Mail Out MSC 98-27

NOTICE OF PUBLIC MEETING TO CONSIDER THE APPROVAL OF CALIFORNIA'S OFF-ROAD LARGE SPARK-IGNITED ENGINE EMISSIONS INVENTORY

The Air Resources Board (ARB) will conduct a public meeting at the time and place noted below to consider approving the large spark-ignited engine emission inventory.

DATE: October 22, 1998

TIME: 9:30 A.M.

PLACE: Air Resources Board
Board Hearing Room, Lower Level
2020 L Street
Sacramento, California

This item will be considered at a two-day meeting of the ARB commencing at 9:30 a.m., October 22, 1998, and continuing at 8:30 a.m., October 23, 1998, if necessary. This item may not be considered until October 23, 1998. Please consult the agenda for this meeting, which will be available at least ten days before October 22, 1998, to determine the day on which this item will be considered.

This facility is accessible to persons with disabilities. If accommodation is needed, please contact the Clerk of the Board at (916) 322-5594 or TDD (916) 324-9531 or (800) 700-8326 for TDD calls from outside the Sacramento area, by October 8, 1998.

INFORMATIVE DIGEST OF PROPOSED ACTION/PLAIN ENGLISH POLICY STATEMENT OVERVIEW

Proposed Actions: The ARB staff recommends the Board approve the update to the off-road large spark-ignited engine emissions inventory.

Background: California's emissions inventory for off-road large spark-ignited engines is an estimate of the amounts and types of pollutants emitted from thousands of pieces of equipment used in many industrial and commercial applications. The development of the emissions inventory is a multi-agency effort. The ARB compiles the final, statewide inventory.

Section 39607(b) of the California Health and Safety Code has, for many years required the ARB to inventory emissions from sources of air pollution. The ARB has published inventories and updates for over 25 years. Improvements have been made periodically to maintain and provide the most complete, accurate, and up-to-date inventory practicable.

SB 2174 (Health and Safety Code section 39607.3), passed in 1996, requires the Board to approve, at a non-regulatory public meeting, the emissions inventory for criteria pollutants including emissions from mobile, stationary, area-wide, and nonanthropogenic sources. While the Board met its H&SC 39607.3 obligation by approving the statewide emissions inventory in December, 1997, staff at that time committed to return to the Board for approval of the OFFROAD inventory. Staff is therefore proposing this update to the off-road large spark-ignited engine portion of the new off-road inventory both to meet its H&SC 39607(b) commitment, and to fulfill its promise to the Board.

AVAILABILITY OF DOCUMENTS AND CONTACT PERSON

The ARB staff has prepared a Staff Report entitled "Public Meeting To Consider Approval Of The California Off-Road Large Spark-Ignited Engine Emissions Inventory" (Staff Report), which includes a summary of the proposed action. Copies of the Staff Report may be obtained from the California Air Resources Board, Public Information Office, 2020 L Street, Sacramento, California, 95814, (916) 322-2990.

Copies of the Emissions Inventory for off-road large spark-ignited engines can be obtained by calling ARB's Mobile Source Control Division at (626) 575-6800.

Further inquires regarding this matter should be directed to Mark Carlock, Chief, Motor Vehicle Analysis Branch, 9528 Telstar Avenue, El Monte California 91731, (626) 575-6608.

SUBMITTAL OF COMMENTS

The public may present comments relating to this matter verbally or in writing. To be considered by the Board, written submissions must be addressed to, and received by the Clerk of the Board, the Air Resources Board, P.O. Box 2815, Sacramento California 95812, no later than 12:00 noon, October 21, 1998, or received by the Clerk of the Board at the meeting.

The Board requests, but does not require, that 20 copies of any written statement be submitted and that all written statements be filed at least ten days prior to the meeting. The ARB encourages members of the public to bring any suggestions for modification of the proposed action to the attention of staff in advance of the meeting.

CALIFORNIA AIR RESOURCES BOARD

Michael P. Kenny
Executive Officer

Date: October 2, 1998

California Environmental Protection Agency

AIR RESOURCES BOARD

PUBLIC MEETING TO CONSIDER APPROVAL OF THE CALIFORNIA OFF-ROAD LARGE SPARK-IGNITED ENGINE EMISSIONS INVENTORY

Air Resources Board
Mobile Source Control Division

October 1998

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List of Figures and Tables

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Acronyms Used in Staff Report

ARB	Air Resources Board
BAH	Booz, Allen and Hamilton
BER	Basic Emission Rate
Board	Air Resources Board
CNG	Compressed Natural Gas
CO	Carbon Monoxide
EMA	Engine Manufacturers Association
EEA	Energy and Environmental Analysis, Inc.
gm/bhp-hr	Grams per Brake-Horsepower-Hour
HC	Hydrocarbons
H&SC	Health and Safety Code
HP	Horsepower
IC	Internal Combustion
ITA	Industrial Truck Association
LPG	Liquid Petroleum Gas
N	Non-preempt
NOx	Oxides of Nitrogen
P	Preempt
PM	Particulate Matter
PSR	Power Systems Research
SB	Senate Bill
SwRI	Southwest Research Institute
U.S. EPA	United States Environmental Protection Agency

**PUBLIC MEETING TO CONSIDER APPROVAL
OF THE CALIFORNIA
OFF-ROAD LARGE SPARK-IGNITED ENGINE EMISSIONS INVENTORY**

RECOMMENDATION

The staff recommends the Air Resources Board (ARB or Board) approve the draft, statewide, annual average, Emissions Inventory for Off-Road Large Spark-Ignited Engines (greater than or equal to 25 horsepower). This inventory utilizes the latest data available including a wealth of additional information on industry trends provided through the public comment process. This ensures that projections of this inventory are accurate. The 1990 inventory, as presented in Table 1, represents the reference year from which all projections are made.

The staff will use the approved inventory to produce other types of inventories, such as inventories for past and future years, and inventories used for planning and air quality modeling purposes. Senate Bill 2174 requires the Board to review the emission inventory at a minimum of every three years. Staff intends to follow this three year schedule, however, staff may seek Board review of portions of the inventory sooner than three years if significant changes with major policy consequences are suggested by new information.

**TABLE 1
OFF-ROAD LARGE SPARK-IGNITED ENGINE EMISSIONS INVENTORY
(Statewide - Tons per Day)**

Fuel	Type	HC	CO	NOx	PM
Gasoline	**4 Stroke**	11.49	230.74	30.11	0.16
LPG/CNG	**4 Stroke**	6.46	68.80	29.91	0.16
Total		**18.21**	**299.54**	**60.02**	**.32**

CHAPTER I. INTRODUCTION

California's off-road large spark-ignited engine emission inventory is an estimate of the amount and types of pollutants emitted from thousands of pieces of equipment with a rating of greater than or equal to 25 horsepower, which are used in off-road applications such as industrial, commercial, construction and agriculture.

The Air Resources Board and local districts use emissions inventories to describe and compare the contribution of various sources to air pollution, to establish priorities for developing methods of emission control, to prepare air quality plans, develop rules, and assess the progress of the State's air pollution control program.

Statutory Requirement

The California Health and Safety Code (H&SC) section 39607(b) for many years has required the Air Resources Board to inventory emissions from sources of air pollution. Staff has periodically updated and published statewide emissions inventories.

Senate Bill 2174 (H&SC section 39607.3), signed by Governor Wilson on September 21, 1996, requires the Board to approve at a public meeting, the emissions inventory for criteria pollutants including emissions from mobile, stationary, area-wide, and non-anthropogenic sources. The Board's initial approval was required no later than January 1, 1998 and subsequent updates to the inventory are required at least every three years.

