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EPA's Newest Draft Nonroad Emission Inventory Model

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ABSTRACT

The EPA is developing a mobile source emissions inventory model for nonroad equipment (NONROAD), which covers all equipment except locomotives, aircraft, and commercial marine vessels. The model will provide a tool for EPA, States, regional air pollution organizations, and local air pollution control agencies to use in estimating pollution from nonroad equipment for State Implementation Plans (SIPs), as required by the 1990 Clean Air Act Amendments and other regulatory needs. This paper briefly describes the most current draft of the NONROAD model and how it version differs from prior versions. Nationwide model outputs are presented and compared for HC, CO, NOx, PM, SOx (SO_2), and fuel consumption, for diesel and for spark-ignition engines. In some cases, such as PM and SOx, the revised model projections are substantially different from earlier draft versions of the NONROAD model.

INTRODUCTION

The draft NONROAD model predicts emissions of exhaust, diurnal, and refueling hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), sulfur oxides (SOx), exhaust particulate matter (PM), carbon dioxide (CO2), as well as volume of fuel consumed by all types of mobile nonroad equipment except locomotives, aircraft, and commercial marine vessels. The level of detail from the model includes fuel type (diesel, gasoline, LPG, and CNG), individual Source Category Classification (SCC), power range, geographic area (nationwide, state, or county), and temporal (annual, seasonal, monthly, weekday/weekend) for calendar years 1970 to 2050.

During the model development process a number of model versions have been released for public comment and used in EPA rulemaking inventory estimates. The Draft EPA NONROAD2002 emission inventory model was distributed for a limited secure review to State and local air agencies in December 2002.

The purpose of this paper is to describe the major changes in this version of the model relative to the previously released draft version (June 2000, "HD07" used in the 2007 heavy-duty highway diesel rulemaking) and to present the resulting changes in predicted emission inventories. Although there have been various draft versions of the model, the focus of this paper is the comparison to the June 2000 HD07 draft version of NONROAD, since that was the last one to be publically released, and it has been used by some state/local governments, industry trade associations, and others interested in emissions and air quality analysis.

It should be noted that these comparisons do not include the effects of the September 2002 Final Rule for Recreational Vehicles, Large Spark-Ignition Engines, and Diesel Recreational Marine Engines over 50 Hp. Also, the inventory comparisons presented here do not include any controls associated with the nonroad diesel Notice of Proposed Rulemaking that is planned for spring of 2003. The rulemaking support documentation will provide a description of model and inventory changes related to those proposed controls.

This paper will first present brief descriptions of the input and code changes incorporated into draft NONROAD2002, and then it will show the net effects of these changes on nationwide emission inventories. For a more detailed explanation of all the individual model changes one can consult the November 5, 2002, workshop presentation materials[1].

BODY

Model Changes: Diesel Inputs

Emission Factors (EFs)

For HC, CO, and NOx, the exhaust emission factor for a given diesel equipment type in a given model year/age is calculated as follows:

Equation (1) $$EF_{adj(HC,CO,NOx)} = EF_{ss} \times TAF \times DF$$

where

$EF_{adj(HC,CO,NOx)}$ = final emission factor used in model, after adjustments to account for transient operation and deterioration (g/hp-hr)

EF_{ss} = zero-hour, steady-state emission factor (g/hp-hr)

TAF = transient adjustment factor (unitless)

DF = deterioration factor (unitless)

The zero-hour, steady-state emission factors (EF_{ss}) are mainly a function of model year and horsepower category, which defines the technology type. The transient adjustment factors (TAFs) vary by equipment type. The deterioration factor (DF) is a function of the technology type and age of the engine.

