumstances as less time to utilize recreational equipment or lower fuel consumption due to increases in fuel prices, in which case the EIA data would more properly reflect the growth rate for emissions purposes (assuming that activity levels are not changed in the model). Alternatively, the discrepancy could be a result of the growth rate in stationary industrial fuel use being significantly lower than the growth rate in mobile industrial fuel use, in which case the current NONROAD factors are more appropriate than the EIA data. (Note that this could be verified by checking the current growth rates being utilized for area and/or point sources.) However, because the Department of Commerce also estimated significantly lower growth rates than NONROAD, more consideration should be given to lowering the estimated growth rates.

Figure 3. Growth in petroleum usage. (NONROAD fuel usage was converted to Btu assuming that the heating values of diesel, gasoline, and LPG were 140,000 Btu/gal, 130,000 Btu/gal, and 94,000 Btu/gal, respectively.)



A simple means of adjusting NONROAD predictions for a future year might involve projecting future year fuel usage by applying revised growth rates to the fuel usage predicted by NONROAD for the base year, and then scaling down future emission estimates by the ratio of that fuel usage to the future-year fuel usage predicted by NONROAD. However, the more technically correct approach would involve scaling down the application-specific growth rates incorporated into the model's NATION.GRW input file, since these rates are used in calculating engine age distributions.

Age Distributions

Although new regulations for nonroad engines may reduce the extent to which engine age affects emissions through requirements for long-term and/or in-use emission testing, the ages of most existing engines can have a significant effect on the NONROAD Emission Factors (see Table 4). Age distributions for all equipment are calculated on a single S-shaped curve which describes the ages at which equipment are scrapped as a function of their estimated median lifetimes (see Figure 4), combined with application-specific information about equipment lifetimes and nationwide growth in new equipment sales. The resulting age distributions (equipment population levels as a function of age) also tend to be S-shaped (an example is shown in Figure 5).

Table 4. Maximum effect[a] of age upon exhaust emission factors.

	HC	CO	NO_x	PM
2-Stroke Engines < 25 hp	20-77%	20-24%	0%	20-77%
4-Stroke Engines < 25 hp	110-510%	89%-130%	0%	110-510%
Spark-Ignition Engines > 25 hp	15-64%	17-36%	0-15%	15-64%
Diesels	3-5%	10-19%	1-2%	47%

[a] Maximum effect occurs for engines that have reached 100% of the median estimated useful life. Data are from U.S. EPA.[13,18]

The extensiveness of data used to develop Figure 4 is not described in EPA's documentation for the model. For comparison, Figure 6 shows age distributions for on-road mobile sources which are expected to be of higher quality, because annual registration data for on-road sources are computerized. Although the lightest vehicle types exhibit an S-shaped age distribution, heavier vehicles do not. Though the data in Figure 6 cannot be used to QA the nonroad distributions directly, they provide an illustration of how the S-curve may not always be an accurate representation of the true age distribution.

Unfortunately, a true adjustment of the age distribution information in NONROAD would likely require a detailed survey, and the information cannot be input as easily into the NONROAD model as, for example, EPA's MOBILE model. Instead, NONROAD requires inputs of the scrappage curve, growth rates, lifetimes, and operating hour estimates to arrive at an age distribution. For cases where improved age distribution information are available, it may be preferable to (1) modify the NONROAD option file to output age-specific results, (2) read the output file into Excel, and then (3) edit the age distributions manually.