The Board approved the emissions inventory in December of 1997. However, because the new computer model for the estimation of the off-road emissions inventory called "**OFFROAD**" was not complete, the Board approved the existing inventory for off-road mobile sources. At that time, staff made a commitment to bring the revised estimates before the Board prior to the end of 1998. The staff is seeking Board approval of the revisions to the off-road large spark-ignited engine emissions inventory per this process. Staff is therefore proposing this update both to meet its H&SC 39607(b) commitment, and to fulfill its promise to the Board.

CHAPTER II. PUBLIC PROCESS AND PUBLIC AVAILABILITY

The revisions to the off-road large spark-ignited engine emissions inventory were performed through a public process in which input was solicited from various agencies, air quality management districts, engine manufacturers, and technical consultants. ARB staff is ultimately responsible for the compilation of the final statewide emissions inventory, which is maintained in an electronic database.

The regulated community and interested stakeholders play a critical role in the review and development of the emissions inventory during the planning and regulatory process. They also participate actively in inventory workshops and in development of data and methodologies that improve the inventory. The ARB staff met often with representatives of industry associations to better understand the emission processes and to use their technical expertise and data to improve the inventory.

Two public workshops were conducted in early April of 1997, one in Sacramento and the other in EL Monte, in order to discuss the implications of SB 2174 on inventory development, and provide detailed descriptions of the data and methodologies used in the new OFFROAD model. The OFFROAD model is used by staff to estimate the emissions inventory for off-road large spark-ignited engines (and all other off-road mobile sources).

These workshops were well attended by representatives of both government and industry. In these workshops, staff presented the program structure, features, and data sources used in the

OFFROAD model. Staff also released a report entitled “Documentation of Input Factors for the new Off-Road Mobile Source Emissions Inventory Model” for public comment. In early May the same report was mailed to other parties who expressed an interest but could not attend the workshops. Since that time, staff has responded to many of the comments related to data sources used in the OFFROAD model and the structure of the model itself.

In June of 1998, staff published and mailed out a document describing various input factors and the resulting emissions inventory of off-road large spark-ignited engines contained in the OFFROAD model for public comments. Per their request staff provided electronic copies of all databases and the source code of the OFFROAD model to those technical consultants retained by the Engine Manufacturers’ Association (EMA), Outdoor Power Equipment Institute (OPEI) and Equipment Manufacturers Institute (EMI) collectively. Staff’s response to comments received by various organizations is detailed in attachment 3.

CHAPTER III. EMISSION INVENTORY MODEL STRUCTURE

A. Introduction

The Emission Inventory for off-road large spark-ignited engines includes total emissions for the entire state, subtotals for each of the 16 air basins and subtotals for each county or portion of a county in each air basin. The data in Table 1 summarize the statewide inventory of reactive organic gases (ROG), carbon monoxide (CO), oxides of nitrogen (NOx), and particulate matter (PM). Collectively, these pollutants are known as “criteria” pollutants.

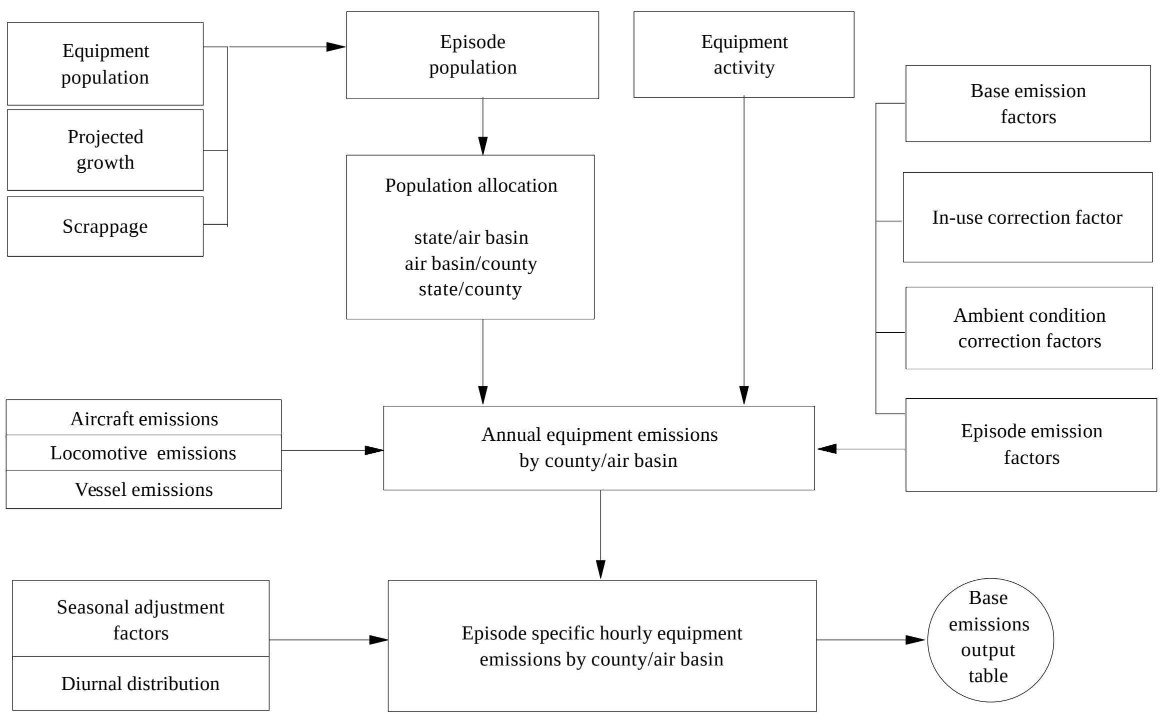
From the data used to produce the basic annual average emission inventory, staff prepares other types of inventory products. Some examples are: future year forecasts used to judge attainment prospects, trends to show historical patterns, seasonal inventories for planning purposes, day-specific inventories for use in ambient air quality models, and updated, prior-year inventories used in trend and progress assessments. These other estimates are based on the annual average emission inventory data and additional data needed to produce the specific estimate. Some of the other data sets required include temporal data, growth and control assumptions, spatial data, and historical assumptions.

The inventory category “Other Mobile Sources” is not limited to off-road large spark-ignited engines. Other Mobile Sources include 14 categories of emissions sources such as: small off-road engines (engines less than 25 hp), off-road recreational vehicles, aircraft, trains, ships, commercial boats, and recreational boats. Estimating the emissions from these categories is primarily the responsibility of the ARB, but some categories are estimated by the districts or the United States Environmental Protection Agency (U.S. EPA), such as emissions from aircraft and ships. In this Section, staff presents the structure and algorithms used to revise and improve the emission inventory of off-road large spark-ignited engines using the OFFROAD model.

B. Program Structure

The primary emphasis in designing OFFROAD was to provide an overall structure to incorporate the various aspects of off-road source emissions modeling, such as the effects of various adopted and proposed regulations, technology types, and seasonal conditions on emissions. This overall structure is illustrated in Figure 1. Fundamentally, the population, activity, and emission factors are still combined to yield the annual equipment emissions by county, air basin, or state. However, spatial and temporal features have been incorporated, making the new model more accurate in its depiction of emissions.

FIGURE 1
Flowchart of Overall Program Structure of OFFROAD



OFFROAD consists of four main modules: population, activity, emissions, and control factor. The 1990 base year equipment population is adjusted for growth and scrappage, producing model-year specific population distributions for specified calendar years from 1970 through 2020. The statewide population is allocated to each geographic region. The base emission factors are corrected for in-use and ambient conditions. The annual equipment emissions are adjusted for seasonal and diurnal factors producing the base emissions output.