Since PM emissions are dependent on the sulfur content of the fuel the engine is burning, the equation used for PM is slightly modified from Equation (1) as follows:

Equation (2) $EF_{adj(PM)} = EF_{ss} \times TAF \times DF - S_{PMadj}$

where

S_{PMadj} = adjustment to PM emission factor to account for variations in fuel sulfur content (g/hp-hr)

Compared to the June 2000 version, the new version uses updated EF_{ss} estimates for Tier 1 and later engines. For Tier 1 engines and 300-600 hp Tier 2 engines, the EF_{ss} estimates were updated using the latest certification data. For other Tier 2 engines and Tier 3 engines for which certification data are not yet available, five options were considered for each combination of pollutant/hp/tier, including:

1) Examine the likely impact of expected technology changes.
2) Assign an emission factor from another hp category.
3) Continue to use Tier 1 or Tier 2 EF_{ss}.
4) Reduce the regulatory standard by a compliance margin derived from highway engines.
5) Apply a default compliance margin of 10 percent.

The resulting impact of revised EF_{ss} estimates varied in both direction and magnitude depending on the pollutant, tier, and horsepower category of the engines.

Transient adjustment factors (TAFs) are used to account for how engine speed and load variations in the field affect emissions. The TAFs are estimated by collecting emission measurements on specific engines using both transient and steady-state cycles, and calculating the ratio given in Equation (3) below.

Equation (3) $TAF = EF_{transient} / EF_{ss}$

where

$EF_{transient}$ = measurement for a given engine on a specific transient cycle (g/hp-hr)

EF_{ss} = corresponding measurement for the same engine on the 8-mode certification steady-state test cycle (g/hp-hr)

Data from seven transient cycles were used to develop seven TAFs for each of the four pollutants. The seven cycle TAFs were then binned into two categories based on the cycle load factors. TAFs were then assigned to each equipment type in the model on the basis of engineering judgment. If steady-state operation was typical of an equipment type, no adjustment was made (i.e., TAF = 1.0).

Compared to the June 2000 version, the new TAFs incorporate data from additional tests using an excavator cycle. In addition, the binning by load factor category is a new approach which was thought to be more reasonable given the limited cycle test data available. Also, lacking a transient certification test requirement, Tier 3 engine designs using EGR are likely to produce higher transient emissions. As a result, for Tier 3 engines the new PM TAFs are increased by 20 percent and the new NOx TAFs by 10 percent. As with EF_{ss}, the effect of the revised TAFs vary in both direction and magnitude depending on the pollutant, tier, and equipment type.

Deterioration factors (DFs) are used to attempt to account for age-related deterioration. The June 2000 version uses very low DFs for all pollutants based on highway engine certification data in MOBILE6. For HC, CO, and NOx, the new version continues to use DFs based on highway certification data for well maintained engines. This was done based on the belief that maintenance and tampering issues do not greatly affect the emission rates of these pollutants. Since maintenance and tampering are thought to affect PM more dramatically, the PM DF from the California Air Resources Board's OFFROAD model was adopted, since it attempts to account for deterioration due to maintenance and tampering. The new PM DF is larger than that used in the June 2000 version of the model.

Load Factor (LF)

Load factor represents the average fraction of rated power that an engine uses during operation in any given type of equipment. For the new model, diesel load factors were derived from the results of the same transient cycle test data used to develop the TAFs. Specific load factors for the seven cycles fell into two broad groups, designated as "high" and "low" as shown in Table 1. An average LF was calculated for each group, with the high group containing four LFs and the low group three; resulting LFs were 0.59 for the high group and 0.21 for the low group. One of these two LFs was assigned to each equipment type for which we believed engineering judgment was sufficient to make an assignment. For the remaining equipment types, a "steady-state" load factor was assigned, calculated as the average of the load factors for all seven transient cycles. Of the 90 diesel applications in the model, half were assigned "high" or "low" LFs, with the remainder assigned "steady-state" LFs. Compared to the June 2000 version, the new LFs tend to be lower, with the magnitude dependent on the specific equipment type.

Median Life

Median (expected) useful life inputs, expressed in terms of hours of use at full load, are used in the model to estimate the timing of fleet turnover to newer equipment as older equipment is scrapped. Additionally, for this new version of the model these median life inputs are used to generate the initial base year diesel equipment populations, in conjunction with available sales histories and scrappage assumptions as described in the Equipment Population section below.