Figure 4. Scrappage curve utilized for all equipment in NONROAD.[19]

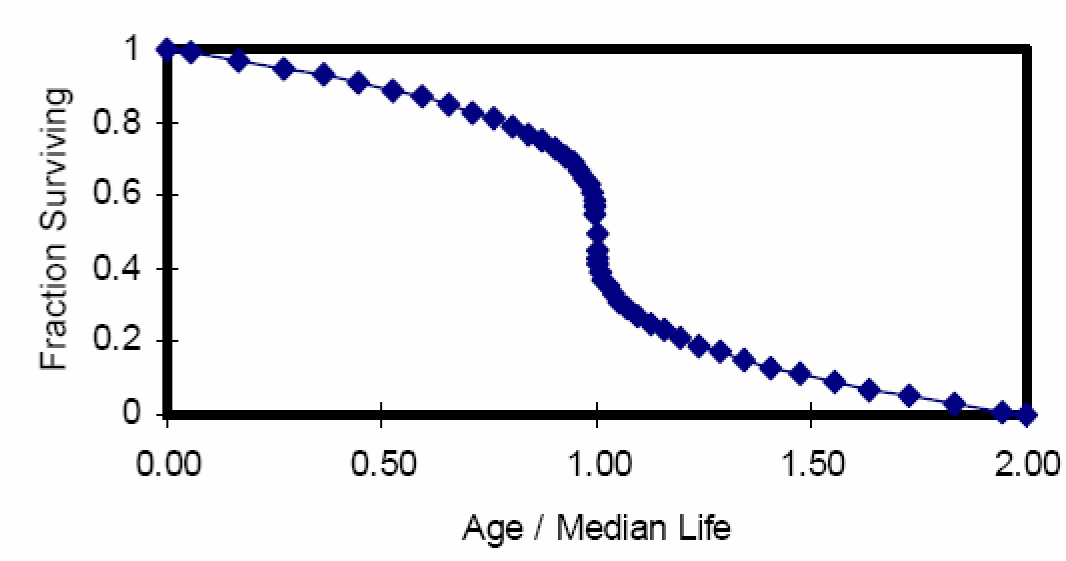


Figure 5. Age distribution for diesel agricultural tractors in the 50-100 hp size range.[19]

