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NONROAD EMISSION FACTORS

By

Melvin N. Ingalls

INTERIM REPORT

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
2565 Plymouth Road
Ann Arbor, Michigan 48105

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SOUTHWEST RESEARCH INSTITUTE
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I. INTRODUCTION

There are a number of areas in the United States that do not meet the national ambient air quality standards, despite increasingly stringent highway motor vehicle exhaust regulations. To help meet these ambient standards, other mobile sources of pollution are being examined. There are a number of sources of air pollution that can be classed as mobile, but that are not currently subject to regulations. Some of these sources, such as aircraft and locomotives are transportation related; others, such as construction equipment and lawn and garden equipment are not. The air pollution from all these sources is related to the combustion engines which power them.

The Clean Air Act Amendments of 1990 directed the EPA to "...conduct a study of emissions from nonroad engines and nonroad vehicles (other than locomotives or engines used in locomotives) to determine if such emissions cause, or significantly contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare."[I-1] As part of the work to fulfill the requirements of the Clean Air Act, this report is the first of two planned reports on emission factors from nonroad sources.

A. Objective

There were two objectives for this project. The first objective was to examine the nonroad source categories (exclusive of aircraft and locomotives) currently listed in the EPA document commonly referred to as "AP-42,"[I-2] and the categories being used by California in their current work in regulating nonroad mobile sources, to determine if the individual sources are properly categorized.

The second objective was to obtain the "best currently available" emission factors for each of these categories. For the gaseous emissions of HC, CO, and NO_x, these efforts were to be completed and reported to EPA within 30 days from the start of work. For particulates and toxics, the emission factors were to be compiled and reported within 90 days after the start of work.

B. Approach

The work was to be divided into two phases with a report at the end of each phase. Since there was so little time available for the project, a thorough review of the literature and other data sources was not possible. The best that could be done was to use the reports that were on hand (which were many of the most useful nonroad emission reports), and to contact those persons in EPA and the California Air Resources Board (CARB) that are working on nonroad emission factors to obtain their latest information.

C. Reports

This report is the first of two reports planned for this study. It presents an analysis of the nonroad categories currently used, and recommends a new set of categories. This report also presents the "best currently available" HC, CO, and NO_x emission factors for these categories. A second report will be issued at a later date, presenting emission factors for particulates and some toxic compounds for the nonroad categories.

REFERENCES FOR SECTION I

I-1 Clean Air Act Amendments of 1990.

I-2 "Compilation of Air Pollutant Emission Factors," Volume II, EPA Report No. AP-42, Fourth Edition, September 1985, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

II. RECOMMENDED NONROAD CATEGORIES

The first part of this study was to examine the current categorization of nonroad emission sources (both EPA and California Air Resources Board categories) to determine if the emission factors of individual sources are properly characterized by these categories. After examination of the categories and sources, SwRI was to recommend new categories if needed, and recommend what nonroad sources should be assigned to these categories. The EPA nonroad categories are listed in the fourth edition, Volume II, of AP-42.(II-1)

A. AP-42 Categories

The AP-42 categories are listed in Table II-1, except for aircraft and locomotives, which are excluded from this study. A more complete description of the sources in each category, quoted from AP-42, is presented below.

1. Inboard-Powered Vessels

This category of marine vessels is described in a AP-42 as follows: "...Vessels classified on the basis of use will generally fall into one of three categories: commercial, pleasure, or military... Commercial vessel population and usage data have further been subdivided by a number of industrial and government researchers into waterway classifications (for example, Great Lakes vessels, river vessels, and coastal vessels)."

There are five tables of emission factors for Inboard-Powered Vessels. They are:

- Average Emission Factors for Commercial Motorships by Waterway Classification
- Emission Factors for Commercial Steamships
- Diesel Vessel Emission Factors by Operating Mode
- Average Emission Factors for Diesel-Powered Electrical Generators in Vessels
- Average Emission Factors for Inboard Pleasure Craft.

2. Outboard-Powered Vessels

The AP-42 section on outboard-powered vessels does not describe which vessels are in this category, probably assuming that it is self-explanatory.

3. Small, General Utility Engines

AP-42 describes this category as follows: "This category of engines comprises small two-stroke and four-stroke, air cooled, gasoline-powered motors. Examples of the uses of these engines are:

TABLE II-1. NONROAD ENGINE AND VEHICLE CATEGORIES

AP-42	California	Recommended Categories
Inboard-Powered Vessels: Commercial Pleasure Military	Marine (except pleasure craft)	Marine Inboard: Steam Slow Speed Diesel Med. speed Diesel High Speed Diesel Otto Cycle Gas Turbine
Outboard-Powered Vessels		Marine Outboard
Small, General utility Engines	Small Utility, Lawn and Garden (under 25 hp)	Small Utility, Lawn and Garden (under 25 hp)
Agricultural Equip.		Agricultural Equip.
H.D. Construction Equipment	H.D. Construction and Agriculture (40 hp and above)	Construction, Mining, and Forestry Equipment,
Snowmobiles		Nonroad Recreation Vehicles (includes snowmobiles, motorcycles, ATV's, jet skis, and maybe ultralights)
		Large Utility and Utility Vehicles
	Off-Road Motorcycles	
	Off-Highway vehicles (includes snowmobiles)	

lawnmowers, small electric generators, compressors, pumps, minibikes, snowthrowers, and garden tractors. This category does not include motorcycles, outboard motors, chainsaws, and snowmobiles..."

4. Agricultural Equipment

Agricultural equipment is described in AP-42 as: "Farm equipment can be separated into two major categories: wheeled tractors and other farm machinery;" and, "Self-propelled combines, forage harvesters, irrigation pumps, and auxiliary engines on pull-type combines and balers are examples of non-tractor uses of internal combustion engines."

5. Heavy-Duty Construction Equipment

The description of this diverse category in AP-42 is: "The equipment categories in this section include: track-type tractors, track-type loaders, motor graders, wheel tractor scrapers, off-highway trucks (includes pavement cold planers and wheel dozers), wheeled loaders, wheeled tractors, rollers (static and vibratory), and miscellaneous machines. The latter category contains an array of less numerous mobile and semi-mobile machines used in construction such as log skidders, hydraulic excavators/crawlers, trenchers, concrete pavers, compact loaders, crane lattice booms, cranes, hydraulic excavator wheels, and bituminous pavers. Some of these categories are different from the Third Edition" [emphasis added].

6. Snowmobiles

The category is self-explanatory. AP-42 does not describe the category except to note that in the mid-seventies, 70 percent of all snowmobiles were registered in just four states: Michigan, Minnesota, Wisconsin, and New York.

B. California Air Resources Board Categories

The California Air Resources Board categories were obtained from a two-page document sent to SwRI from CARB, included in Appendix A. CARB categories are also summarized in Table II-1. The categories are briefly described in the paragraphs below (not in the order listed in the CARB document). Appendix A contains more detailed lists of the equipment in each CARB category, for those categories where such detailed information was found.

1. Marine Vessels

The category includes tugs, crew boats, harbor craft, large ocean-going vessels such as tankers and cargo carrying vessels, and commercial fishing fleets. It is understood from conversations with CARB personnel that this category does not include pleasure craft, either inboard or outboard powered.(II-2)

2. Utility Engines

The category includes lawn and garden equipment such as mowers, tillers, chainsaws, blowers, and trimmers. In addition, generators, pumps and other utility type engines up to 25 horsepower are included.

3. Construction and Farm Equipment

The category includes bulldozers, tractors, skid steer loaders, and backhoes.

4. Off-Road Motorcycles

The category includes only off-road motorcycles and all terrain vehicles (ATV's) not registered for on-road use.

5. Off-highway Vehicles

This category is somewhat of a hodgepodge. It includes equipment from industrial, construction, agricultural, recreational, and utility categories. For the industrial, construction, and agricultural equipment, it includes only equipment below 40 horsepower. For tractors, it includes only tractors between 25 and 39 horsepower. For all other equipment, there are no horsepower limits. Included in this category are: forklifts, airport service vehicles, snowmobiles, mobile cranes, light-duty construction and farm equipment, and four-wheel drive vehicles.