The output tables of OFFROAD have a standard layout that displays activity information and emission data. The activity table includes information regarding the population, use hours per day, starts per day, and gallons of fuel consumed per day. The emission estimates are reported for three processes: exhaust, evaporative, and starts. While the output tables aggregate the information by equipment category for the state, the model can also produce more distinct information such as emission estimates of certain equipment type within a county.

C. Methodology

OFFROAD generates an emission inventory for six pollutants by equipment type, accounting for age and for a given scenario year. The basic equation for OFFROAD is:

$$P_{i,y} = \sum_{i} Pop_{i,v} * EF_{i,v} * Hrs_{i,v}$$

where

P = pollutant (HC, CO, NO_X, PM, CO_2, SO_2)
Pop = equipment population
EF = emission factor
Hrs = annual average use hours
y = scenario year (1970-2020)
I = equipment type
v = vintage (age of equipment)

1) Population Module

This module contains growth factors and scrappage curves that are used to derive an equipment-specific model year population distribution for specified calendar years from 1970 through 2020. The statewide equipment population was obtained through various industry and government agency sources and was divided at the air basin and county level using activity indicators that reflect their usage in those areas.

a) Categories and Equipment Types

There are 95 equipment types aggregated into 14 categories as listed in Table 2. In general, the 14 categories include all equipment types used for a similar purpose or industry. According to the Federal Clean Air Act, emissions from certain equipment types can only be regulated by the U.S. EPA and are, therefore, preempted from State regulation. The equipment types are further divided by fuel, engine type, horsepower group, and preempted or non-preempted status to better characterize emissions, adopted and proposed control strategies, and use. Table 3 shows the fuel type, engine type, and horsepower groups included in the model.

Tables 2 and 3 provide the category and horsepower information for all off-road sources. Those portions of the table shown in bold letters are specific to off-road large spark-ignited engines.

b) Growth and Scrappage

The growth factors are based on socioeconomic indicators such as housing units and manufacturing employment by category, by county, and with respect to the 1990 base year sales. Scrappage is a static function of equipment age and use which varies by engine type and horsepower group. For all equipment types, except lawn and garden equipment and recreational vehicles, the equipment useful life equals the life of the engine represented in years. The number of model years accounted for are twice the equipment useful life. The maximum useful life modeled is 16 years, which translates to 32 model years in a given calendar year. Therefore, the baseline model year distribution is also dependent on the useful life of the equipment. Due to the lack of any other information, the 1990 model year distribution is used for the 1970-1989 calendar years.

TABLE 2
List of Equipment by Category

a. Lawn and Garden Equipment
1. Trimmers/Edgers/Brush cutters
2. Lawn mowers
3. Leaf blowers/vacuums
4. Rear engine riding mowers
5. Front mowers
6. Chainsaws < 5 HP
7. Shredders < 5 HP
8. Tillers < 5 HP
9. **Lawn and garden tractors**
10. Wood splitters
11. Snow blowers
12. Chippers/Stump grinders
13. **Commercial turf equipment**
14. **Other lawn and garden equipment**

b. Light Commercial Equipment (0-50 HP)
1. **Generator sets**
2. **Pumps**
3. **Air compressors**
4. **Gasoline compressors**
5. **Welding machines**
6. **Pressure washers**

c. Recreational Equipment
1. **All Terrain Vehicles (3 & 4 wheel vehicles)**
2. **Off-road motorcycles**
3. **Golf carts**
4. **Specialty vehicles/carts**
5. **Snowmobiles**

d. Industrial Equipment
1. **Aerial lifts**
2. **Forklifts**
3. **Sweepers**
4. **Other general industrial equipment**
   - **Abrasive blasting equipment**
   - **Industrial blowers/vacuums**
   - **Marine/industrial winches and hoists**
   - **Multipurpose tool carriers**
   - **Other misc. industrial equipment (catch all)**

* (Industrial continues next column)

d. Industrial Equipment (cont)

5. **Other material handling equipment**
   - **Conveyors**
   - **Other misc. material handling (catch all)**
   - **Industrial tractors**

e. Construction and Mining Equipment
1. **Asphalt pavers**
2. **Tampers/Rammers**
3. **Plate compactors**
4. **Concrete pavers**
5. **Rollers**
6. **Scrapers**
7. **Paving equipment**
8. **Surfacing equipment**
9. **Signal boards**
10. **Trenchers**
11. **Bore/Drill rigs**
12. **Excavators**
13. **Concrete/Industrial saws**
14. **Cement and Mortar mixers**
15. **Cranes**
16. **Graders**
17. **Off-Highway trucks**
18. **Crushers/Processing equipment**
19. **Rough terrain forklifts**
20. **Rubber tire loaders**
21. **Rubber tire dozers**
22. **Tractor/Loaders/Backhoes**
23. **Crawler tractors**
24. **Skid steer loaders**
25. **Off-Highway tractors**
26. **Dumpers/Tenders**
27. **Other construction equipment**

f. Agricultural Equipment
1. **2-Wheel tractors**
2. **Agricultural tractors**
3. **Agricultural mowers**
4. **Combines**
5. **Sprayers**
6. **Balers**
7. **Tillers > 5 HP**
8. **Swathers**
9. **Hydro power units**
10. **Other agriculture equipment**

TABLE 2 (continued)

g. Logging Equipment
1. **Chain saws > 5 HP**
2. **Shredders > 5 HP**
3. **Log skidders**
4. **Fellers/Bunchers**

h. Airport Ground Support Equipment
1. **Airplane tow tractors**
2. **Baggage/Cargo tow tractors**
3. **Ground power units**
4. **Start units**
5. **Deicing units**
6. **Load lifting and handling**
7. **Service utility carts**
8. **Pressure washers**

i. Pleasure Craft
1. Inboard powerboats <250 HP
2. Outboard powerboats
3. Sterndrive powerboats
4. Inboard sail-auxiliary
5. Outboard sail-auxiliary

j. Commercial and Government Vessels
1. Commercial inboard boats >250 HP
2. Commercial in/outboard boats
3. Commercial tug boats
4. US Coasts Guard boats
5. Seagoing vessels
   - Motorships
   - Steamships

k. Transport Refrigeration Units
1. Small units < 25 HP
2. **Large units > 25 HP**

l. Locomotive and Rail Operations
1. Line haul operations
2. Yard operations

m. Aircraft: Commercial, Military, and General Aviation
1. Landing and Takeoff Operations (LTO)

n. Agricultural Aircraft
1. Aircraft operations below 3,000 ft.

- **The portions of the table shown in bold letters are specific to off-road large spark-ignited engines.**

TABLE 3
Various Fuels, Engine Types, and Horsepower Groups Used in the OFFROAD Model

Fuel	Engine Type	Horsepower Groups
Gasoline	2-stroke	0-2, 2-15, 15-25, 25-50, 50-120, 120-175, 175-250, 250-500, 500-750
Gasoline and LPG/CNG	4-stroke	0-5, 5-15, 15-25, 25-50, 50-120, 120-175, 175-250, 250-500, 500-750

Diesel		0-15, 15-25, 25-50, 50-120, 120-175, 175-250, 250-500, 500-750, 750+

2) Activity Module

This module contains information such as annual average use hours, load factor, brake-specific fuel consumption, and starts per year for each equipment type by fuel, engine type, and horsepower group. The activity information reflects seasonal and temporal conditions, as described below.

a) Seasonal and Temporal Parameters

The equipment types from diverse industries such as agriculture, construction, and recreation, are included in the OFFROAD model, and their usage patterns are not identical. These seasonal and temporal influences are resolved by monthly, weekly, and daily use patterns for each type of equipment.