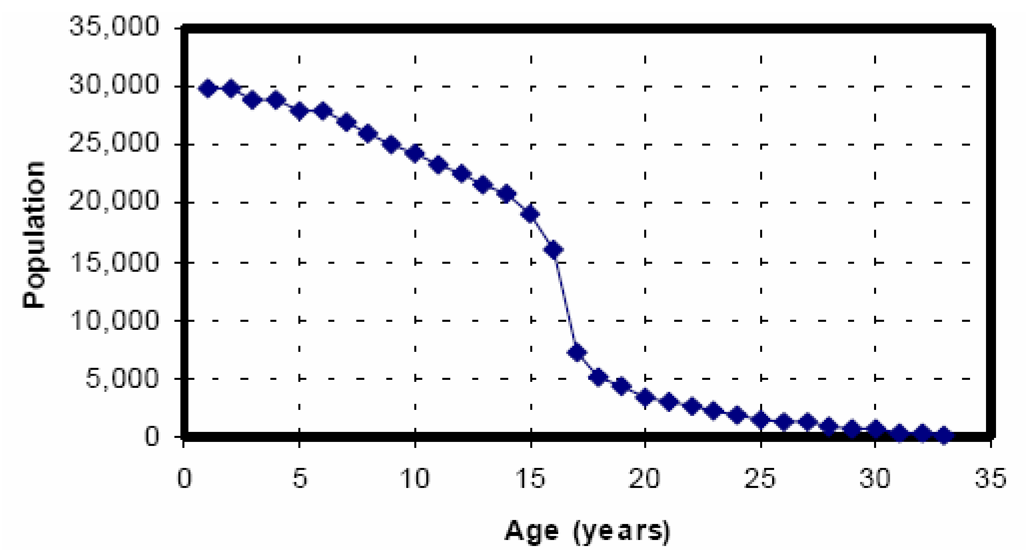
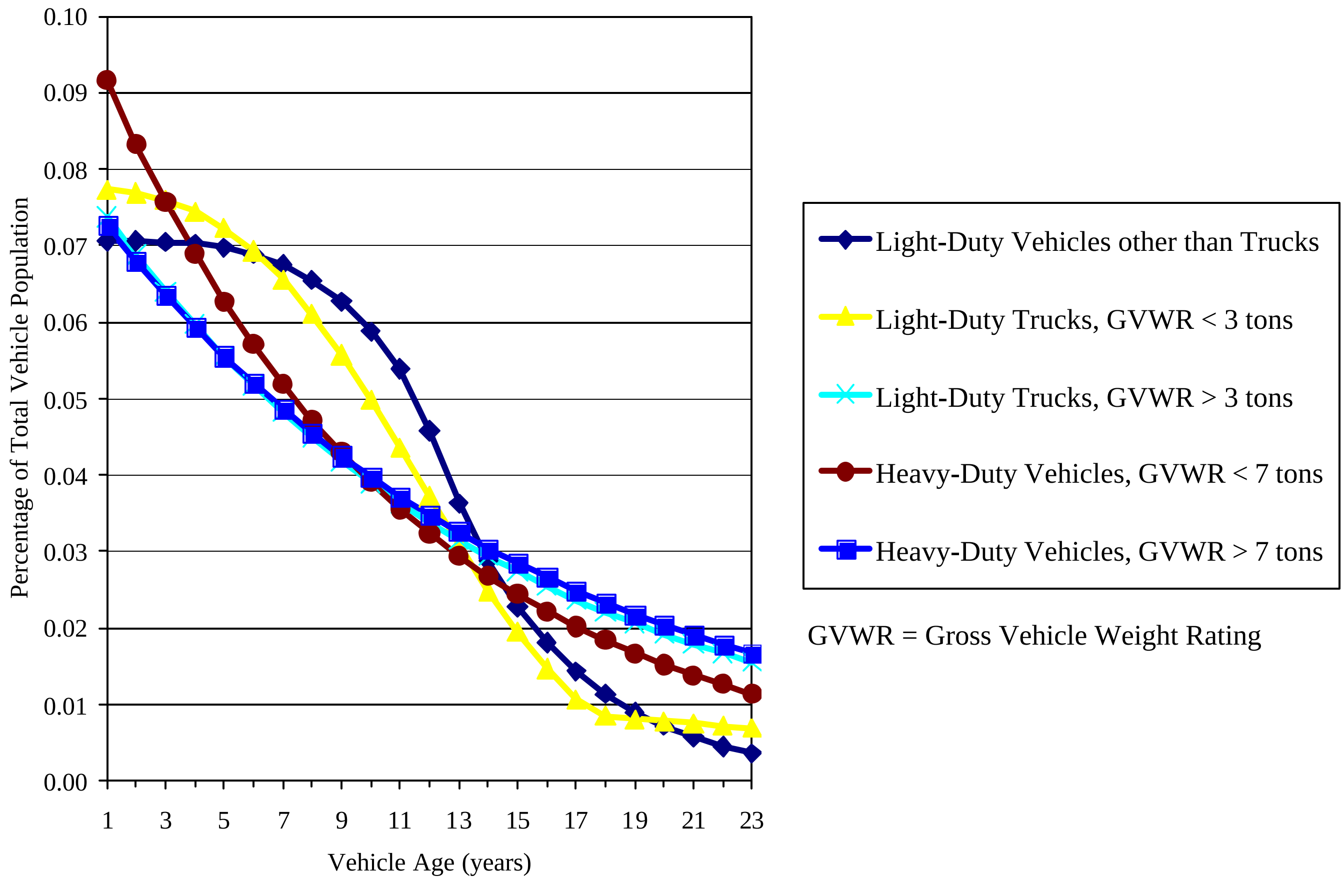


Figure 6. Default vehicle age distributions from EPA's MOBILE6 model.



Age 0 is not shown; data would be skewed because new model years are not sold on July 1, the date when vehicle registration data are assumed to be queried. Age 24 is not shown because MOBILE6 combines all vehicles older than age 24 in one group.

QA for Large SI Engines

EPA was able to use relatively extensive emissions data (e.g., from engine certification testing) to develop emission factors for diesel engines and small (< 25 hp) SI engines. However, large SI engines (> 25 hp) account for 40% of the total VOC emissions from gasoline-fueled engines shown in Figure 1, and exhaust emission factors for these engines were based on very limited data.