C. Recommended Categories

After reviewing the nonroad categories from AP-42, it does appear that there should be a new set of EPA categories for nonroad sources, since AP-42 does not claim to cover all nonroad mobile sources. The CARB categories, however, do not appear to be completely adequate replacements. Particularly cumbersome in the CARB categories, is the placement of tractors under 25 horsepower in the Lawn and Garden category, tractors from 25 to 39 horsepower in the Off-Highway Vehicle category, and tractors 40 horsepower and over in the H.D Construction and Agricultural category.

A set of recommended categories is listed in Table II-1. Each of the recommended categories is explained and discussed in the paragraphs below.

1. Marine Inboard

There is good reason to change from type of usage (commercial, military, pleasure, Great Lakes, river, or coastal) to type of engine for this category. It appears that regardless of ship usage, for ships with a given type and size of engine, the duty cycle will be similar. Also, the different power plants are associated mostly with one size of vessel. For instance, slow speed diesel engines are mostly used in large ocean-going ships.

2. Marine Outboard

Outboard engines are different enough to remain a separate category.

3. Small Utility, Lawn and Garden

It is recommended that the California category be adopted. In addition to the equipment in the CARB category, this recommended category also contains golf carts, since they are similar to riding lawnmowers. For CARB, golf carts are in the "Off-Highway Vehicle" category. The current AP-42 category contains most of the same equipment but excludes chain saws. AP-42 says that 89 percent of this class are used in lawn and garden applications, so the name change is needed. The CARB category is for engines under 25 horsepower. This recommended category has the same horsepower limits.

4. Agricultural Equipment

There are good arguments for retaining agricultural equipment as a separate category as done in AP-42, rather than combine it with construction equipment as CARB has done. While it is true that some manufacturers make both agricultural and construction equipment, it is also true that there are manufacturers that make only agricultural equipment. These companies definitely do not have the emissions control experience that construction engine makers have, since construction engines are often derivations of on-road engines. The seasonal usage of agricultural equipment, and the generally rural locations where it is used, may argue for different standards than construction equipment. Finally, the fact that agricultural interests are a powerful political lobby, may mean that agricultural equipment could have separate standards legislated by Congress.

5. Construction, Mining, and Forestry Equipment

This category removes the words "heavy duty" from the current category so that all construction equipment would be in this category. The name is expanded to emphasize that mining and forestry equipment are also included. Note that this category includes all construction equipment, so that it contains the construction and industrial equipment under 40 horsepower that is included in the CARB "Off-Highway Vehicles" category.

6. Nonroad Recreation Vehicles

This category includes the snowmobile category presently in AP-42 and the off-highway motorcycles of the California category. In addition, it includes other vehicles that use similar engines or engine technology, such as jet skis, ATV's, and maybe ultralight aircraft, if not included in the aircraft category. This category does not include four-wheel drive vehicles that are essentially off-highway derivatives of on-highway vehicles. It also does not include forklifts, mobile cranes, or aircraft service vehicles which are included in the CARB category of Off-Highway Vehicles.

7. Large Utility and Utility Vehicles

At the start of this study, we thought that this category should be called "Other," since it seemed like a good idea to have a category in which to put equipment that had been overlooked, or that on closer examination, did not fit into the category it was thought to. Upon examining some the nonroad equipment not included in the other categories, it was found that this category would include large refrigeration units (which includes railroad units, some of which are over 90 hp), aircraft service vehicles, forklifts, and some of the equipment from the CARB "Off-Highway Vehicles" category. The CARB "Off-Highway Vehicle" category seemed to have too many diverse sources to be a useful category, however. "Large Utility and Utility Vehicles" seemed to be a better description of the category, even though it is intended to be a category for anything that did not fit into one of the other categories.

REFERENCES FOR SECTION II

II-1. "Compilation of Air Pollutant Emission Factors," Volume II, EPA Report No. AP-42, Fourth Edition, September 1985, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

II-2. Telephone conversation between Melvin Ingalls, Southwest Research Institute and Jacline Lourenco, State of California Air Resources Board staff, Mobile Source Division, El Monte, California, January 21, 1991.

III. EMISSION FACTORS

Development of emission factors for nonroad vehicles has received very little attention, mainly because the resources required to develop good emission factors were not available. Those studies that were done were generally of the nature of "check what is available and report it," rather than to actually measure emissions from various sources. This study is the most recent of that type. The emission factors found are presented in this section.

A. Information Required for Emission Factors

Before presenting the emission factors, some discussion about what constitutes an emission factor is in order. Emission factors are used for a variety of purposes, but the principal use is probably for determining the impact of a given pollution source at a local, regional, or national level. Thus, emission factors should represent average mass emission rates from a source when that source is operating in an average manner. For automobiles, the emission factor is generally expressed in grams per mile emitted over a given driving schedule, such as the Urban Dynamometer Driving Schedule (UDDS). Nonroad emission factors are generally mass-based, and are expressed in mass per unit of time, mass per unit of work, or mass per unit of fuel used.

The engines used in mobile pollution sources emit different amounts of pollutants at different speed and load conditions. Thus, emission measurements need to be made at a number of engine speed and load conditions. Determining the emission factor requires more than measuring the emissions from a source at a various conditions, however. The time the source spends in those various speed and load modes must also be known. This time-in-mode information is often referred to as the "operating" or "duty" cycle. The duty cycle enables the emissions at the various engine speeds and loads to be apportioned correctly. As mentioned above, the "duty cycle" for automobiles is often the UDDS.

A third element in the calculation of an emission factor for a specific source is that different engines have different emissions. Sometimes this difference is caused by engine type; for example, two-stroke diesels have different emissions than four-stroke diesels, and of course, diesel engines have different emissions than gasoline-fueled engines. Sometimes there are differences in emissions from one manufacturer to another. In automobiles, emission standards that all manufacturers must meet tend to limit differences from one manufacturer to another. Nonroad emissions, however, are not currently constrained by regulations, and so can have greater differences from manufacturer to manufacturer.

Thus, to obtain an emission factor for a given nonroad source, for instance lawnmowers, there should be available emissions measurements over some average lawnmower usage cycle, from both new and used lawnmowers, for all the major manufacturers. An average emission factor for lawnmowers could then be calculated by sales- (or use-) weighting the emissions from each of the lawnmowers tested, then summing the weighted values.

For the nonroad emission sources investigated in this study, there have been few emission measurements, data on the "average operating pattern" has not always been collected, and the extent of usage of each manufacturer's product is not always known. Thus, nonroad emission factors suffer from deficiencies in all three areas of required information. These deficiencies affect the accuracy with which emission factors are known.

B. Overall Accuracy of Emission Factors

It is important to realize that while this section presents single values for emission factors from many sources, these values are estimates based on very little actual measured data. Thus, assessing the accuracy of these emission factors is a problem.

For automobiles, certification testing of new vehicles and laboratory testing of in-use vehicles has been undertaken for years to develop automotive emission factors. Yet in a recent project for the Coordinating Research Council (CRC) to determine in-use emissions by measuring pollutant concentrations in a tunnel, it was found that the CARB emission factor program, EMFAC7C, underestimated emission factors for HC by a factor of approximately 3, underestimated emission factors for CO by a factor of approximately 2, and correctly estimated the emission factors for NO_x.(III-1) Other studies of in-use vehicles on the road have also shown that automobile emission factors are generally underestimated. This underestimation occurred despite testing of thousands of new and in-use vehicles in the laboratory.

Engine emissions are not just a single number. Rather, they are a distribution, caused by differences in engine design, build tolerances, differences in operation, and differences in maintenance. For HC and CO especially, the distribution is not the familiar bell-shaped curve of a normal (Gaussian) distribution, but rather takes the form of a distribution with an extremely long tail, such as a lognormal distribution. It is hypothesized that the underestimation that occurs in automotive emission factors from laboratory testing is the result of not being able to sample the "tail" of the distribution.