In prior draft versions of NONROAD the median life estimates of most equipment (CI and SI) came from the California Air Resources Board (ARB) OFFROAD model. As a result of a more thorough review of the basis for these values, EPA determined that modifications to the median life estimates were appropriate. Table 2 shows the prior median life inputs compared to the new ones as well as the EPA regulatory useful life values that are used for purposes of emissions certification and recall.

Equipment Populations

Draft NONROAD2002 incorporates a number of significant changes affecting CI equipment populations. In order to maintain consistency between population estimates and the revised model inputs for load factor and median life, instead of using the 1998 PSR populations directly, EPA used PSR historical sales estimates in conjunction with the latest model input values and the default scrappage curve to calculate the 1998 base year diesel populations. The 1998 populations are a sum of equipment in operation from model years 1948 through 1998, based on a backcast extrapolation of sales data from 1973.

Model Changes: Spark-Ignition Inputs

Equipment populations and certain other model inputs for snowmobiles, ATV's, off-road motorcycles, and forklifts were updated following the June 2000 draft model release. This was generally due to the acquisition of new sales, activity, and/or emission test data in preparation for the proposed and final rules for recreational vehicles and other spark-ignition equipment.

There were also modifications to the calculation of evaporative emissions, most notably refinements to the fuel tank size inputs for most SI equipment, which affect refueling spillage loss estimates, and to the vapor displacement equation, which was updated to match what has been used by EPA for highway vehicles.

One other specific change worth noting is a substantial decrease in the estimated population of large (greater than 6 hp) commercial chain saws (from the unrealistic estimate of about 1.4 million to about 30,000 units) . Since these are relatively large 2-stroke engines, this results in a significant reduction in overall spark-ignition HC and PM inventories.

Model Changes: Code Modifications

Quality assurance reviews of the model revealed a few calculations that were either incorrect or in need of enhancement. The most significant of these were the PM and SOx calculations, for which the equations in the code were not correct.

PM Calculation

The equation used to calculate exhaust PM in the model was incorrect in three ways:

1) It was missing Load Factor.
2) It was missing Horsepower.
3) The correction for addition of sulfate PM from fuel sulfur was off by a factor of 100.

The effects of these problems on estimated PM varied depending on the horsepower mix of engines, the in-use fuel sulfur level, and the calendar year being modeled, since that determines the mix of engine technologies with different base (certification) fuel sulfur levels. But in general the net result of correcting this calculation is a substantial decrease in estimated PM.

Related to sulfate PM calculation, an additional enhancement is the addition of different base sulfur inputs for different diesel engine technologies. This allows more accurate modeling of Tier 2 and later engines, which are tested on lower sulfur fuel than the 3300 ppm that had been assumed in prior model versions. These inputs appear in the /Base PM Sulfur/ packet of the Options (.OPT) file, but most users should have no reason to modify the default inputs; thus these do not appear as options in the graphic user interface (GUI).

SOx (SO_2) Calculation

The equation used to calculate SOx emissions from all CI and SI engines was missing the Load Factor. Correcting this calculation has the effect of reducing estimated SOx inventories on the order of 40 percent.

Scrappage and Age Distribution

Prior versions of NONROAD attempted to calculate each model year's population in a given calendar year using a multi-step process that first applied scrappage to the existing fleet and then added enough new engines to meet the predicted total population accounting for growth. Unfortunately, this calculation did not account for all the factors needed to make it work properly. Most notably, the age distribution of the base year fleet population (before application of any growth) did not in itself account for the effects of past growth. In a case where future growth is expected to be relatively high (e.g., 3 percent per year), the result was an unrealistic spike in expected new engine sales (i.e., an unrealistically high proportion of brand new engines in the age distribution). This effect is shown in the dotted line of Figure 1. To deal with this a new simplified method of calculating the age distribution has been incorporated into the model. The steps are:

1) Use the growth inputs to calculate the expected equipment population in the desired calendar year.
2) Apply the default age distribution based on the input scrappage curve and no growth.
3) Adjust this age distribution based on the initial growth rate in the growth input file.