Most of the categories including off-road large spark-ignited engine category (construction, industrial, light commercial, and airport ground service equipment) have uniform activity throughout the year. Recreational vehicles, lawn and garden, and farm equipment display various seasonal use patterns. Equipment types within a category have the same monthly use pattern except for snowmobiles, snow blowers, chain saws (<=5 HP), and tillers. Although most lawn and garden equipment undergo peak use during the summer, chain saw and tiller use peaks during the winter and spring, respectively. In order to be consistent with the seasonal attributes of reformulated fuels, summertime is defined as May through October while wintertime is considered November through April.

There are three types of weekly use patterns: average, weekday, and weekend. The average, or no peak, use pattern is exhibited by airport ground service and transport refrigeration units. Construction, industrial, and farm display mostly weekday, some Saturday, and less Sunday activity. Instances where weekend use is greater than weekday use would be recreational vehicles and lawn and garden equipment.

The daily activity is distributed into eight 3-hour periods (e.g., 3:00, 6:00, 9:00, etc.). The bulk of the activity occurs between 9 a.m. and 6 p.m., which is the daytime use pattern. Airport ground service equipment is utilized whenever the airport is open, and includes servicing of cargo and regular maintenance. Therefore, the use pattern is primarily during business hours with some off-peak activity. In contrast, transport refrigeration units are operated more evenly throughout the entire day because perishables are shipped at night for morning delivery.

3) Emissions Module

This module contains emission rate equations (emission factors) by model year for HC, CO, NO_X, PM, CO_2, and SO_X emissions. HC emissions are modeled for three types of processes: exhaust, evaporative, and start. The emission factors are a function of new engine emissions expressed in gram per brake horsepower hour (g/bhp-hr), and deterioration rates, expressed as a rate of increase in emissions per useful life.

Since several equipment types use the same types of engines, the exhaust emission factors are engine-specific. Equipment-specific emission rates are obtained by adjusting the appropriate engine emission rate according to how the equipment is used (duty cycle). The model-year-specific emission rates also reflect the effect of reformulated fuels and stringent emission standards adopted by the Board. Due to the lack of emission data, the deterioration rates are generally based on on-road emissions data[1], with the exception of small off-road engines, which were obtained from emission test results provided by engine manufacturers.

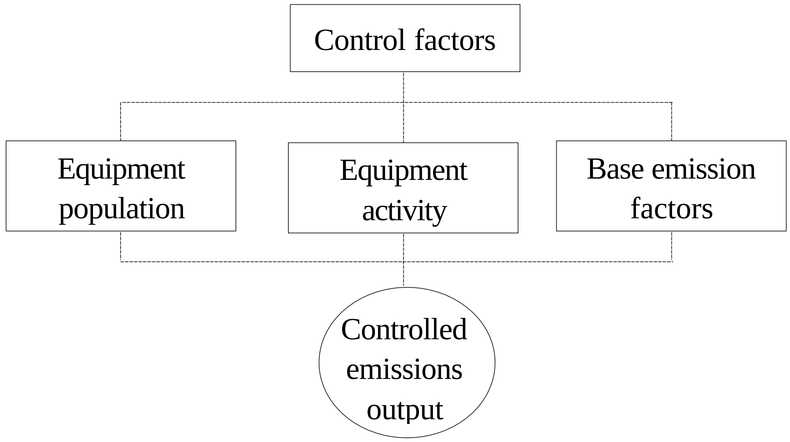
Evaporative emission factors account for refueling, diurnal, hot soak, running, and resting losses. Evaporative emissions are equipment-specific and dependent on fuel systems. Evaporative emissions are only necessary for gasoline equipment since diesel fuel has low volatility and LPG systems are pressure sealed. Due to the lack of data, placeholders are used for hot soak, running, and resting losses. This module also contains correction factors for temperature, reformulated fuels, and volatility. Although no data are currently available, the model is equipped to provide emissions due to start up procedures.

4) Control Factor Module

OFFROAD can also account for regulatory control scenarios as illustrated in Figure 2. The control factor file is a multiplicative adjustment indicated by polluting source, pollutant, beginning year, and ending year. Control factors can be applied to emission rates, activity, and populations. An example of a population control strategy would be to retrofit a particular model year group with an emission control device. Limiting use during peak hours would be an example of an activity control scenario. When this feature is employed, the output consists of both baseline and controlled scenarios.

FIGURE 2
Controlled Emissions Output

1 **California Air Resources Board, "Technical Support Document, Derivation of the EMFAC7E Emission and Correction Factors for On-Road Motor Vehicles," July 1990.**



CHAPTER IV. REVISIONS TO THE BASELINE INVENTORY

A. Introduction

Off-road large spark-ignited (SI) engines are defined as engines of greater than or equal to 25 horsepower and are included in the following OFFROAD categories:

1. Agricultural
2. Airport Ground Support
3. Construction
4. Lawn and Garden
5. Light Duty Commercial
6. Light Duty Industrial
7. Logging
8. Transport Refrigeration Units

B. Emission Factors

The large SI engine equipment classification includes a wide variety of equipment with diverse application that cannot be characterized by one test cycle. Emission test results available from different test projects include the ISO-8178-C2 (“C2”) and ISO-8178-D2 (“D2”) test cycles. The seven-mode C2 cycle is based on variable speed applications such as the lift-truck equipment and is supported by the Industrial Truck Association (ITA). The five-mode D2 cycle is representative of constant speed applications such as generators and compressors where the equipment is started and operated at constant speed for a prolonged period of time. Although most of the equipment in the SI engine >= 25 hp categories may have transient-like characteristics, no consensus has been formed on what transient cycle best describes these engines and there is a lack of emissions test data on transient cycles. Table 4 lists the description of the available test cycles and suggested corresponding applications.

Table 4. Test Cycle Description and Suggested Applications

TEST CYCLE	TEST MODES	APPLICATIONS
ISO-8178-C2	7	SI Engine >= 25hp in Construction, Agricultural, Light Industrial, Lawn & Garden (turf care), Logging, and Airport Ground Support
ISO-8178-D2	5	SI Engine >= 25hp in Light Commercial , Transport Refrigeration Units

Based on the cycles described above for gasoline and gaseous fuel (such as liquefied petroleum gas (LPG) and compressed natural gas (CNG)) powered engines, emissions test data gathered during different test projects are listed in Table 5.

Table 5. Gasoline and LPG Emissions Test Data, Uncontrolled (g/bhp-hr)

ENGINE	HP GROUP	HC	NOX	CO	LOAD FACTOR	TEST FUEL	SOURCE
Gasoline	25-50	5.00 (C2)	6.90 (C2)	95.20 (C2)	0.235	Pre-Phase 2	41.4 hp engine, SwRI/ITA 1993
		3.81 (C2)	7.74 (C2)	50.70 (C2)	0.230	Phase 2	40 hp engine, ARB preliminary
		10.60 (D2)	1.74 (D2)	479.40 (D2)	0.393	Phase 2	37 hp engine, ARB preliminary
	51-120	3.61 (C2)	13.26 (C2)	20.20 (C2)	0.227	Pre-Phase 2	85 hp engine, SwRI/ITA 1993
		3.23 (C2)	13.67 (C2)	49.90 (C2)	0.232	Pre-Phase 2	100 hp engine, Ford/SwRI 1994
		1.49 (C2)	8.32 (C2)	16.33 (C2)	0.283	Phase 2	53 hp engine, ARB preliminary
		3.99 (C2)	5.38 (C2)	124.42 (C2)	0.213	Phase 2	54 hp engine, ARB preliminary
	121+	1.69 (C2)	11.96 (C2)	20.09 (C2)	0.211	Phase 2	205 hp engine, ARB preliminary
LPG	25-50	1.17 (C2)	13.80 (C2)	5.74 (C2)	0.268	LPG	40 hp engine, SwRI/ARB 1993
		1.70 (C2)	11.50 (C2)	8.80 (C2)	0.220	LPG	40 hp engine, ARB preliminary
	51-120	2.30 (C2)	8.60 (C2)	33.80 (C2)	0.218	LPG	85 hp engine, SwRI/ITA 1993
		2.90 (C2)	4.93 (C2)	141.00 (C2)	0.237	LPG	100 hp engine, Ford/SwRI 1994
		0.94 (C2)	11.67 (C2)	7.37 (C2)	0.274	LPG	53 hp engine, ARB preliminary
		0.89 (D2)	9.86 (D2)	2.08 (D2)	0.297	LPG	54 hp engine, ARB preliminary
	121+						no data