For the nonroad sources presented here, with the exception of the marine emissions, almost all the measured data was for a few pieces of new equipment. For the emission sources discussed in this report, there has been no testing of in-use units to determine the actual emissions of equipment in the field. Thus, it is highly unlikely that for any of the nonroad sources discussed in this report, sufficient testing has been done to define the distribution of emissions from any of the categories. Based on the comparison of traffic-to-laboratory-test emission factors for automobiles, it is estimated that the emission factors presented in this report represent the true emission factor for the category within one-half to twice the value presented.

C. Emission Factor Measurement Units

A word should be said about the measurement units of the emission factors in this section. An attempt was made to present the factors in units that would be the most useful in determining local, regional, and national impact of these sources. For sources that have a fuel supply for which separate statistics are available (such as marine vessels and farm equipment), mass of emission per unit of fuel burned is generally the best way to express an emission factor. Traditionally, these emissions have been expressed in terms of pounds per 1000 gallon of fuel burned. This traditional unit has been maintained in this report.

For sources that do not have separate fuel accountability, such as utility engines or construction equipment, the best unit for the emission factor appears to be grams per horsepower hour. Where it was necessary to convert measured data from one set of units to the other and brake specific fuel consumption (BSFC) was not available, it was assumed to be 0.4 for diesel engines and 0.5 for gasoline engines. Diesel fuel was assumed to weigh 7.1 pounds per gallon and gasoline 6.2 pounds per gallon.

D. Emission Factors by Category

The actual emission factors judged to be the "best currently available" are presented in this section, together with some discussion of their origin. The emission factors are from several sources. Sometimes the best available factors for a category were those currently in AP-42, sometimes from emission factors developed in other studies, and sometimes the best available factors had to be developed from data on hand at SwRI. For ease of reference, the tables containing the emission factors are grouped together at the end of this report subsection, rather than immediately following their text reference, as is usually done.

1. Marine Inboard

Five sources of marine inboard emission factors were located. These five sources are: AP-42,[III-2] a 1984 draft report to EPA by Engineering Science,[III-3] a 1985 SWRI report to EPA,[III-4] a 1988 Radian report to EPA,[III-5] and a CARB listing of marine emission factors[III-6]. It has been recommended in Section II of this report that the subcategories of this category be changed to type of propulsion system. This should work well because propulsion system type is generally related to vessel size.

Steam propulsion is generally found on larger ships, but is becoming less popular. Slow speed diesels are used in large ocean-going ships, and medium speed diesels are used in larger tugboats, towboats, oil rig crew and supply boats, and larger fishing boats. High speed diesels are used in fishing boats, small utility boats, and pleasure craft. Gas turbine engines are used in some U.S. Navy ships and in a few commercial cargo ships. Otto cycle (gasoline) inboard engines are used almost exclusively in small pleasure craft. Thus, each engine type is generally associated with one size range of vessel.

a. Steam

Marine steam power emission factors were found in references III-2, III-3, III-4, and III-6. All the emission factors were essential those currently in AP-42; therefore, it is recommended that the steam emission factors in AP-42 be used for marine steam engine sources. These factors are presented in Table III-1. There is no "duty cycle" available for marine steam engines, but the table presents emissions at three conditions: hoteling (at a pier, or at anchor, providing "hotel" services to the ship), cruise, and full.

b. Slow Speed Diesel

Measured emissions from seven slow speed diesels (two four-stroke and five two-stroke) were found in Reference III-3. The emissions from these engines were averaged in Reference III-4, and recommended for use as marine slow speed diesel emission factors. These data were reviewed for this project. It appears that it would be advantageous to split these factors up into two-stroke and four-stroke emission factors. The resulting emission factors are shown in Table III-2, as the slow speed diesel marine emission factors. Again, there is no duty cycle available. The emission factors represent emissions over the 60 percent to full power range.

The two-stroke emission factors in Table III-2 are similar to those presented in a table of diesel propulsion emission factors provided by CARB for HC and CO, but the NO_x emission factor presented here is much higher than the factor in the CARB information. It is important to note that all of the two-stroke and one of the four-stroke engines were manufactured by M.A.N. It is not known how M.A.N. engine emissions compare with other manufacturers.

c. Medium Speed Diesel (propulsion)

Radian Corporation, under contract to EPA, developed a set of marine medium speed diesel emission factors in 1988. The report of that work is contained in Reference III-5. The Radian report argues that "The great majority of medium speed diesels in marine use in the U.S. are essentially seagoing locomotive engines." Also, that "Since the emission factors for locomotives are reasonably well defined, and the duty cycle for marine engines is not too dissimilar from that of locomotives, it was decided to apply the 'best estimate' emission factors developed [by Radian] for locomotives to medium speed marine engines as well." This argument appears reasonable; therefore, the marine medium speed diesel emission factors from that report, as presented in Table III-2, are recommended for use. These emission factors do represent emissions over a duty cycle (average locomotive) and are weighted by manufacturers (considering only G.E. & EMD).

d. High Speed Diesel (propulsion)

There have been few measurements of high speed marine diesel engine emissions. Marine high speed diesel engine emission factors were also listed in the Radian report and in the Engineering Science report. The Engineering Science diesel emission factors suffer from a number of deficiencies as discussed in Reference III-4, and were therefore not used. The estimates of high speed diesel emission factors from the Radian study appear to be the best available, and are also presented in Table III-2. The methodology used by Radian to produce these emission factors is not spelled out, however. The Radian report also states that these high speed diesel emission factors should be considered only very rough approximations. The duty cycle and engines that these factors represent are unknown.

e. Gas Turbines

A small percentage of the U.S. Navy ships are gas turbine powered, and there are a few commercial ships that are gas turbine powered. There were no emission tests of marine gas turbines found during this study. Many of the marine gas turbine installations use derivatives of aircraft gas turbines, and most of these are manufactured by either General Electric (G.E.) or Pratt and Whitney Aircraft (P&WA). Therefore, for the marine gas turbine emission factors, it was decided to average the aircraft emissions from AP-42 for G.E. and P&WA engines since these manufacturers have most of the marine installations. The aircraft emission levels of "approach," "climbout," and "takeoff" were used to represent the marine emission levels of "hoteling," "cruise," and "full," respectively. These emission factors, in terms of pounds per thousand gallons of fuel, are presented in Table III-3.

f. Otto Cycle (gasoline-fueled)

Otto cycle (gasoline-fueled) inboard engines are mostly used in pleasure boats. No measured emissions from these engines were found. The best estimate of these emissions appears to be the AP-42 pleasure craft gasoline engine emission factors. These factors, in terms of pounds per thousand pounds of fuel, are also listed in Table III-4.

g. Diesel-Powered Electric Generators in Vessels

In addition to the main propulsion engines, exhaust from engine powered electric generators is a source of marine emissions. These generators are powered mostly by diesel engines. AP-42 includes a table for diesel-powered marine electrical generators. These factors are best available, and are listed in Table III-5 in terms of pounds per thousand pounds of fuel.

2. Marine Outboard

As far as can be ascertained there have been no measurements of outboard motor emissions since those done at SwRI in the early 1970's, except for some tests in Germany which would not be representative of outboards in the U.S. The SwRI tests are the basis for the emission factors in AP-42. It is recommended that the current AP-42 outboard motor emission factors, as listed in Table III-6, be retained.

3. Small Utility, Lawn and Garden

CARB has done some testing on this class of equipment, and has published emission factors for this category of nonroad sources.[III-7] Since this testing represents the most up-to-date information available for this category, it is recommended that the CARB emission factors, as listed in Table III-7 in terms of grams per horsepower hour, be used for this category of nonroad sources. Some work was done to define operating cycles for this equipment. The emission factors can be considered as average emissions over an average operating cycle.

4. Agricultural Equipment

No new emission measurements on farm equipment have been found since the factors reported in the CAL/ERT report.[III-8] The current California categories list farm equipment with heavy-duty construction equipment. In the recent report to CARB by EEA[III-9] on H.D. construction equipment, there is a list of HC and NO_x emission factors by several model year groups. While these emission factors are in the reasonable range, there is no indication as to the methodology used to obtain these factors and they are not recommended for use.