The solid line of Figure 1 shows the resulting age distribution of this new method for the same equipment population.

Model Changes: Geographic Allocation

Some effort has been made in the new model to improve the geographic allocation methodology for certain types of equipment, namely construction equipment, snowblowers, and recreational marine vessels. These changes do not affect the national total inventory projections, but they may be of interest to state and local air quality planners.

Construction Equipment

Prior versions of NONROAD used data on the total dollar value of construction to allocate construction equipment populations to the county level. For the draft NONROAD2002 model this method has been refined in an effort to account for differences in equipment activity per dollar value of construction for different types of construction. The construction value database used by EPA includes separate dollar values for residential, commercial, and industrial building construction, as well as road and other public works-related heavy construction. Although the construction of residential, commercial, and industrial buildings accounts for a large portion of the total dollar value of construction, road and other types of heavy construction constitute a much larger share of actual equipment activity per dollar valuation.

Therefore, EPA has modified the allocation method to weight the various categories of the construction value based on a survey findings of construction activity versus dollar value. The equation used is shown below.

Equation (1) $$\text{Allocation Factor}_j = (SFH_j + 3*OBLDG_j + 18.4*R\&B_j + 8.5*PW_j) / (SFH + 3*OBLDG + 18.4*R\&B + 8.5*PW)$$

Where

variables are the dollar valuation for the county (j) or US total

j	= county of interest
SFH	= for single/double-family housing construction,
OBLDG	= for other building construction,
R&B	= for road and bridge construction, and
PW	= is public works (sewer, water, and drainage) construction.

Snowblowers

Due to time and resource constraints the June 1998 draft version of the model could only estimate national annual snowblower emissions, but snowblower populations at the state and county levels were set to zero to avoid misallocation problems. In subsequent model versions prior to draft NONROAD2002 snowblower populations were assigned to states based on snowmobile registration data. The model then allocated the snowblowers to the county level using the same factors used to allocate other types of lawn and garden equipment. This method has now been further refined.

The allocation of snowblowers in the draft NONROAD2002 model involves estimating which counties in the U.S. receive enough snowfall to justify the use of snowblowers. These counties were chosen using a map of average annual snowfall along with a minimum snowfall limit of fifteen inches. The same allocation factors used for other residential or commercial lawn and garden equipment were used to allocate the national snowblower population to the state and county level, ignoring counties below the minimum snowfall limit.

Recreational Marine

Prior versions of NONROAD used total water surface area as the allocation surrogate for recreational marine vessels (including 1 mile out into large bodies of water where applicable). For the draft NONROAD2002 model this method has been refined to allocate from national to state level using marine fuel consumption data. Allocation from state to county level was also refined by using different distances from shore to determine the relevant water surface area for larger boats with inboard engines (2 miles) versus smaller outboards and personal watercraft (a quarter mile).

These modifications tend to (a) shift recreational marine allocations away from states like Alaska that have large shorelines but less boating than warmer states, and (b) increase the allocation of larger boats to coastal counties while shifting smaller personal watercraft and outboards more to waterways in inland counties.

Inventory Comparison

Table 3 and Figures 2 through 6 show emission inventory comparisons of the June 2000 version and draft NONROAD2002 for spark-ignition, diesel, and the combined total. These inventories only include the equipment types covered by the NONROAD model. They are based on annual US-total model runs, and thus differ slightly from EPA's National Emission Inventory (Air Pollution Trends) projections which are calculated on a seasonal county-by-county basis taking into account the geographic and seasonal variations in temperature and fuel properties.

The largest change is the 71 percent decrease in estimated SOx. Much of this change is due to the correction of the calculation to include load factor. There were also substantial decreases in all diesel inventories. One major contributing factor was the revised method for calculating equipment populations, which cut the population estimates by about 25 percent.

CONCLUSIONS

The draft NONROAD model is currently the best overall tool we are aware of for estimating national and regional nonroad inventories, but as a draft model it continues to be in transition, sometimes with substantial changes to estimated inventories as shown in this paper. State air quality planners may use NONROAD, but until it is final it does not carry the presumptive weight of an approved model when EPA reviews a State Implementation Plan (SIP) submittal.