Note: **SwRI/ITA 1993** : Final letter report entitled “Emission Tests of Three Lift-Truck Engines”, prepared by Southwest Research Institute (SwRI) for Industrial Truck Association in 1993

ARB preliminary: Preliminary test data obtained through a current ARB project with SwRI entitled "Three–Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines" .
Ford/SwRI 1994: Final report entitled "Emission Tests of a 4.9 Liter Ford Utility Engine in Twelve Configurations", prepared by SwRI for Geometric Results Inc. in 1994.
SwRI/ARB 1993: Final report entitled "Development of Baseline and Controlled Exhaust Emission Rates for Off-Highway Vehicle Engines", prepared by SwRI for the ARB in 1993.

Using the emissions test data listed above, an average zero-hour emission rate (gm/bhp-hr) by horsepower group was calculated for each cycle. Emissions measured using pre-phase 2 fuel were first corrected to phase 2 fuel level. Since the number of engines tested over the D2 cycle was small, staff used the emissions data from the fourth mode of the C2 test cycle in order to approximate the characteristics of the D2 cycle. The load factor is defined as the ratio of the average horsepower to the maximum rated horsepower of the equipment. Table 6 shows the average zero-hour emission rates by variable and constant speed application. Depending on the application type, specific zero-hour emission rates were assigned to each equipment type.

Table 6. Average Zero-Hour Emission Rates (Uncontrolled, g/bhp-hr)

ENGINE	HP GROUP	VARIABLE SPEED APPLICATION			CONSTANT SPEED APPLICATION		
		HC	NOX	CO	HC	NOX	CO
GASOLINE	25-50	4.21	7.41	65.72	4.77	6.77	140.81
	51-120	2.95	10.32	50.05	2.31	10.84	36.23
	121+	1.69	11.96	20.09	1.46	13.49	12.30
LPG	25-50	1.44	12.65	7.27	1.08	13.75	2.08
	51+	1.62	10.14	20.58	0.77	13.53	1.35

The 100 hp engine tested on LPG fuel was not used because the air-fuel ratio was richer than it should have been due to improper calibration. As stated by the carburetor manufacturer, the test result was not representative of a properly calibrated LPG system.

Most of the engines tested were liquid-cooled. The 37 hp gasoline engine tested by SwRI was an air-cooled, side-valve engine design which was calibrated extremely rich and had very high HC and CO and very low NOx readings. These types of engines are typically calibrated to be used in constant speed applications such as generators, compressors, pumps, and welders. From SwRI, staff obtained the manufacturer and model of the 37 hp engine shown in Table 5. Using the manufacturer and model information from the test project mentioned above and Power System Research (PSR) database which contains manufacturer and model specific information for engines installed in majority of the off-road equipment used in North America, staff was able to identify that 22 percent of the light commercial equipment in the 25 to 50 hp range are equipped with air-cooled engines. In the 25-50 hp range shown in Table 6, the emission factor for gasoline powered constant speed application reflected 22% air-cooled design (based on 37 hp engine test data) and 78% liquid-cooled engines. For 51+ hp categories, 100 percent of the engines were assumed to be liquid-cooled.

Particulate matter emission factor are taken from the 1992 report entitled "Off-Road Mobile Equipment Emission Inventory Estimate" prepared by Booz Allen & Hamilton (BAH) for the ARB.

C. Load Factor Correction

The emission rates shown in Table 6 reflect the load factor of the cycle being used for testing, staff evaluated the effect that various loads have on emissions. The majority of the equipment in the large SI engine category is characterized with load factors ranging from 0.20 to 0.80. Emission test results by mode based on the C2 test cycle were used to derive load correction factors. The average emissions and load factor for each mode were computed and normalized against the composite cycle average emissions. The results were plotted by load factor. The normalized emissions versus load factor data points were then curve fit to obtain equations for load correction factors. Figures 3-8 show the results of the analysis performed on mode specific emission data.