In November of 1987, CARB included a draft of estimated farm equipment emission factors in a notice of a meeting on emission inventories of diesel motor vehicles.[III-10] The NO_x emission factors were reportedly developed from the CAL/ERT report, while the HC emission factors were from AP-42. These emission factors are somewhat higher than those currently in AP-42, however, and somewhat lower than would be obtained from the CAL/ERT report, if the farm emissions in that report were weighted by percent of total energy output and the weighted sum obtained.

The end result of this investigation into agricultural equipment emission factors is that there still does not appear to be any better emission factors available than presented in the CAL/ERT report. Those emissions, as presented in Table III-8, in terms of grams per horsepower hour, are recommended for use. Since fuel for agricultural use is not subject to taxes, it should be possible to obtain the total agricultural fuel used for various areas. The average grams per horsepower hour emission factors for diesel and gasoline have been used to calculate emission factors in pounds per thousand pounds of fuel, using the factors listed above. Some work was done for the CAL/ERT report to define a duty cycle for the category, and emissions were generally measured on a 13-mode steady-state test. Therefore, these factors can be considered as average emissions over an average operating cycle.

5. Construction, Mining and Forestry

Emission factors for this category are in much the same state as agricultural equipment emission factors. No new emission measurements were found since the CAL/ERT study. There are emission factors in the EEA report to CARB on H.D. construction equipment[III-9], but as explained above, they are presented without explanation as to the methodology used to generate them, or indeed any indication that they are even based on emission measurements.

The best estimate of emission factors in this category are again from the CAL/ERT study. These emission factors were used to update the emissions from a number of sources in the Heavy-Duty Construction Equipment category for the fourth edition of AP-42. The emission factors currently in AP-42 for this category, presented in Table III-9, are recommended to be retained.

6. Nonroad Recreation Vehicles

This class of vehicles is generally powered by two-stroke gasoline engines. While no emissions measurements were found for ATV's, jet skis, or ultralight aircraft engines, there have been emissions measurements of two-stroke motorcycle engines. As part of the CARB off-highway study, emission factors were developed for two-stroke motorcycles.(III-11) These emission factors, as listed in Table III-10, are recommended for use simply because they are all that are available. The emission factors for snowmobiles currently in AP-42 should be retained and used for snowmobiles and jet skis. The CARB motorcycle emissions were converted to g/hr from g/mile based on an average speed of 25 mph.

7. Large Utility (greater than 25 horsepower) and Utility Vehicles

Since this category of nonroad sources was developed during this study, there are no emission factors currently in existence for the category as a whole. Most of the equipment in this category will be four-stroke gasoline and two-stroke or four-stroke diesel engines, with two or more cylinders. Since it is not easy to obtain overall fuel consumption for this category of sources, the emission factors are better expressed in terms of grams per horsepower hour. There are a variety of duty cycles for the equipment in this category. Therefore, until there is further information available on the total number of sources, and the amount each type of source in the category contributes to the total emissions from the category, emission factors should be expressed by type of service. Type of service is broken down into: (1) continuous operation at some base power level, and (2) transient service. Continuous service is for equipment such as refrigeration units and generators; transient service is for vehicles.

The emission factors for these categories, shown in Table III-11, were taken from several sources. For continuous power, the diesel emission factors were taken as the refrigeration unit emission factors in the Radian report.(III-5) The continuous power gasoline factors were taken as the 90 percent power mode from steady state tests of six 1979 model year engines tested at SwRI as part of the EPA Transient Test Procedure development.(III-12) The individual engine emissions used for these emission factors are listed in Appendix B.

For cyclic power emission factors, the diesel forklift factors were taken from 13-mode tests of six forklift engines tested at SwRI for the U.S. Army from 1984-86.(III-13, III-14) The individual 13-mode test results for these engines are contained in Appendix B. Both the cyclic power gasoline and diesel off-highway emission factors were taken from the CAL/ERT report.(III-8)

TABLE III-1. EMISSION FACTORS FOR COMMERCIAL STEAMSHIPS - ALL GEOGRAPHIC AREAS
EMISSION FACTOR RATING: D
(Table is from AP-42)

Pollutant	Fuel and operating mode[a]											
	Residual oil[b]						Distillate oil[b]					
	Hoteling		Cruise		Full		Hoteling		Cruise		Full	
	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal
Particulates[c]	1.20[d]	10.0[d]	2.40	20.0	6.78	56.5	1.8	15	1.78	15	1.78	15
Sulfur oxides (SO_x as SO_2)[e]	19.1S	159S	19.1S	159S	19.1S	159S	17.0S	142S	17.0S	142S	17.0S	142S
Carbon monoxide[c]	Neg[d]	Neg[d]	0.414	3.45	0.872	7.27	0.5	4	0.5	4	0.5	4
Hydrocarbons[c]	0.38[d]	3.2[d]	0.082	0.682	0.206	1.72	0.4	3	0.4	3	0.4	3
Nitrogen oxides (NO_x as NO_2)	4.37	36.4	6.70	55.8	7.63	63.6	2.66	22.2	2.83	23.6	5.34	44.5

[a] The operating modes are based on the percentage of maximum available power: "hoteling" is 10 to 11 percent of available power, "full" is 100 percent of available power, and "cruise" is an intermediate power (35 to 75 percent, depending on the test organization and vessel tested).

[b] Test organizations used "Navy Special" fuel oil, which is not a true residual oil. No vessel test data were available for residual oil combustion. "Residual" oil results are from References 2, 3, and 5. "Distillate" oil results are from References 3 and 5 only. Exceptions are noted. "Navy Distillate" was used as distillate test fuel.

[c] Particulate, carbon monoxide, and hydrocarbon emission factors for distillate oil combustion are based on stationary boilers (see Section 1.3 of this document).

[d] Reference 18 indicates that carbon monoxide emitted during hoteling is small enough to be considered negligible. This reference also places hydrocarbons at 0.38 kg/10³ liter (3.2 lb/10³ gal) and particulate at 1.20 kg/10³ liter (10.0 lb/10³ gal). These data are included for completeness only and are not necessarily comparable with other tabulated data.

[e] Emission factors listed are theoretical in that they are based on all the sulfur in the fuel converting to sulfur dioxide. Actual test data from References 3 and 5 confirm the validity of these theoretical factors. "S" is fuel sulfur content in percent.

TABLE III-2. MARINE INBOARD DIESEL EMISSION FACTORS

Pollutant	g/hp-hr		lb/1000 gal. fuel	
	Two-Stroke	Four-Stroke	Two-Stroke	Four-Stroke
Low speed Diesel Engines (less than 600 rpm)				
HC	0.4	0.1	20[a]	8[a]
CO	1.4	0.7	79[a]	37[a]
NO_x	9.4	9.6	523[a]	534[a]
Medium Speed Diesel Engines (600 to 1300 rpm)[b]				
HC	1.0		41	
CO	4.7		187	
NO_x	13.4		533	
High Speed Diesel Engines (above 1300 rpm)[b]				
HC	0.8		32	
CO	3.0		119	
NO_x	11.0		436	

[a] Assumes BSFC = 0.313 lb/hp-hr and No. 6 fuel oil density = 7.9 lb/gal.
[b] From Reference III-5.

TABLE III-3. MARINE INBOARD GAS TURBINE EMISSION FACTORS

Pollutant	Hoteling	Cruise	Full
	lb/1000 gal of Fuel	lb/1000 gal of Fuel	lb/1000 gal of Fuel
G.E. Engines			
HC	10	2	1
CO	285	94	88
NOx	43	115	141
P&WA Engines			
HC	10	1	1
CO	87	7	4
NOx	47	113	146

TABLE III-4. MARINE INBOARD OTTO CYCLE (GASOLINE-POWERED) EMISSION FACTORS[a]

(Table is from AP-42)

Pollutant	Based on Fuel Consumption		Based on Operating Time	
	Gasoline Engine[b]		Gasoline Engine[b]	
	$kg/10^3$ liter	$lb/10^3$ gal	kg/hr	lb/hr
Carbon monoxide	149	1240	1.69	3.73
Hydrocarbons	10.3	86	0.117	0.258
Nitrogen oxides (NO_x as NO_2)	15,7	131	0.179	0.394

[a]Average emission factors are based on the duty cycle developed for large outboards ($\geq$48 kilowatts or $\geq$65 horsepower). The above factors take into account the impact of water scrubbing of underwater gasoline engine exhaust. All values given are for single engine craft and must be modified for multiple engine vessels.