NONROAD assumes that the emission factors for large SI engines (see Table 5) are the same for all applications. Emission factors for 2-stroke engines are based on uncited "new engine emission factors" from 1991,[20] and emission factors for CNG-fueled engines were assumed to be the same as those for LPG-fueled engines. In the case of hydrocarbons, it was assumed that CNG-fueled engines had the same non-methane hydrocarbon (NMHC) emissions as LPG-fueled engines.[21] EPA cites a 1991 publication[20] as the source of the PM emission factor of 0.06 g/hp-hr for 4-stroke gasoline-fueled engines, although that publication lists PM emission factors ranging from 0.06 to 5.18 g/hp-hr). The PM emission factor for LPG-fueled engines cites the same publication, noting that PM emissions were reduced 13% when LPG, rather than gasoline was utilized in a 4.5 hp walk-behind mower.

Table 5. Emission factors assumed for large SI engines in NONROAD, expressed in grams per horsepower-hour (g/hp-hr). (Emission factors do not include adjustments for ambient temperature, gasoline oxygenate content, transient operation, or age.)

Engine Type	VOC[a]	CO	NO_x	PM
2-stroke gasoline-fueled[b]	215.1	486	0.29	7.7
4-stroke gasoline-fueled[c]	5.8 (±6)	203.4 (±267)	7.13 (±5)	0.06
LPG-fueled[d]	1.7 (±0.7)	28.23 (±50)	11.99 (±4)	0.05
CNG-fueled[e]	0.1	28.23	11.99	0.05

[a]Determined by multiplying HC emission factors by NONROAD VOC/HC ratios for each technology.[22]
[b]Emission factors are based on uncited "new engine emission factors" identified in a 1991 report.[20]
[c]HC, CO, and NO_x emission factors are based on an unweighted average of seven test program results for six different engines. Uncertainties shown are the standard deviations of the data.[23] For PM, the reference cited by EPA[20] identified PM emission factors ranging from 0.06 to 5.18 g/hp-hr [24].
[d]HC, CO, and NO_x emission factors are based on an unweighted average of seven test results for six different engines. Uncertainties shown are the standard deviations of the data.[23] PM emission factor based on that for 4-stroke gasoline engines, and the fact that PM emissions were reduced 13% when LPG rather than gasoline was used in a 4.5 hp walk-behind mower engine.[20]
[e]Assumed to be the same as LPG, except that VOC emissions differ due to different assumptions about HC speciation.[22]

Only the VOC, CO, and NO_x factors for 4-stroke gasoline-fueled and LPG-fueled engines appear to be based on multiple tests; and for each of these technologies, the factors represent the averages of seven test program results, conducted on engines (some of which had been modified by the testers) running on different test cycles. The standard deviations of these averages ranged from 33% to 177%. The factors shown in Table 5 were used in EPA's Draft Regulatory Support Document (RSD) for the regulation of large SI engines.[21] However, the VOC, CO, and NO_x factors were changed in the subsequent Final RSD (see Table 6) to reflect "a population-weighted average of water-cooled and air-cooled average emission levels, assuming air-cooled engines are 3% of all large spark-ignition engines, or 13% of gasoline large spark-ignition engines".[25] Therefore, at a minimum, results for these engines should be adjusted by the ratio of the factors in Tables 5 and 6. A more detailed QA analysis could involve investigation of the prevalence of lean-burn vs. rich-burn engines and comparison of emission factors to those in EPA's AP-42 compilation.[26-28]

Table 6. Revised emission factors for 4-stroke gasoline fueled engines > 25 hp.[25]

	VOC	CO	NO_x
4-stroke gasoline-fueled	3.6[a]	107.2	8.4

[a]Determined by multiplying the THC emission factor of 3.9[25] by EPA's VOC/THC ratio of 0.933.[22]

The California Air Resources Board (CARB) required that new large SI nonroad engines eliminate crankcase emissions entirely by 2001, and phased in standards for new large SI nonroad engines between 2001 and 2003, requiring that the sum of hydrocarbon (HC) and NO_x emissions be no more than 3.0 g/hp-hr. In fall 2002, CARB estimated that most diesels were already well ahead of the phased-in regulatory standards,[29] and given that at least some manufacturers may have been selling these engines nationwide, the average VOC and/or NO_x emission factors in 2002 (the base year for the latest round of emission inventories) were probably lower than those indicated by either Table 5 or Table 6. However, no data are readily available to quantify the extent to which this is the case.