For more complete documentation of all the model changes mentioned in this paper, please see http://www.epa.gov/otaq/nonrdmdl.htm, especially the documentation section titled "Nonroad Model Workshop #4, November 5, 2002: Ann Arbor." Any updated technical reports covering the derivation of the model inputs will also be posted on that web page when released.

REFERENCES

1. Assessment and Standards Division, Presentations of the Draft NONROAD2002 Workshop, U.S. Environmental Protection Agency, Ann Arbor, MI, November 5, 2002; http://www.epa.gov/otaq/nonrdmdl.htm.

Table 1. Compression-ignition load factors.

Cycle	Cycle Load Factor	Assignment	Average
Agricultural Tractor	0.78	High	0.59
Crawler Dozer	0.58		
Rubber-tired Loader	0.48		
Excavator	0.53		
Backhoe Loader	0.21	Low	0.21
Skid-steer Loader	0.23		
Arc Welder	0.19		
7-cycle average	---	Steady-state	0.43

Table 2. CI median life comparison.

Hp Range	Previous NONROAD Median Life	New NONROAD Median Life	Regulatory Useful Life*
0 - 16	1,250	2,500	3,000
16 - 25	2,500	2,500	3,000
25 - 50	2,500	2,500	5,000
50 - 300	4,000	4,667	8,000
300+	6,000	7,000	8,000

* The Regulatory Useful Life is considered to represent in-use loads, rather than full load. NONROAD model diesel load factors range from 0.21 to 0.59.

Table 3. Inventory comparison of NONROAD model versions.

	1999 National Emissions (tons)*								
	Spark-Ignition			Diesel			Total		
	June 2000 Version	NONROAD 2002	% change	June 2000 Version	NONROAD 2002	% change	June 2000 Version	NONROAD 2002	% change
VOC	2,700,000	2,350,000	-13%	362,000	211,000	-42%	3,062,000	2,561,000	-16%
CO	23,200,000	22,500,000	-3%	1,270,000	967,000	-24%	24,470,000	23,467,000	-4%
NOx	400,000	454,000	14%	2,670,000	1,610,000	-40%	3,070,000	2,064,000	-33%
PM10	92,300	71,500	-23%	262,000	184,000	-30%	354,000	256,000	-28%
SOx	31,500	11,200	-64%	666,000	192,000	-71%	698,000	203,000	-71%
Fuel Consumption				17,400,000,000	10,300,000,000	-41%			

* Results are rounded to the nearest thousand. Fuel consumption reported in gallons, rounded to the nearest hundred million.