[b]Based on tests of automotive engines. Fuel consumption of 11.4 liter/hr (3 gal/hr) assumed. The resulting factors are only *rough* estimates.

TABLE III-5. MARINE INBOARD DIESEL ELECTRICAL GENERATOR EMISSION FACTORS
(Table is from AP-42)

Rated output,[b] kW	Load,[c] % rated output	Emissions: Sulfur oxides (SO_x as SO_2)[d] lb/10^3 gal	kg/10^3 liter	Carbon monoxide lb/10^3 gal	kg/10^3 liter	Hydrocarbons lb/10^3 gal	kg/10^3 liter	Nitrogen oxides (NO_x as NO_2) lb/10^3 gal	kg/10^3 liter
20	0	27	3.2	150	18.0	263	31.5	434	52.0
	25	27	3.2	79.7	9.55	204	24.4	444	53.2
	50	27	3.2	53.4	6.40	144	17.3	477	57.2
	75	27	3.2	28.5	3.42	84.7	10.2	495	59.3
40	0	27	3.2	153	18.3	584	70.0	214	25.6
	25	27	3.2	89.0	10.7	370	44.3	219	26.2
	50	27	3.2	67.6	8.10	285	34.2	226	27.1
	75	27	3.2	64.1	7.68	231	27.7	233	27.9
200	0	27	3.2	134	16.1	135	16.2	142	17.0
	25	27	3.2	97.9	11.7	33.5	4.01	141	16.9
	50	27	3.2	62.3	7.47	17.8	2.13	140	16.8
	75	27	3.2	26.7	3.20	17.5	2.10	137	16.4
500	0	27	3.2	58.4	7.00	209	25.0	153	18.3
	25	27	3.2	53.4	6.40	109	13.0	222	26.6
	50	27	3.2	48.1	5.76	81.9	9.8	293	35.1
	75	27	3.2	43.7	5.24	59.1	7.08	364	43.6

[a] Reference 2.

[b] Maximum rated output of the diesel-powered generator.

[c] Generator electrical output (for example, a 20 kW generator at 50 percent load equals 10 kW output).

[d] Calculated, not measured, based on 0.20 percent fuel sulfur content and density of 0.854 kg/liter (7.12 lb/gal) from Reference 17.

TABLE III-6. MARINE OUTBOARD EMISSION FACTORS
(Table is from AP-42)

Pollutant[b]	Based on fuel consumption		Based on work output[c]	
	lb/10^3 gal	kg/10^3 liter	g/hphr	g/metric nphr
Sulfur oxides[d] (SO_x as SO_2)	6.4	0.77	0.49	0.49
Carbon monoxide	3300	400	250	250
Hydrocarbons[e]	1100	130	85	85
Nitrogen oxides (NO_x as NO_2)	6.6	0.79	0.50	0.50

[a] Reference 1. Data in this table are emissions to the atmosphere. A portion of the exhaust remains behind in the water.

[b] Particulate emission factors are not available because of the problems involved with measurement from an underwater exhaust system but are considered negligible.

[c] Horsepower hours are calculated by multiplying the average power produced during the hours of usage by the population of outboards in a given area. In the absence of data specific to a given geographic area, the hphr value can be estimated using average nationwide values from Reference 1. Reference 1 reports the average power produced (not the available power) as 9.1 hp and the average annual usage per engine as 50 hours. Thus, hphr = (number of outboards) (9.1 hp) (50 hours/outboard-year). Metric hphr = 0.9863 hphr.

[d] Based on fuel sulfur content of 0.043 percent from Reference 2 and on a density of 6.17 lb/gal.

[e] Includes exhaust hydrocarbons only. No crankcase emissions occur because the majority of outboards are 2-stroke engines that use crankcase induction. Evaporative emissions are limited by the widespread use of unvented tanks.

TABLE III-7. SMALL UTILITY, LAWN AND GARDEN EMISSION FACTORS

AVERAGE EMISSION FACTORS FOR ALL ENGINES
(GR/HP-HR)

	HC	CO	NOX	PM
AVEGAGE SMALL ENGINE (1)	37.68	430.33	2.02	0.74
AVERGAE MIDSIZE ENGINE (2)	9.28	352.93	2.03	0.05
AVERAGE LARGE ENGINE (3)	9.60	357.67	2.30	0.21

1) ASSUMES 95% SIDE VALVE AND 5% OHV

2) ASSUMES 90% SIDE VALVE AND 10% OHV

3) NO DATA AVAILABLE FOR LARGE OHV ENGINES

RESIDENTAIL EMISSION FACTORS FOR UTILITY ENGINES
(GRAMS PER HP-HOUR)

	4 CYCLE				2 CYCLE			
PRODUCT CATEGORY	HC	CO	NOX	PART	HC	CO	NOX	PART
WALK BEHIND MOWERS	37.7	430	2.02	0.74	208	486	0.29	7.7
RIDING MOWER (FRT ENG)	9.3	353	2.03	0.05				
RIDING MOWER (REAR ENG)	9.3	353	2.03	0.05				
GARDEN TRACTOR	9.6	357	2.3	0.21				
TILLERS	37.7	430	2.02	0.74				
SNOWTHROWERS	37.7	430	2.02	0.74	208	486	0.29	7.7
GENERAL UTILITY	37.7	430	2.02	0.74	208	486	0.29	7.7
SHREDDERS/GRINDERS	37.7	430	2.02	0.74	208	486	0.29	7.7
SPECIALIZED TURF CARE	9.3	353	2.03	0.05				
4-CYC BLOWERS/VACUUMS	37.7	430	2.02	0.74				
4-CYC EDGERS/TRIMMERS	37.7	430	2.02	0.74				
2-CYC EDGERS/TRIMMERS					287	920	0.96	3.6
2-CYC BLOWERS/VACUUMS					283	908	0.96	3.6
CHAIN SAWS					298	699	0.96	3.6

COMMERCIAL EMISSION FACTORS FOR UTILITY ENGINES
(GRAMS PER HP-HOUR)

	4 CYCLE				2 CYCLE			
PRODUCT CATEGORY	HC	CO	NOX	PM	HC	CO	NOX	PART
WALK BEHIND MOWERS	37.7	430	2.02	0.74	208	486	0.29	7.7
RIDING MOWER (FRT ENG)	9.3	353	2.03	0.05				
RIDING MOWER (REAR ENG)	9.3	353	2.03	0.05				
GARDEN TRACTOR	9.6	357	2.3	0.21				
TILLERS	37.7	430	2.02	0.74				
SNOWTHROWERS	37.7	430	2.02	0.74	208	486	0.29	7.7
GENERAL UTILITY	9.3	353	2.02	0.05	208	486	0.29	7.7
SHREDDERS/GRINDERS	9.3	353	2.02	0.05	208	486	0.29	7.7
SPECIALIZED TURF CARE	9.3	353	2.03	0.05				
4-CYC BLOWERS/VACUUMS	9.3	353	2.03	0.05				
4-CYC EDGERS/TRIMMERS	37.7	430	2.02	0.74				
2-CYC EDGERS/TRIMMERS					198	668	0.96	3.6
2-CYC BLOWERS/VACUUMS					283	908	0.96	3.6
CHAIN SAWS					152	513	0.96	3.6

NOTE: EMISSION FACTORS FOR FOUR STROKE ENGINES ARE BASED ON AVERAGE EQUIPMENT HORSEPOWER RATINGS LISTED IN EXHIBIT 2-13, AND ON THE EMISSION FACTORS LISTED IN EXHIBIT 2-17.

EMISSION FACTORS FOR HAND HELD TWO STROKES ARE BASED ON THE HEIDEN ASSOCIATES REPORT TO PPEMA.