Both CARB and EPA require 100% of new large SI engines to meet the Tier 1 standard (3.0 g/hp-hr) beginning in 2004, and the Tier 2 standard (2.0 g/hp-hr), which will apply in 2007. Neither of these requirements are accounted for in NONROAD currently, and future-year inventories will need to reflect this fact. EPA has recommended that model users either refer to the Final RSD[30] or wait for the final version of NONROAD.[1]

Table 5 shows the extent to which 4-stroke SI engines using gasoline or LPG/CNG can have a significant impact upon emissions. The NONROAD model assumes all engines smaller than 25 hp are gasoline-fueled, and establishes a rough fuel breakdown for engines larger than 25 hp (shown in Table 7). Even very limited surveys might yield more accurate information than the assumptions shown in Table 7, since the documentation indicates these assumptions were not based on a significant amount of information.[3]

Table 7. NONROAD assumptions about fuel types in SI engines larger than 25 hp, for the calendar years that population data are incorporated into the model (late 1990s); future-year distributions are affected by different growth rate assumptions for the different fuel types. (All SI engines smaller than 25 hp are assumed to be gasoline-fueled.)[3]

Application type	% Gasoline-Fueled	% LPG or CNG-fueled
Recreational		
Specialty vehicles/carts	50%	50%
All others	100%	0%
Construction & Mining		
Tampers/Rammers, Plate Compactors, Signal Boards/Light Plants, Cement & Mortar Mixers, Dumpers/Tenders	100%	0%
All others	50%	50%
Industrial		
Forklifts	5%	95%
Refrigeration/AC	0%	100%
All others	50%	50%
Lawn and Garden		
Chippers/grinders	50%	50%
All others	100%	0%
Agricultural		
Hydro Power Units, Irrigation Sets	50%	50%
All others	100%	0%
Commercial		
Generators, Gas Compressors	0%	100%
All others	50%	50%
Logging	100%	0%
Aircraft Ground Support	50%	50%
Underground Mining	N/A[a]	N/A[a]
Oil Field Equipment	0%	100%
Pleasure Craft	100%	0%
Railroad Maintenance Equipment	50%	50%

[a]No SI engines were identified for this application type.

QA of Specific Applications

A number of additional QA considerations pertain to NONROAD runs, not all of which can be discussed in detail here. Spatial and temporal allocation factors can be important, and are often addressed by survey-based approaches; CARB has developed alternative surrogates to those incorporated into NONROAD.[31] To the extent that surveys are used to replace NONROAD results for specific categories, care needs to be taken that emissions from the proper source types are revised to prevent doublecounting or omitting a source type. Although most AMS codes were defined in a stratighforward manner, others are not; for example, pumps, compressors, and gensets are all classified as "commercial" by NONROAD even though they are also used in industrial operations. EPA has specifically identified how PSR engine categories were mapped into the AMS codes;[3] therefore, PSR's pictorial booklet of nonroad source types[32] can be useful for providing more specific information. For example, although both PSR and EPA have "aircraft ground support" equipment categories, the PSR booklet clearly shows that terminal tractors used for pushing aircraft were not included in that category, and EPA's documentation shows that tractors were instead incorporated into the "Industrial" category. Though such definitional issues may not be significant for the inventory as a whole, they can be important when individual sections of the inventory are being investigated; for example, one study of emissions from airport ground support equipment included a significant contribution from pushback tractors.[33]

CONCLUSIONS

Several assumptions incorporated into the NONROAD model deserve additional investigation. Nationwide, the diesel fuel usage estimated for construction equipment is more than twice the amount estimated by the EIA. It is not known whether this discrepancy is due primarily to errors in engine population data (which could in turn be a result of scrappage assumptions) or activity data. Growth rates in industrial petroleum usage (starting with calendar year 2002 as a base year) are also estimated to be significantly higher by the model (2.5% per year) than data over the last 20 years indicate (0.9% per year).