Figure 3. HC, Gas

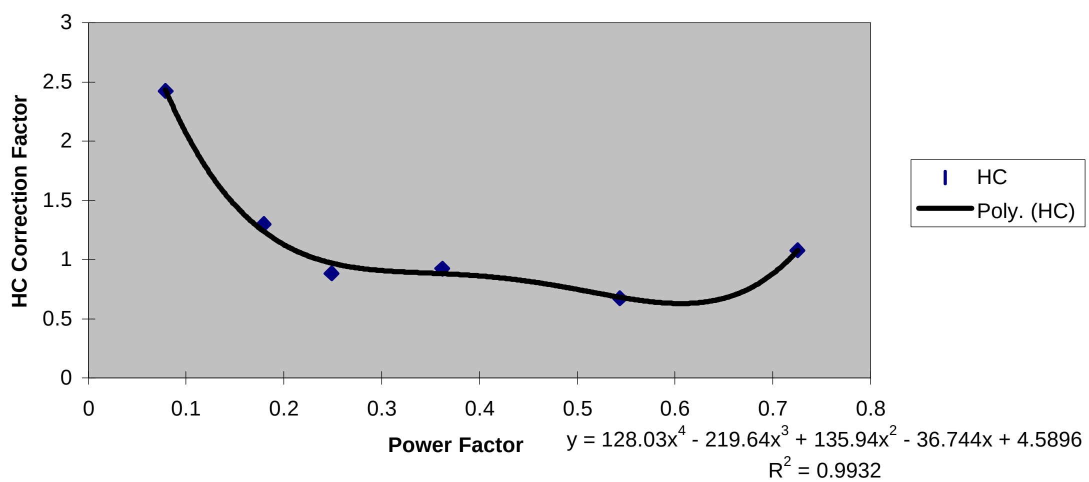


Figure 4. NOx, Gas

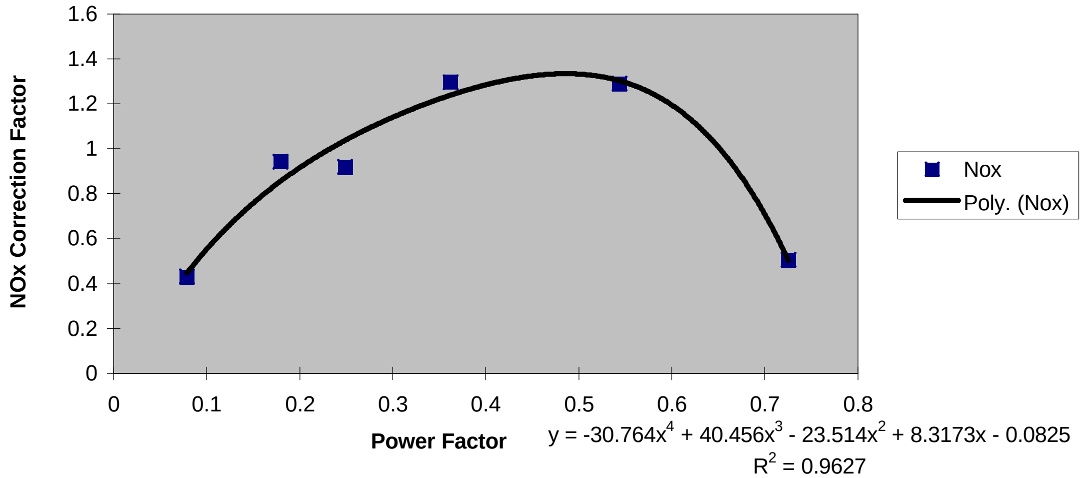


Figure 5. CO, Gas

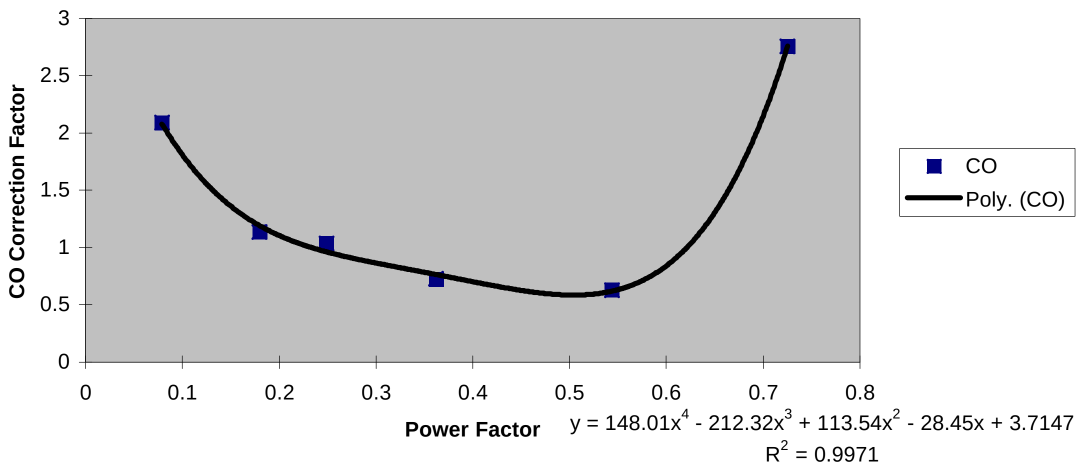


Figure 6. HC, LPG

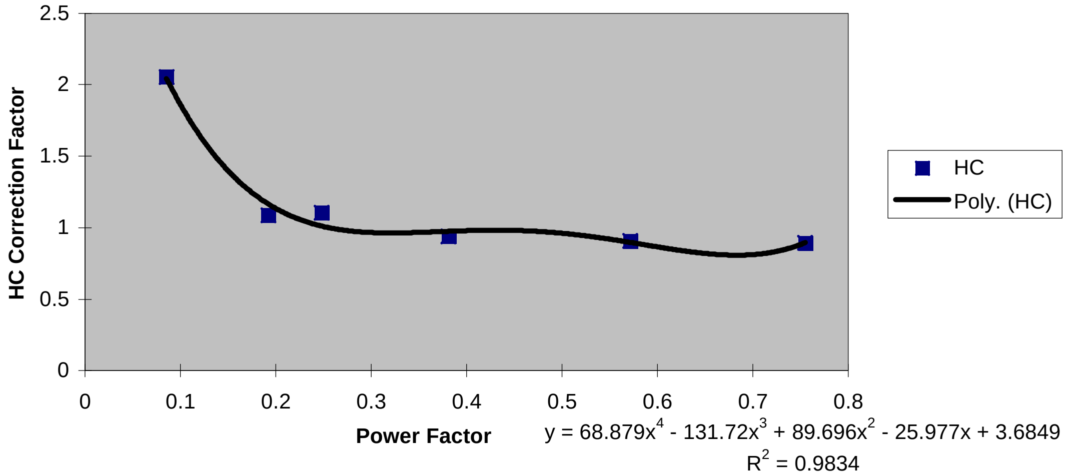


Figure 7. NOx, LPG

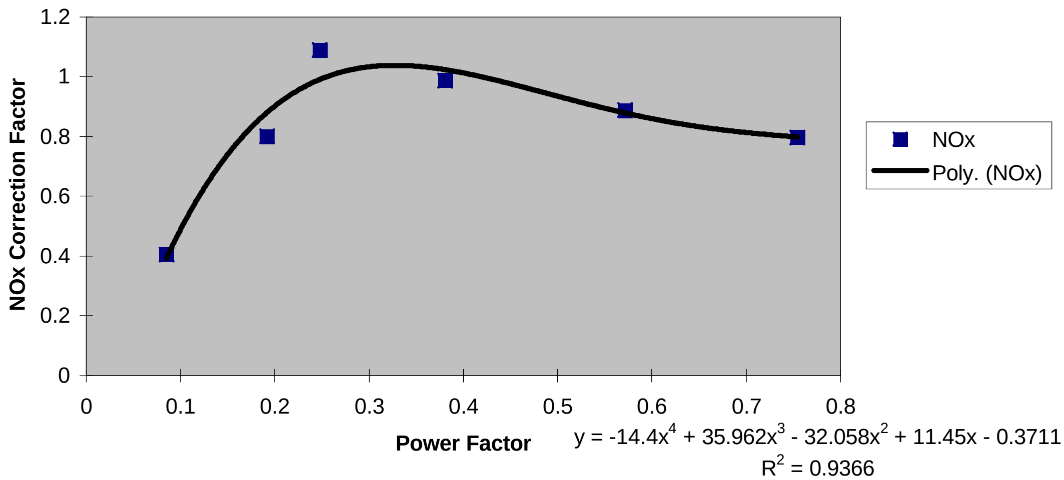
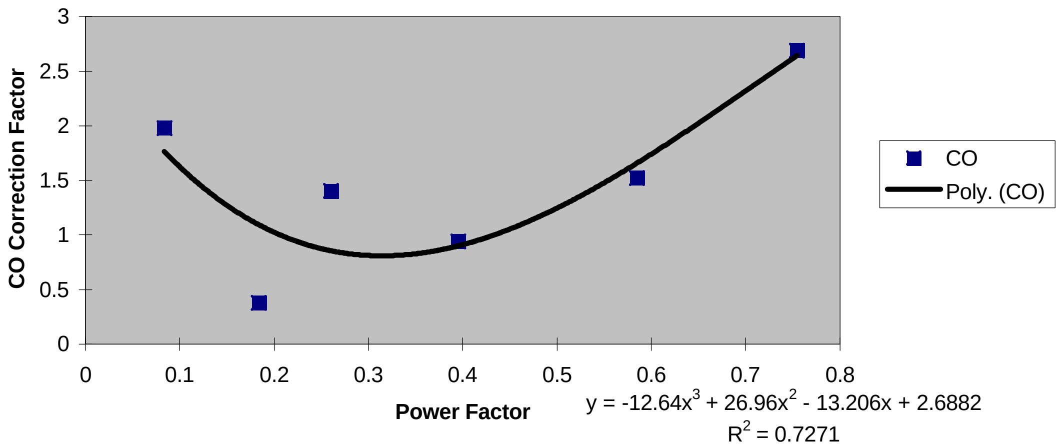


Figure 8. CO, LPG



Using the results of this analysis, equipment specific zero-hour emission rates were corrected for respective loads. Since the OFFROAD model for SI engine >= 25 hp requires emissions factor by fuel and by horsepower groups, each of the equipment specific load factor corrected emission factor was weighted by that equipment's activity (average hp, usage, and population) to derive a composite emission factor by horsepower group. The composite zero-hour emission rates are shown in Table 7.