EMISSION FACTORS FOR WALK BEHIND TWO STROKES ARE BASED ON CARB TESTING AT SWRI.

TABLE III-8. AGRICULTURAL EQUIPMENT EMISSION FACTORS

	% Energy Output	g/bhp-hr			Weighted, g/bhp-hr		
		HC	CO	NO_X	HC	CO	NO_X
Diesel							
Tractor, 2WD 100+ hp	33.0	1.84	4.23	11.59	0.607	1.40	3.82
Tractor, 4WD	29.5	0.89	3.28	10.98	0.263	0.97	3.24
Tractor, 2WD, 20-90 hp	22.0	2.16	6.42	10.94	0.475	1.41	2.41
Combines, Self-Propelled	5.8	1.90	3.25	13.36	0.110	0.19	0.77
Windrower, Self-Propelled	4.3	2.21	6.85	10.50	0.095	0.29	0.45
Forage Harvester Sweet Corn Harvester	2.0	0.96	2.84	9.98	0.019	0.06	0.20
Balers, Self-Propelled Cotton Pickers Cotton Strippers Orchard Sprayers	1.7	2.23	3.78	7.78	0.038	0.06	0.13
Mower Conditioner Compact Loaders	1.7	1.13	4.29	9.69	0.019	0.07	0.16
Average Diesel					1.63	4.4	11.2
Gasoline							
Average					2.8	163	7.8

	lb/1000 gallons of fuel		
	HC	CO	NO_X
Average Diesel	64	174	437
Average Gasoline	77	4456	213

TABLE III-9. CONSTRUCTION, MINING, AND FORESTRY EMISSION FACTORS

	% Energy Output	g/bhp-hr			Weighted, g/bhp-hr		
		HC	CO	NO_x	HC	CO	NO_x
Diesel							
Track Type Tractor, 90+ hp	21.82	0.37	1.65	6.60	0.081	0.360	1.440
Wheel Load 2-1/2 cu. yd.	13.32	0.60	2.07	8.31	0.080	0.276	1.107
Ind. Wheel Tractor	11.37	1.76	7.34	11.91	0.200	0.835	1.354
Wheel Tractor Scraper	10.79	0.55	2.45	7.46	0.059	0.264	0.805
Log Skidder	6.31	0.61	3.18	9.82	0.038	0.201	0.620
Off-Highway Trucks	5.84	0.37	2.28	8.15	0.022	0.133	0.476
Motor Graders	5.59	0.36	1.54	7.14	0.020	0.086	0.399
Hydraulic Excavator, Crawler	4.94	1.22	3.18	11.01	0.060	0.157	0.544
Trencher, Concrete Paver, Compact Loader	3.89	1.10	4.57	10.02	0.043	0.178	0.390
Wheel Loader 2-1/2 cu. yd	3.60	1.29	3.26	9.24	0.046	0.117	0.333
Track Type Loader, 90+ hp	2.81	0.47	1.56	7.76	0.013	0.044	0.218
Track Type Tractor 20-89 hp	2.21	1.33	2.91	9.63	0.029	0.064	0.213
Track Type Loader, 20-89 hp	1.97	1.80	3.02	10.97	0.035	0.059	0.216
Roller Compactor, Static	1.24	0.88	5.33	11.84	0.011	0.066	0.147
Crane Lattice Boom, Wheel & Crawler	1.04	0.59	4.99	12.45	0.006	0.052	0.129
Crane, Hydraulic, Wheel, One Station	0.97	0.80	7.80	14.69	0.008	0.076	0.142
Hydraulic Excavator, Wheel	0.96	1.22	3.18	11.01	0.012	0.031	0.106
Roller Compactor, Vibratory	0.68	1.06	6.72	14.27	0.007	0.046	0.097
Crane, Hyd. Wheel, Multi-Station	0.41	0.68	3.71	12.47	0.003	0.015	0.051
Bituminous Paver	0.24	0.99	5.19	11.18	0.002	0.012	0.027
Total Diesel					0.78	3.07	8.81
Average Gasoline					2.8	163	7.8

TABLE III-10. NONROAD RECREATIONAL VEHICLES

Vehicle Type	Engine Type	Emissions, g/hr		
		HC	CO	NO_x
Nonroad Motorcycles	2-stroke	600	800	1.5
Nonroad Motorcycles	4-stroke	100	975	9.0
Snowmobiles	All	630	978	10

TABLE III-11. LARGE UTILITY AND UTILITY VEHICLES

	Emissions, g/bhp-hr		
	HC	CO	NO_x
Continuous Power Level Operation			
Diesel < 50 hp [a]	1.2	5.0	8.0
Diesel > 50 hp [a]	1.0	4.0	16.0
Gasoline [b]	1.1	3.2	6.1
Cyclic Power Levels			
Diesel forklifts [c]	0.9	2.9	5.0
Diesel off-highway [d]	0.4	2.3	8.2
Gasoline [d]	2.8	163	7.8

[a] Reference III-5
[b] Reference III-12
[c] Reference III-13 and III-14
[d] Reference III-8

REFERENCES FOR SECTION III

III-1. Ingalls, M.N., Smith, L.R., and Kirksey, R.E., "Measurement of On-Road Vehicle Emission Factors in the California South Coast Air Basin," Volume I, Regulated Emissions, Final Report by Southwest Research Institute for Project SCAQS-1 to the Coordinating Research Council, Inc., Atlanta, GA, June 1989.

III-2. "Compilation of Air Pollutant Emission Factors," Volume II, EPA Report No. AP-42, Fourth Edition, September 1985, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

III-3. Draft copy of Emission Factor Documentation of AP-42: Section 3.2.3 Inboard Powered Vessels," EPA 450/4-84-001, Report by Engineering Sciences, Arcodia, CA to U.S. EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC under Contract 68-02-3509, undated.

III-4. Ingalls, M.N., "Recommended Revisions to Gaseous Emission Factors from Several Classes of Off-Highway Mobile Sources," report by Southwest Research Institute under EPA Contract 68-03-3162, Work Assignment 8, U.S. EPA, Ann Arbor, MI, March 1985.

III-5. Weaver, C.S., "Feasibility and Cost-Effectiveness of Controlling Emissions from Diesel Engines in Rail, Marine, Construction, Farm, and Other Mobile Off-Highway Equipment," Final Report by Radian Corporation for U.S. EPA, Office of Policy Analysis, under Contract 68-01-7288, February 1988.

III-6. Personal communication to Melvin Ingalls of Southwest Research Institute from Todd Sherwood, U.S. EPA, Motor Vehicle Emissions Laboratory, January 24, 1991.

III-7. "Technical Support Documents for California Exhaust Emission Standards and Test Procedures for 1994 and Subsequent Model Year Utility and Lawn and Garden Equipment Engines," State of California Air Resources Board, Sacramento, CA, undated (contained in Mailout 90-64).

III-8. "Feasibility, Cost and Air Quality Impact of Potential Emission Control Requirements on Farm, Construction, and Industrial Equipment in California," prepared by Environmental Research and Technology, Inc., under sponsorship of the Farm and Industrial Equipment Institute, Engine Manufacturers Association, and Construction Industry Manufacturers Association, Document PA841, May 1982.

III-9. "Feasibility of Controlling Emissions from Off-Road, Heavy-Duty Construction Equipment," Final Report by Energy and Environmental Analysis, Inc., Arlington, VA to the California Air Resources Board, El Monte, CA, December 1988.

III-10. "Documentation of Methods used to Estimate Emissions from Off-Road Vehicles," Enclosure E to a mail-out from the State of California Air Resources Board, Sacramento, CA, November 30, 1987.

III-11. State of California Air Resources Board, El Monte, CA, Mailout #90-58, dated September 7, 1990, Subject: Proposal to Control Emissions from Off-Road Motorcycles.

III-12. Martin, S.F., "Emissions from Heavy-Duty Engines Using the 1984 Transient Test Procedure, Volume I - Gasoline," Final Report by Southwest Research Institute to U.S. EPA Standards Development and Support Branch, Ann Arbor, MI, under Contract No. 68-03-2603, July 1981.