With respect to emissions, the most significant assumptions and most limited data are associated with SI engines larger than 25 hp, that account for approximately 40% of the total NONROAD inventory of VOC and CO emissions. Assumptions about the fuels used in these engines appear to be qualitative (i.e., based on little or no actual data), and emission factors are based on the averages of very few tests (with standard deviations ranging from 33% to 177%). (Emission factors for 4-stroke gasoline-fueled SI engines are also significantly different than those in the Final RSD.) Recent regulations that probably affect the 2002 inventory have also not been taken into account.

Because the issues identifies here are significant to both the baseline inventory and future projections, we recommend that EIA data be used to adjust NONROAD inventories based on calculated fuel usage, that limited surveys be conducted to check the extent to which engines are mobile or stationary (see Table 2) and the fuels used in large SI engines (Table 7). Emission factors for large SI engines should also be corrected to match the final RSD.

REFERENCES

1. Tierney, G., Cook, L.H. "Public release of the Draft NONROAD2002a emissions inventory model"; Memorandum to regional mobile source program officers and staff 2003.
2. ENVIRON International Corporation. "User's guide for the EPA nonroad emissions model draft NONROAD 2002"; EPA420-P-02-013, Prepared for the U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI, by ENVIRON International Corporation, Novato, CA. 2002.
3. U.S. Environmental Protection Agency. "Nonroad engine population estimates"; EPA420-P-02-004, Report No. NR-006b, 2002.
4. Booz Allen Hamilton Inc. "Off-road mobile equipment emission inventory estimate"; Prepared for the California Air Resources Board, Sacramento, CA by Booz Allen Hamilton Inc., Los Angeles, CA. 1992.
5. Bowditch, F. W. "The automobile and air pollution", Presented at Society of Automotive Engineers Mid-Year Meeting, Milwaukee, WI, May, 1968; SAE Paper No. 680242.
6. U.S. Environmental Protection Agency. "Basic evaporative emission rates for nonroad engine modeling"; EPA420-P-02-002, Report No. NR-012a, 2002.
7. U.S. Environmental Protection Agency. "Geographic allocation of state level nonroad engine population data to the county level"; EPA420-P-02-009. Report No. NR-014b, 2002.
8. U.S. Environmental Protection Agency. "Seasonal and monthly activity allocation fractions for nonroad engine emissions modeling"; EPA420-P-02-010, Report No. NR-004a, 2002.
9. U.S. Environmental Protection Agency. "Weekday and weekend day temporal allocation of activity in the nonroad model"; EPA420-P-99-033. Report No. NR-015, 1999.
10. U.S. Environmental Protection Agency. "Technical guidance – Stage II vapor recovery systems for control of vehicle refueling emissions at gasoline dispensing facilities, vol. I – chapters"; EPA-450/3-91-022a, Report prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emission Standards Divisions (MD-13), Research Triangle Park, NC. 1991.
11. U.S. Environmental Protection Agency. "RVP and temperature corrections for nonroad engine modeling"; EPA420-P-02-011, Report No. NR-001a, 2002.
12. U.S. Environmental Protection Agency. "Exhaust emission effects of fuel sulfur and oxygen on gasoline nonroad engines"; EPA420-P-02-012, Report No. NR-003a, 2002.
13. U.S. Environmental Protection Agency. "Spark-ignition engine emission deterioration factors for the draft NONROAD2002 emissions model"; EPA420-P-02-019, Report No. NR-011a, 2002.
14. Energy Information Administration. "Fuel oil and kerosene sales 2002"; DOE/EIA-0535(02), Report prepared by the Energy Information Administration Office of Oil and Gas, U.S. Department of Energy, Washington, DC. 2003.
15. Pechan-Avanti Group. "Emission Inventory Improvement Program (EIIP) document series: Volume X, emission projections"; Report prepared for Projections Committee, Emission Inventory Improvement Program by The Pechan-Avanti Group, Springfield, VA. 1999.
16. U.S. Environmental Protection Agency. "Nonroad engine growth estimates"; EPA420-P-02-018, Report No. NR-008b, 2002.
17. Chinkin, L. R.; Haste, T. L.; Coe, D. L.; Puri, A. K.; Hall, J. V.; Levy, S. "Emission inventory projection project", Presented at Air & Waste Management Association's Emission Inventory: Living in a Global Environment, New Orleans, LA, December 8-10, 1998; STI 1840.
18. U.S. Environmental Protection Agency. "Exhaust and crankcase emission factors for nonroad engine modeling - compression-ignition"; EPA420-P-02-016, Report No. NR-009b, 2002.
19. U.S. Environmental Protection Agency. "Calculations of age distributions in the nonroad model: growth and scrappage"; EPA420-P-02-017, Report No. NR-007a, 2002.