Table 7. Activity-Weighted Load-Corrected Zero-Hour Emission Rates (g/bhp-hr)

HP GROUP	GAS HC	GAS NOX	GAS CO	LPG HC	LPG NOX	LPG CO
25-50	3.76	8.01	89.90	1.38	13.00	7.02
51-120	2.63	11.84	43.80	1.55	10.53	19.72
121+	1.61	12.94	20.80	1.38	10.51	16.47

D. Deterioration Rates

Deterioration rates, the change in emissions as a function of usage, were derived from a report prepared for the ARB by Energy and Environmental Analysis (EEA) entitled, "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model" dated 1997. EEA calculated deterioration factors for the 25+ hp range based on observed deterioration factors for on-highway engines with similar horsepower ranges. The deterioration rates, as discussed in the EEA documentation, were presented as a percent increase in emissions over the percent of life consumed. Table 8 shows the deterioration factors and on-highway engine surrogates used to estimate the OFFROAD deterioration rates.

Table 8. On-Highway Surrogate for OFFROAD Deterioration Factors

HP Group	Deterioration Factor % increase			On-Highway Equivalent
	HC	CO	NOX	
25-50 hp	1.38	0.83	0.064	No market equivalent, assume 51-120 hp range numbers.
51-120 hp	1.38	0.83	0.064	Compared to non-catalyst, 1969 gasoline light duty trucks
120+ hp	0.37	0.56	0.14	Compared to non-catalyst, 1970 heavy duty gasoline vehicles.

Using the average useful life within a horsepower group, deterioration factors presented in terms of percentages were converted to deterioration rates with units of grams/brakehorsepower-hour^2 (g/bhp-hr^2). The deterioration rates are a function of cumulative hours of use. Due to lack of data, LPG/CNG engines were assumed to have the same deterioration factors as gasoline engines.

Since deterioration rates are based on on-road vehicle data instead of off-road engine test data, staff used the highest lifetime hours for each horsepower group in calculating the deterioration rates. In doing so, staff ensured that over its useful life, an off-road engine would not deteriorate more than the on-road engine surrogate. For example, the deterioration rate for gasoline 25-50 hp group was calculated by multiplying the activity weighted zero-hour emission rate for each equipment in the horsepower group by the appropriate deterioration factor (for HC, it is 1.38 percent increase per % of useful life consumed) divided by the highest lifetime hours (for the gasoline 25-50 hp group, it is 12,600 hours). Table 9 shows the different highest lifetime hours used.

Table 9. Lifetime Hours Used for DR Calculations

HP GROUP	HIGHEST LIFETIME HOURS
Gasoline 25-50	12,600
Gasoline 51-120	12,600
Gasoline 121+	14,289
LPG 25-50	12,600
LPG 51-120	12,600
LPG 121+	14,289

E. Useful Life

Useful life as used in the OFFROAD model is a calculated value based on the equipment's useful life hours. From the Power System Research (PSR) database, a useful hours figure is given for each equipment. To calculate useful life, the useful hours for a specific type of equipment is divided by the activity of that equipment (regardless of horsepower) and its appropriate load factor.

F. Activity Inputs

Input factors such as population, usage, useful life, and load factors for the base year (1990) were obtained from the 1996 edition of PSR database. PSR is an independent research firm with more than 15 years of experience in research and development related to engine product life cycles. This database is a flexible tool containing a large amount of off-road equipment data from one independent source.

Wherever possible, other resources such as other government agency's data, research publications, and industry association data were evaluated to cross check PSR's accuracy. This analysis resulted in the following major changes to PSR's in-use population estimates. (1) Population estimates for the forklift category were revised. In the BAH report, the California in-use population estimates and the LPG to gasoline split are different from PSR. Based upon manufacturer's product shipment data provided by the U.S. Census Bureau, Manufactures - Industry Series data indicated that there are more LPG-equipped forklifts than there are gasoline forklifts. The Industry Series indicated a 70/30 LPG to gasoline split, while PSR indicated a 50/50 split between LPG and gasoline forklifts. One reason for the discrepancy could be because PSR estimates the population of the engines leaving the factory. In many cases, the engines are later retrofitted for LPG fuel. BAH reported a 62/38 split between LPG and gasoline forklifts. (2) The BAH report indicated an in-use forklift population of 35,586 while PSR reported 20,378.

A 1996 report prepared for the National Propane Gas Association (NPGA) entitled "The Role of Propane in the Fork Lift/Industrial Truck Market: A Study of its Status, Threats, and Opportunities" indicated population estimates closer to the BAH estimates than PSR. Since the source for the forklift estimates in the BAH report is from the Industrial Truck Association and the LPG to gasoline split seems reasonable, BAH estimates for forklift population by fuel type are used instead of PSR. Table 10 shows the forklift gasoline/LPG distribution used in the OFFROAD model.

Table 10. Forklift Gasoline/LPG Distribution Used in OFFROAD Model

HP GROUP	GASOLINE	LPG
25-50	2916	4757
51-120	10233	16695
121-175	374	611
Total	13523	22063

From anecdotal evidence and other research findings, the population estimates in the light commercial equipment category, which consists of generators, compressors, pumps, welders, and pressure washers, were revised from the original PSR estimates. In the light commercial category, PSR's database does not distinguish between what is considered off-road and stationary equipment. The 1992 BAH report stated "interviews with engine manufacturers (DDC, Caterpillar, Cummins, and Deutz) and equipment manufacturers (Stewart & Stevenson and Valley Diesel) suggest that the majority of equipment in these categories over 100 HP is in fact stationary." The report provides the split between portable and stationary engines by horsepower as shown in Table 11. Using Table 11, staff modified the PSR's estimates for compressors, generators, welders, pumps and pressure washers.

Table 11. Light-Duty Commercial Portable/Stationary Adjustments

HP GROUP	PERCENT PORTABLE	PERCENT STATIONARY
25-50	90	10
51-120	70	30
121-175	20	80
176-250	15	85
251-500	10	90

PSR's database indicated that generators in the greater than 25hp range were mostly gasoline-fueled as opposed to LPG-fueled. Staff believes that generators, like forklifts, may be retrofitted to LPG fuel after it is shipped from the original equipment manufacturers. Because of the lack of

data indicating the split between these two types of generators, the original population estimates are used.
In addition to forklifts that use internal combustion (IC) engine, there is a majority of forklifts that operate on electricity. In the NPGA report, electric forklifts (both ride-on and motorized walk-behind) are listed as having an in-use nationwide population in 1995 of 730,860. Applying the IC forklift California percentage (11%), the California in-use population for electric forklifts in 1995 is estimated as 80,395 (62%) as compared to 50,166 IC forklifts (38%).

The population estimates, activity and other input factors used for the large SI engines category are shown in Attachment 1. The emission factor inputs are shown in Attachment 2.

G. Growth Factors

The growth factors were obtained from the 1994 California State Fullerton report prepared for ARB entitled "A Study to Develop Projected Activity for Non-Road Mobile Categories in California, 1970-2020" using 1990 as the base year. Growth factors for major categories, non-farm equipment (construction, light duty commercial, light duty industrial, logging) and farm equipment (agricultural), are based on employment and gasoline sales data respectively. Based upon received written comments, the growth factors for construction and agricultural equipment have been revised to show the decrease in the gasoline construction and agricultural equipment in the future.

H. Non-Preempted/Preempted Classification

In the OFFROAD model, each equipment type is classified as preempted (P) or non-preempted (N) as shown in Attachment 2. The U.S. Environmental Protection Agency (USEPA) has the sole authority to adopt emissions control standards for preempted equipment. Generally, the U.S EPA has control over new farm and construction equipment less than 175 horsepower. The list below shows equipment that utilizes engines with 25 or greater horsepower and are not considered construction or farm equipment.