III-13. Dietzmann, H.E., "Emissions Characterization of Diesel Forklift Engines," SAE Paper 841396, October 1984.

III-14. Dietzmann, H.E., "Clean-Burning Diesel Engines - Phase III," U.S. Army Belvoir Fuels and Lubricants Research Facility (SwRI), Interim Report BLFRF No. 215 to U.S. Army Belvoir Research, Development and Engineering Center, under Contract DAAK70-85-C-0007, March 1986.

IV. DISCUSSION AND RECOMMENDATIONS

One of the tasks of this project was to identify those emission factors that would benefit from updating that can be accomplished over the next four to six months, then recommend the specific work to be done, and explain how the work would improve the emission factor value. It should be obvious, from the discussions in this report, that all of the emission factors for the nonroad emission sources investigated require updating. There is, however, little that can be done in the next four to six months.

Except for the initial work done for AP-42 and the measurement work sponsored by CARB for small utility engines, the work done on nonroad emission factors has all been of the "review" nature. Six years ago, the author of this report investigated emission factors for several nonroad sources[IV-1] for EPA. The SwRI Final Report for that project noted that more emissions measurements were needed for every source studied. Three years ago, in a Radian Corporation report to EPA on Off-Highway equipment, the same recommendations were made.[IV-2]

It should be pointed out that neither of these studies examined whether or not the benefits from additional measurements would justify the considerable cost. If, however, the emission factors for these sources are ever to be known, a long range program to address the deficiencies in the current set of emission factors must be planned and funded. Otherwise, five or even ten years from now, "review" reports will still be written presenting essentially the same emission factors, with the same comments about lack of measured data, and the same recommendations that more measurements are needed.

In the meantime, are there things that can be done in the next four to six months? There are some things that can be done that might improve some of the emission factors. Table IV-1 is a comparison of impact (in tons per day) of the various California nonroad categories in the California South Coast Air Basin. This data was taken from a mail-out from the CARB.[IV-3] While this information is for only one part of one state, the relative importance of each group is probably representative of many urban areas of the country.

As can be seen from the table, the largest contribution to HC and CO is the small utility class. This California category is the same as the category recommended in this project. It should be possible to arrange for testing of some in-use utility engines, and to integrate these results into the current data base, within the four-to-six month time frame. This testing would provide information that is now lacking on emissions from in-use engines, thus giving more accurate emission factors for the category that contributes the most HC and CO.

While it is believed that the reports examined in this study have located all the major government and industry studies on nonroad emissions, there is one source that could be investigated in the next four to six months that apparently has not been fully covered. That source is masters theses and doctoral dissertations. It is possible that, for the engines used in the farm, construction, and large utility categories, actual emissions measurements could have been made at universities as part of their masters and doctoral degree programs.

These theses and dissertations are collected by at least one abstracting service. A literature search of these abstracts might result in additional emissions measurements for some of these categories. While there is no guarantee that any information will be found, if additional emission measurements cannot be made, then at least a thorough search for all possible measurements could be made. It might be difficult to integrate emission results from single engine tests into the farm and construction equipment categories.

TABLE IV-1. COMPARISON OF OFF-ROAD VEHICLE EMISSIONS FOR CALIFORNIA'S SCAB IN YEAR 2000
(TONS PER DAY)

Vehicle Type	Emission Type			Usage
	HC	CO	NO_x	
Off-Road Motorcycles[a]	2.5	9.3	0.03	daily
Off-Road Motorcycles[a]	8.8	32.6	0.1	weekends
Utility	24.7	165.0	0.7	daily
Ships	5.9	13.1	32.1	daily
Trains	1.4	4.3	28.8	daily
Off-Road Vehicles	14.0	124.0	32.0	daily
Construction & Farm Equipment	12.9	43.2	124.5	daily

[a] Includes ATV's.

which are already aggregates of a number of tests; but it should not be difficult to integrate such test results into the Large Utility category.

There is additional work that can be done in the Large Utility and Utility Vehicle category. It is assumed that the EPA has contractors who are developing engine and equipment inventories for the various categories of nonroad sources, and that these inventories either are available or will be available soon. Once these inventories have identified the engine manufacturers in these categories, SwRI could search its records of over twenty years of emissions tests for emissions tests that would be applicable to this category. If the tests were not performed for a government agency, permission from the commercial sponsor of the tests would be needed; and if necessary, a protocol could be devised to divorce the emissions from a specific manufacturer or engine. Unfortunately, there was neither time nor funds to conduct such a study in this project.

To summarize, the following additional work is recommended in the next four to six month time frame to improve the nonroad emission factors.

- Conduct emission tests of in-use small utility engines.
- Conduct a literature search of masters theses and doctoral dissertations for measured emissions from engines used in nonroad mobile sources.
- After determining the engine population by manufacturer for the Large Utility category, contract with SwRI to review its records of emissions tests for applicable emission data.

REFERENCES FOR SECTION IV

IV-1. Ingalls, M.N., "Recommended Revisions to Gaseous Emission Factors from Several Classes of Off-Highway Mobile Sources," report by Southwest Research Institute under EPA Contract 68-03-3162, Work Assignment 8, U.S. EPA, Ann Arbor, MI, March 1985.

IV-2. Weaver, C.S., "Feasibility and Cost-Effectiveness of Controlling Emissions from Diesel Engines in Rail, Marine, Construction, Farm, and Other Mobile Off-Highway Equipment," Final Report by Radian Corporation for U.S. EPA, Office of Policy Analysis, under Contract 68-01-7288, February 1988.

IV-3. State of California Air Resources Board, El Monte, CA, Mailout #90-58, dated September 7, 1990, Subject: Proposal to Control Emissions from Off-Road Motorcycles.

APPENDIX A

LIST OF NONROAD VEHICLES AND EQUIPMENT BY CATEGORY

California Off-Road Vehicle Categories and Potential Emission Control

The following includes a listing and description of the six off-road vehicle categories, as noted in the California Clean Air Act. In addition, the staff has estimated the emission control technologies that may be used to comply with upcoming, proposed regulations. Certain categories are less developed in terms of regulatory strategy and thus, more tentative in predicting potential emission controls. These categories are marine vessels and off-highway vehicles. The regulatory strategies associated with the following emission controls is subject to change as more information is received from industry and other interested parties.

1. Utility Engines

The category includes lawn and garden equipment such as mowers, tillers, chainsaws, blowers, and trimmers. In addition, generators, pumps and other utility type engines up to 25 horsepower are included.

Major Pollutants of concern: Hydrocarbons, carbon monoxide, and oxides of nitrogen.

Potential Emission Controls: Leaner fuel operation, improved carburetor and combustion design, and conversion of smaller residential units to electric. For long term, the conversion to LPG and the use of catalysts may be feasible.

2. Construction and Farm Equipment

The category includes bulldozers, tractors, skid steer loaders, and backhoes.

Major pollutants of concern: Oxides of nitrogen and particulates

Potential Emission Controls: Improved combustion chamber design, increased fuel injection pressure, improved injectors, and turbocharging.

The use of low sulfur diesel fuel.

For the long term, air-to-air aftercooling, particulate traps, and alternate fuels may be feasible.

3. Locomotives

The category includes yard, local service, and line haul locomotives.

Major pollutants of concern: Oxides of nitrogen

Potential Emission Controls: Injection timing retard, use of improved injectors on in-use EMD engines, and reduced idling time for yard and local locomotives.

The use of low sulfur diesel fuel.

For long term, the use of air-to-air aftercooling, selective catalytic reduction, and electrification may be feasible.

4. Marine Vessels

The category includes tugs, crew boats, harbor craft, large ocean-going vessels such as tankers and cargo carrying vessels, and commercial fishing fleets.

Major pollutants of concern: Sulfur oxides and oxides of nitrogen

Potential Emission Controls: Injection timing retard and aftercooling.
The use of low sulfur diesel fuel.
For long term, the use of selective catalytic reduction may be feasible.