20. U.S. Environmental Protection Agency. "Nonroad engine and vehicle emission study-report"; EPA 460/3-91-02, 1991.
21. U.S. Environmental Protection Agency. "Draft regulatory support document: control of emissions from unregulated nonroad engines"; EPA420-D-01-004, 2001.
22. U.S. Environmental Protection Agency. "Conversion factors for hydrocarbon emission components"; EPA420-P-03-002, Report No. NR-002a, 2002.
23. White, J. J.; Ingalls, M. N.; Carroll, J. N.; Chan, L. "Three-way catalyst technology for off-road equipment powered by gasoline and LPG engines"; Contract No. 95-340, Final report prepared for California Air Resources Board, Sacramento, CA by Southwest Research Institute, San Antonio, TX. 1999.
24. U.S. Environmental Protection Agency. "Compilation of air pollutant emission factors, AP-42, Vol. II and supplements thereto: mobile sources, 4th ed." Report prepared by U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Test and Evaluation Branch, Motor Vehicle Emission Laboratory, Ann Arbor, MI. AP-42-ED-4-VOL-2. 1985.
25. U.S. Environmental Protection Agency. "Final regulatory support document: control of emissions from unregulated nonroad engines"; EPA420-R-02-022, 2002.
26. U.S. Environmental Protection Agency. "Compilation of air pollutant emission factors, AP-42. Vol. 1: stationary point and area sources. Section 3.2. Natural gas-fired reciprocating engines"; Report prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. 2000.
27. U.S. Environmental Protection Agency. "Compilation of air pollutant emission factors, AP-42. Vol. 1: stationary point and area sources. Section 3.3. Gasoline and diesel industrial engines"; Report prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. 1996.
28. U.S. Environmental Protection Agency. "Compilation of air pollutant emission factors, AP-42. Vol. 1: stationary point and area sources. Section 3.4. Large stationary diesel and all stationary dual-fuel engines"; Report prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. 1996.
29. California Air Resources Board "Off-road status review", Presented, 2002
30. U.S. Environmental Protection Agency. "Frequently asked questions: Draft NONROAD2002a emission inventory model"; EPA420-F-03-023, 2003.
31. Energy and Environmental Analysis, Inc. "Documentation of input factors for the new off-road mobile source emissions inventory model"; Prepared for the California Air Resources Board, Sacramento, CA, by Energy and Environmental Analysis, Inc., Arlington, VA. 1997.
32. Power Systems Research. "OE Link for windows: OE product guide, version 1.2"; 1998.
33. Sierra Research, Inc. "Technical support for development of airport ground support equipment emission reductions"; EPA420-R-99-007, Report prepared for the U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, by Sierra Research, Inc., Sacramento, CA. 1999.

KEY WORDS

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