<u>Non-Preempted Equipment List</u>
Aircraft Ground Power
Baggage Handling
Forklifts (not rough terrain) not powered by diesel engines
Generator Sets
Mining Equipment not otherwise primarily used in the construction industry
Off-Highway Recreational Vehicles (Specialty Vehicles)
Other Industrial Equipment
Refrigeration Units less than 50 horsepower
Scrubbers/Sweepers
Tow/Push
Turf Care Equipment

I. Large SI Engine (25HP+) Emission Inventory

Tables 12 and 13 show the 1990 and 2010 statewide uncontrolled exhaust emission inventory for the large SI off-road engines category respectively. The OFFROAD model uses the designation of G4 for gasoline fueled 4-stroke engines and C4 for gaseous fueled 4-stroke engines.

Table 12. Uncontrolled Exhaust Emissions for 1990

Calendar Year 1990 Statewide, Uncontrol

P/N	FUEL	HP	1990 Pop	Activity (hrs/day)	ROG Exh	CO Exh	NOX Exh	PM Exh
N	C4	50	4,947	23,818	0.79	3.36	4.37	0.02
		120	16,983	82,632	5.30	56.28	20.98	0.12
		175	770	3,069	0.25	3.39	1.70	0.01
		250	32	277	0.06	0.84	0.44	0.00
		500	6	163	0.08	1.06	0.57	0.00
	C4 Total		22,738	109,959	6.48	64.94	28.05	0.15
	G4	50	18,664	23,254	2.25	57.99	3.09	0.02
		120	14,807	54,990	6.43	113.94	16.91	0.08
		175	928	2,461	0.26	4.56	1.85	0.01
		250	183	524	0.04	0.78	0.30	0.00
		500	14	21	0.02	0.27	0.12	0.00
	G4 Total		34,596	81,250	9.00	177.54	22.27	0.12
N Total			57,334	191,209	15.48	242.48	50.32	0.27
P	C4	50	29	675	0.04	0.19	0.27	0.00
		120	60	1,397	0.27	3.01	1.24	0.01
		175	9	233	0.05	0.66	0.35	0.00
	C4 Total		98	2,305	0.36	3.86	1.86	0.01
	G4	50	10,652	6,542	0.69	19.09	1.15	0.01
		120	14,525	9,690	1.64	31.36	5.46	0.03
		175	3,122	1,200	0.16	2.76	1.23	0.01
	G4 Total		28,299	17,431	2.49	53.21	7.84	0.04
P Total			28,397	19,736	2.85	57.06	9.70	0.05
Grand Total			85,731	210,946	18.33	299.54	60.02	0.32

Note : C4 : 4 Stroke LPG/CNG
G4 : 4 Stroke Gasoline

Table 13. Uncontrolled Exhaust Emissions for 2010

Calendar Year 2010 Statewide, Uncontrol

P/N	FUEL	HP	2010 Pop	Activity (hrs/day)	ROG Exh	CO Exh	NOX Exh	PM Exh
N	C4	50	6,384	30,524	1.01	4.29	5.60	0.03
		120	21,689	105,525	6.72	71.52	26.80	0.15
		175	967	3,913	0.31	4.30	2.16	0.01
		250	51	365	0.08	1.01	0.53	0.00
		500	8	189	0.09	1.23	0.66	0.00
	C4 Total		29,099	140,516	8.21	82.35	35.75	0.19
	G4	50	22,397	28,889	2.63	62.20	4.49	0.03
		120	17,754	64,186	6.98	115.40	20.77	0.10
		175	1,213	3,025	0.30	4.84	2.40	0.01
		250	258	846	0.06	1.02	0.48	0.00
		500	24	34	0.02	0.37	0.20	0.00
	G4 Total		41,646	96,980	10.00	183.84	28.34	0.14
N Total			70,745	237,496	18.21	266.19	64.08	0.33
P	C4	50	33	781	0.05	0.22	0.31	0.00
		120	69	1,616	0.31	3.48	1.44	0.01
		175	11	269	0.06	0.76	0.41	0.00
	C4 Total		113	2,666	0.42	4.46	2.15	0.01
	G4	50	8,896	5,728	0.55	14.18	1.03	0.01
		120	11,806	8,332	1.27	22.44	4.74	0.02
		175	2,034	847	0.11	1.67	0.89	0.00
	G4 Total		22,736	14,907	1.93	38.29	6.67	0.04
P Total			22,849	17,573	2.35	42.75	8.82	0.05
Grand Total			93,594	255,069	20.56	308.94	72.90	0.38

Note : C4 : 4 Stroke LPG/CNG
G4 : 4 Stroke Gasoline

CHAPTER V. COMPARISON BETWEEN OFFROAD OUTPUT AND SIP INVENTORY

Table 14 compares the 1990 and 2010 statewide uncontrolled emissions inventory for the 1994 State Implementation Plan (SIP) and the OFFROAD model.

Table 14. Comparison of Uncontrolled Statewide Emission Inventory

YEAR	OFFROAD MODEL			SIP Inventory		
	ROG (tons/day)	NOX (tons/day)	CO (tons/day)	ROG (tons/day)	NOX (tons/day)	CO (tons/day)
1990	18.33	60.02	299.55	70.95	44.61	2065.31
2010	20.56	72.90	308.94	100.20	66.38	3083.00

The difference in emissions inventories are due to updates in baseline emission factors, load factor, population and activity estimates, and the inclusion of deterioration rates. Tables 15 and 16 show the difference in emission factors and various activity input factors. Additional differences between the 2010 SIP and OFFROAD inventory are due to the different growth factors used. SIP estimates were calculated based on 50 percent growth in 2010 population from 1990 and OFFROAD estimates are calculated based on 23 percent growth in 2010 population from 1990.

Table 15. Comparison of Uncontrolled Emission Factors (g/bhp-hr)

FUEL	HP GROUP	OFFROAD MODEL			SIP Inventory			PERCENT DIFF. FROM SIP
		ROG	NOX	ROG+NOX	ROG	NOX	ROG+NOX	ROG+NOX
GASOLINE	25-50	3.76	8.01	11.77	8.50	2.50	11.00	7.0%
	51-120	2.63	11.84	14.47	8.25	3.00	11.25	28.6%
	121+	1.61	12.94	14.55	7.50	4.50	12.00	21.3%
LPG	25-50	1.38	13.00	14.38	6.12	3.00	9.12	57.8%
	51-120	1.55	10.53	12.08	6.12	3.60	9.72	24.3%
	121+	1.38	10.51	11.89	6.12	5.40	11.52	3.2%

Table 16. Stepwise Analysis between OFFROAD and SIP Inventory

Stepwise Analysis	OFFROAD Model	SIP Inventory	Percent Diff. From SIP
1990 Population	86111	105204	-18.15%
Pop*Act (hr/yr)	7.74E+07	7.11E+07	8.86%
Pop*Act*Avg Hp (hr-hp/yr)	5.07E+09	5.60E+09	-9.46%
Pop*Act*Avg Hp*Load (hr-hp/yr)	1.77E+09	3.09E+09	-42.72%

CHAPTER VI. SUMMARY AND CONCLUSIONS

This Board item marks the second in a series of presentations to the Board seeking approval of the off-road inventory in its entirety. The finalization of the off-road large spark-ignited engine inventory is tied to pending regulatory action regarding this portion of the fleet with the understanding that estimates of effectiveness and cost depend heavily upon the accuracy of the inventory estimates.

The off-road large spark-ignited engine inventory estimates presented in this report were subjected to extensive public review and technical scrutiny. All issues regarding the accuracy of the inventory were addressed. It is believed that this is the most accurate estimate of emissions from this class of engines available.

Staff recommends the approval of the statewide, 1990 emissions inventory for off-road large spark-ignited engines as well as the projections to future years.