5. Off-Highway Vehicles
The category includes forklifts, airport service vehicles, snowmobiles, mobile cranes, light-duty construction and farm equipment, and four wheel drive off-road vehicles.
Major pollutants of concern: Oxides of nitrogen and hydrocarbon
Potential Emission Controls: Leaner fuel operation, improved air intake systems,and improved combustion design. Certain vehicles may be converted to LPG and electric.
The use of low sulfur diesel fuel.
For long term, the use of catalysts may be feasible.

6. Off-Road Motorcycles
The category includes off-road motorcycles and all terrain vehicles not registered for on-road use.
Major pollutants of concern: Hydrocarbon and carbon monoxide
Potential Emission Controls: Conversion of 2-stroke to 4-stroke engine usage and improved combustion, fuel delivery, and air injection systems.

TABLE A-1. DETAILED LIST OF EQUIPMENT IN NONROAD CATEGORIES (NOT INTENDED TO BE ALL INCLUSIVE)

AP-42	CARB	PROPOSED
INBOARD-POWERED VESSELS: commercial vessels military vessels pleasure craft	MARINE: tugs harbor craft crew boats large ocean going vessels commercial fishing vessels Specifically NOT included: pleasure craft	MARINE, INBOARD: Steam: U.S. Navy vessels U.S. Flag ocean going vessels Slow Speed Diesel: ocean going tankers ocean going bulk carriers ocean going cargo vessels ocean going ferries cruise ships Medium Speed Diesel: tugs crew boats oil rig supply boats ferries cruise ships U.S. Navy vessels U.S. Coast Guard vessels large fishing boats large yachts High Speed Diesel: fishing boats U.S. Navy boats U.S. Coast Guard boats yachts smaller work boats sail boats (aux. power) Otto Cycle Engines: pleasure craft Gas Turbine Engines: U.S. Navy vessels Commercial vessels
OUTBOARD-BOARD POWERED VESSELS:		MARINE, OUTBOARD:

TABLE A-1 (CONT'D). DETAILED LIST OF EQUIPMENT IN NONROAD CATEGORIES (NOT INTENDED TO BE ALL INCLUSIVE)

AP-42	CARB	PROPOSED
SMALL,GENERAL UTILITY ENGINES: lawnmowers small electric generators compressors pumps minibikes snowthrowers garden tractors Specifically does NOT include: motorcycles chainsaws outboard motors snowmobiles	SMALL UTILITY, LAWN AND GARDEN (UNDER 25 HP): walk-behind mowers Riding mowers/lawn tractors Garden tractors Snow blowers Edge trimmers String trimmers blowers tillers chain saws other lawn and garden implements pumps generators compressors grinders welding machines stump beaters vibrators/finishers portable saw mills portable refrigeration units other miscellaneous utility equipment	SMALL UTILITY, LAWN AND GARDEN (UNDER 25 HP): walk-behind mowers riding mowers/lawn tractors garden tractors snow blowers edge trimmers string trimmers blowers tillers chain saws other lawn and garden implements pumps generators compressors grinders welding machines stump beaters vibrators/finishers portable saw mills portable refrigeration units other miscellaneous utility equipment golf carts
AGRICULTURAL EQUIP.: Wheeled tractors Other farm machinery: self propelled combine pull type combine corn pickers pick-up bailers forage harvesters irrigation pumps		AGRICULTURAL EQUIP.: Wheeled tractors (>25 hp) Other farm machinery: self propelled combine pull type combine corn pickers pick-up bailers forage harvesters irrigation pumps

TABLE A-1 (CONT'D). DETAILED LIST OF EQUIPMENT IN NONROAD CATEGORIES (NOT INTENDED TO BE ALL INCLUSIVE)

AP-42	CARB	PROPOSED
H.D. CONSTRUCTION EQUIP.: tracked tractors tracked loaders motor graders wheel tractor scrapers off-highway trucks cold planers wheel dozers wheeled loaders wheeled tractors rollers log skidders hydraulic excavators/crawlers trenchers concrete pavers compact loaders crane lattice booms cranes hydraulic excavator wheels bituminous pavers	H.D. CONSTRUCTION AND AGRICULTURE EQUIP. (40 HP & ABOVE): forklifts aerial lifts airport service vehicles mobile cranes generator sets construction tractors agricultural tractors (>25 hp) crawler dozers hydraulic excavators pavers combines-harvesters fruit-nut harvesters	CONSTRUCTION, MINING, AND FORESTRY EQUIP.: tracked tractors tracked loaders motor graders wheel tractor scrapers off-highway trucks cold planers wheel dozers wheeled loaders wheeled tractors rollers log skidders hydraulic excavators/crawlers trenchers concrete pavers compact loaders crane lattice booms cranes hydraulic excavator wheels bituminous pavers skid steer loaders rollers compactors backhoe-loaders
SNOWMOBILES		NONROAD RECREATION VEHICLES: nonroad motorcycles all terrain vehicles snowmobiles jet skis ultralight aircraft Specifically does NOT include: off-road derivatives of highway vehicles

TABLE A-1 (CONT'D). DETAILED LIST OF EQUIPMENT IN NONROAD CATEGORIES (NOT INTENDED TO BE ALL INCLUSIVE)

AP-42	CARB	PROPOSED
		LARGE UTILITY & UTILITY VEHICLES (>25 hp): off-road derivatives of highway vehicles forklifts aerial lifts airport service vehicles pumps generators compressors grinders welding machines stump beaters vibrators/finishers portable saw mills portable refrigeration units other miscellaneous large utility equipment
	OFF-ROAD MOTORCYCLES: off-road motorcycles (OFRMs) all-terrain vehicles (ATMs)	

TABLE A-1 (CONT'D). DETAILED LIST OF EQUIPMENT IN NONROAD CATEGORIES (NOT INTENDED TO BE ALL INCLUSIVE)

AP-42	CARB	PROPOSED
	OFF-HIGHWAY VEHICLES: Equipment under 40 hp: forklifts aerial lifts airport service vehicles mobile cranes generator sets skid steer loaders rollers compactors construction tractors agricultural tractors (>25 hp) backhoe-loaders crawler dozers hydraulic excavators pavers combines-harvesters fruit-nut harvesters Other equipment (no hp limit): golf carts snowmobiles four-wheel drive vehicles	

APPENDIX B

SUPPORTING DATA FOR LARGE UTILITY AND UTILITY VEHICLE EMISSION FACTORS

TABLE B-1. 90% POWER MODE EMISSIONS FROM EPA H.D. GASOLINE 9-MODE TESTS FOR SIX 1979 GASOLINE-FUELED TRUCK ENGINES

ENGINE	HC		CO		NOx	
NO.	g/kw-hr	g/bhp-hr	g/kw-hr	g/bhp-hr	g/kw-hr	g/bhp-hr
1	1.3	0.97	37.5	28.0	9.1	6.79
1	1.3	0.97	38.6	28.8	9.1	6.79
6	1.1	0.82	42.6	31.8	6.8	5.07
6	1.0	0.75	37.8	28.2	7.5	5.59
7	0.5	0.37	34.5	25.7	4.9	3.65
7	0.4	0.30	31.6	23.6	5.3	3.95
8	1.0	0.75	29.3	21.8	6.5	4.85
8	0.6	0.45	27.8	20.7	6.2	4.62
10	1.1	0.82	39.1	29.2	15.0	11.19
10	1.1	0.82	57.0	42.5	16.5	12.30
	AVERAGE	0.70		28.02		6.48

TABLE B-2. INDIVIDUAL 13-MODE TEST RESULTS FOR SIX FORKLIFT ENGINE TESTS

ENGINE	DATE	HC	CO	NOX	BSFC
PERKINS	7/26/83	2.740	4.879	6.406	0.474
DEUTZ	9/13/83	0.385	1.851	4.295	0.532
DEUTZ	9/22/83	0.409	1.691	4.302	0.507
PERKINS	12/7/83	1.060	2.396	8.647	0.444
ISUZU	8/22/85	0.532	3.680	3.126	0.541
TELEDYN	11/7/85	0.380	2.948	2.966	0.494
AVERAGE		0.918	2.907	4.957	0.499