Figure 1. Age Distribution / Scrappage

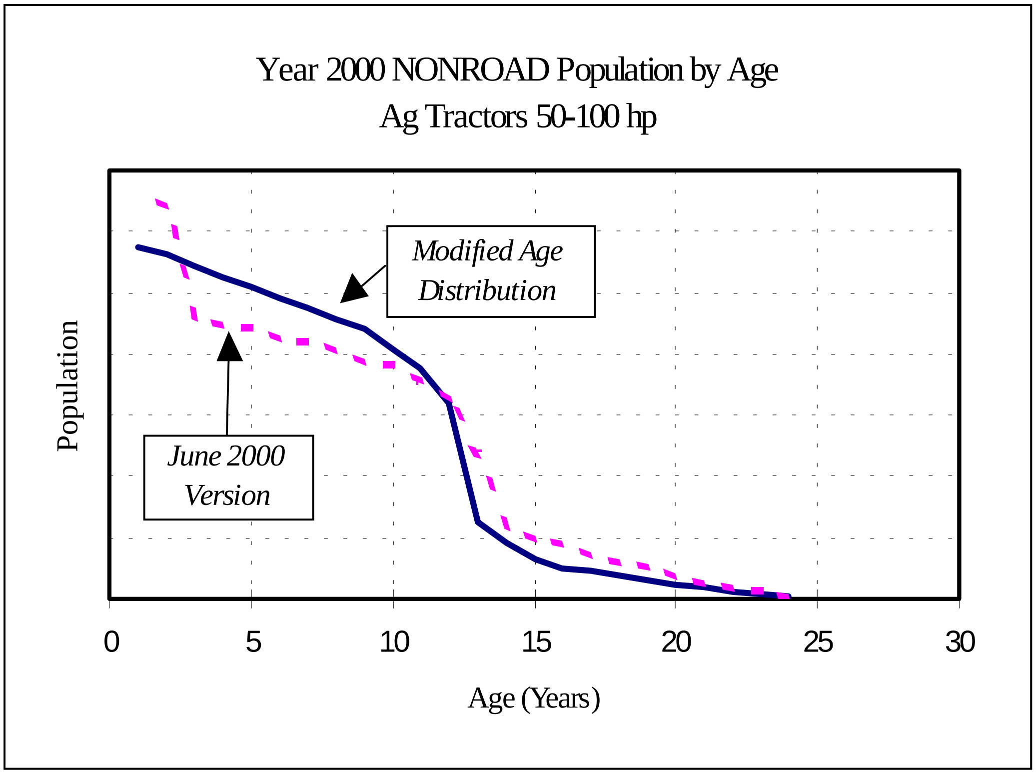

Figure 2. Inventory comparison of NONROAD model versions for VOC.

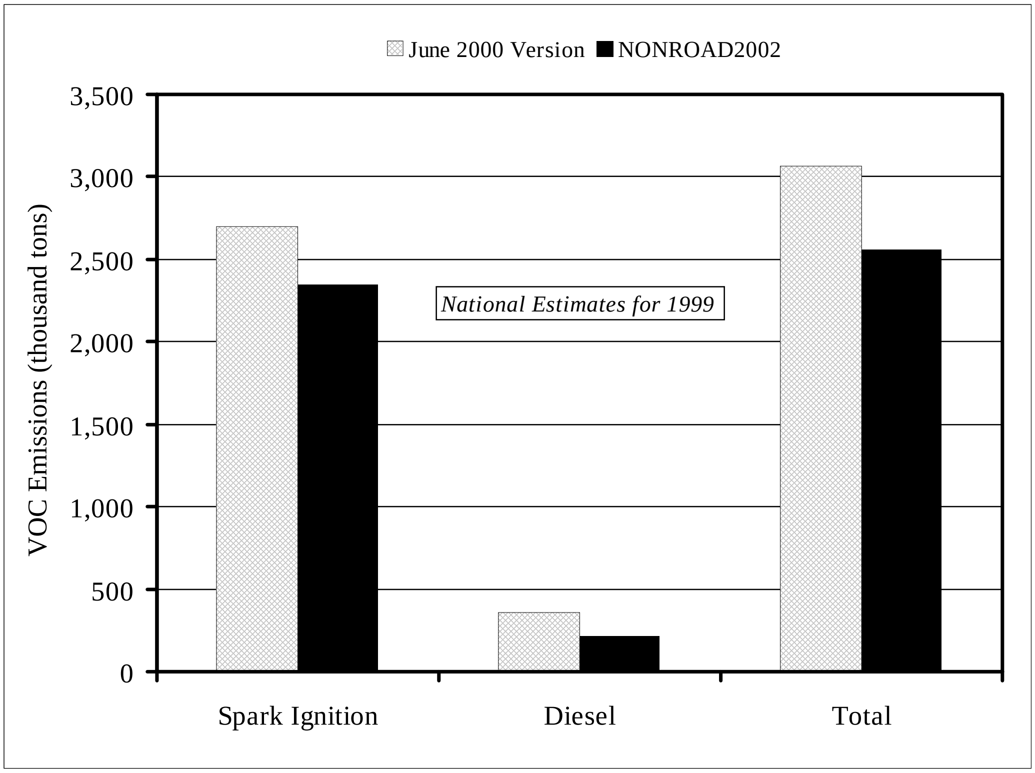

Figure 3. Inventory comparison of NONROAD model versions for CO.

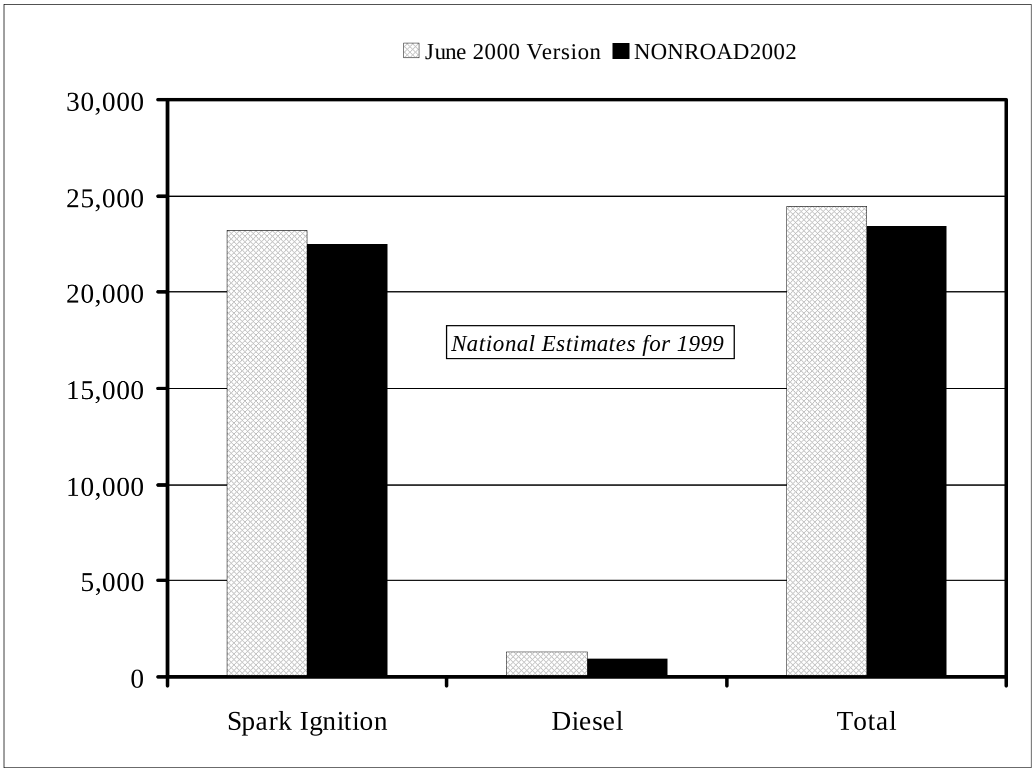

Figure 4. Inventory comparison of NONROAD model versions for NOx.

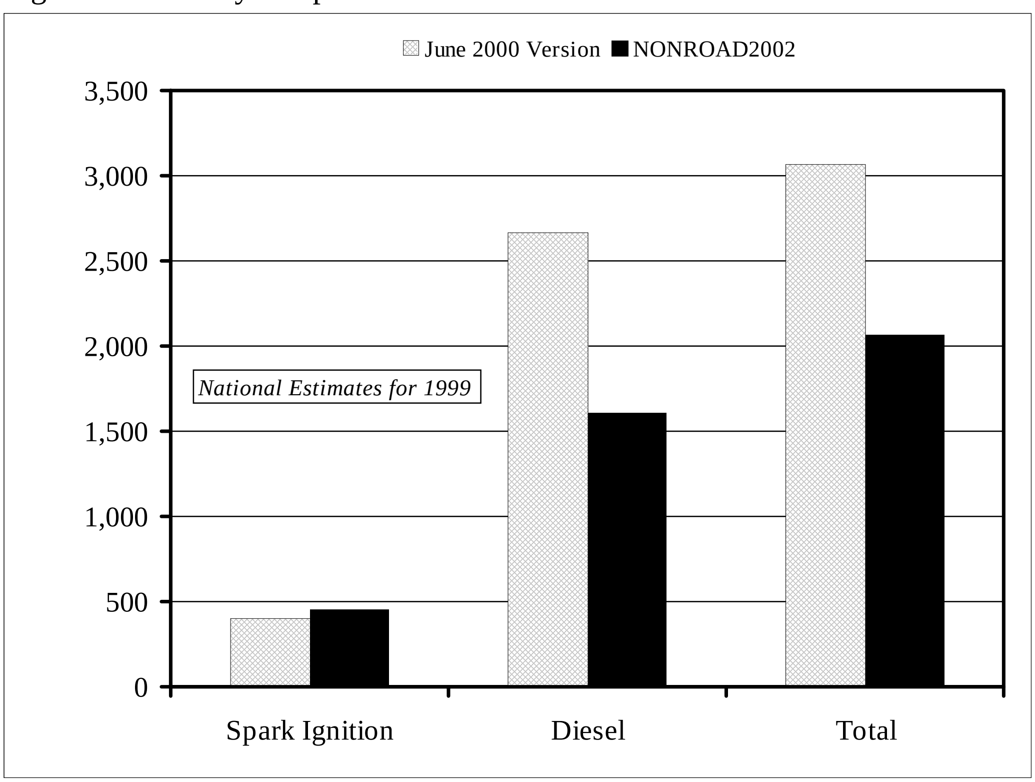

Figure 5. Inventory comparison of NONROAD model versions for PM10.

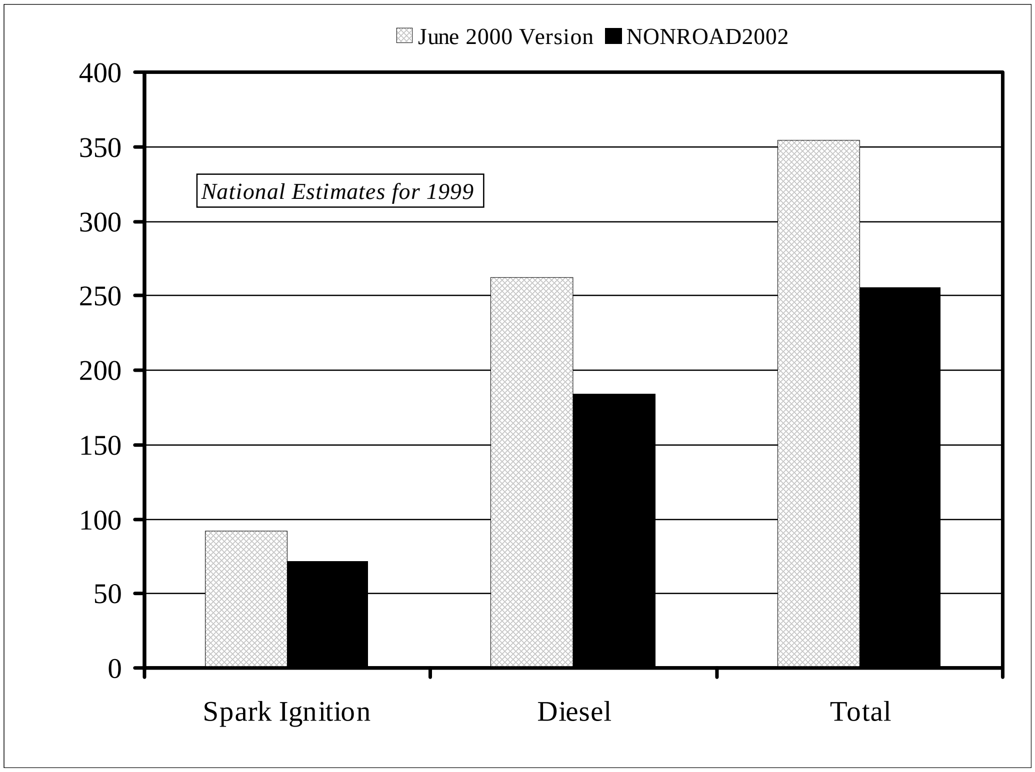

Figure 6. Inventory comparison of NONROAD model versions for SOx.