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OFFROAD Modeling Change Technical Memo

SUBJECT: Addendum to Evaporative Emissions for Small Off-Road Engines to Include Large-Spark Ignition Engines

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Summary

The OFFROAD model is used to estimate the contributions of emissions from various equipment types to the overall off-road emissions inventory. For the first time, OFFROAD will include an estimate of the evaporative emissions from large spark-ignited (LSI) engines, including those used in recreational marine applications. The methodology used to model these emissions is similar to that developed for the small off-road engines (SORE) incorporated into a prior version of OFFROAD. Additional information may be found on ARB's website at:

<http://www.arb.ca.gov/msei/off-road/updates.htm#soreevap>

Evaporative emissions from recreational vehicles (such as all terrain vehicles and off-road motorcycles) will not be included in the OFFROAD model at this time because efforts to gather the information needed to finalize this category is still underway.

It is estimated that the inclusion of evaporative emissions from LSI engines will result in an increase in the statewide reactive organic gas emissions inventory of 24 tons per day in calendar year 2002. Tables 1 and 2 show the emissions impact for various areas of the state.

**Table 1. 2002 Baseline Evaporative Emissions for LSI Equipment
(Annual Average - Tons per Day)**

Area	Diurnal	Hot Soak	Resting	Running	Total
Statewide	4.84	9.58	5.25	4.76	24.43
South Coast AB	1.64	2.67	1.62	1.47	7.40
San Francisco AB	0.50	1.15	0.59	0.66	2.90
San Joaquin Valley AB	0.54	0.93	0.46	0.44	2.37
San Diego AB	0.50	0.95	0.71	0.47	2.63
Sacramento Valley AB	0.64	1.28	0.61	0.58	3.11

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**Table 2. 2015 Baseline Evaporative Emissions for LSI Equipment
(Annual Average - Tons per Day)**

Area	Diurnal	Hot Soak	Resting	Running	Total
Statewide	5.87	10.86	6.39	6.30	29.42
South Coast AB	1.98	3.02	1.97	1.89	8.86
San Francisco AB	0.61	1.31	0.72	0.86	3.50
San Joaquin Valley AB	0.65	1.06	0.55	0.59	2.85
San Diego AB	0.61	1.09	0.85	0.62	3.17
Sacramento Valley AB	0.78	1.46	0.75	0.78	3.77

Background

LSI engines have a rating of greater than, or equal to 25 horsepower, and are typically used in off-road applications such as industrial, commercial, construction and agriculture. The equipment types that use LSI engines include specialty vehicles, forklifts, portable generators, large turf care equipment, irrigation pumps, welders, air compressors, scrubber/sweepers, and airport service vehicles. For a more detailed description of off-road LSI engines, please refer to:

<http://www.arb.ca.gov/msprog/mailouts/msc9827/msc9827.doc>

In support of this analysis, several off-road engine and vehicles were tested in an airtight enclosure or “shed” in a laboratory setting. By varying the temperature in the shed, the evaporative emission rate of each piece of tested equipment was determined.

Methodology

Evaporative emissions are modeled as four separate processes according to the cause of fuel vaporization. Diurnal emissions are attributable to increases in ambient temperature. Hot soaks occur immediately following engine operation where the driving force of vaporization is the radiant heat from the engine or heating of the fuel through circulation. Running losses occur while the engine is being operated and resting losses are primarily permeation.

As stated earlier, the methodology used by staff to determine the evaporative emissions for LSI engines is the same as that described in the SORE memorandum referenced above.

Population and Activity

No changes to population or activity are being proposed for this update. Mail-Out 98-27 presents the population and activity factors for LSI engines included in the current version of the OFFROAD model.

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Emission Testing

Automotive Testing Laboratories, Inc. (ATL) under contract to the ARB performed evaporative emissions testing on the thirteen LSI engines. ATL's report entitled "Collection of Evaporative Emissions Data from Off-Road Equipment" serves as the basis for this proposed modification to the off-road emissions inventory. This report can be accessed via the link below:

<http://www.arb.ca.gov/research/apr/past/mobile.htm#emission%20inventory%20>

Each piece of equipment was selected to be representative of typical LSI engines in various categories of the OFFROAD model. Both new and in-use vehicles and engines were procured for this effort. Table 3 lists the number of tests for each equipment type completed by ATL.

Table 3. Equipment Tested for Baseline Emissions

Equipment Type	Diurnal	Resting Loss	Hot Soak	Running Loss
Outboard (G2)	1	1	1	0
Outboard (G4)	2	2	2	0
Personal Watercraft	3	3	3	0
Sterndrive	3	3	3	0

Basic Emission Rates

The basic emission rates for diurnal, resting, hot soak and running losses were determined in a manner similar to SORE equipment. However, unlike SORE, the equipment in LSI test fleet was segregated into only two strata ('new' and 'old'). Table 4 shows the equipment tested.

Table 4. Evaporative Emissions Test Results

ID	Mfr	MY	Strata	Diurnal (g/day)	Resting (g/day)	Hot Soak (g/event)	Running (g/hr)
Outboard(G2)	Evinrude	77	Old	15.83	3.80	6.14	
Outboard(G4)1	Mercury	01	New	14.49	10.90	4.91	
Outboard(G4)2	Johnson	00	New	35.51	14.35	13.22	
PWC1	Yamaha	92	Old	6.72	7.21	5.71	
PWC2	Bombardier	91	Old	13.22	10.47	7.22	
PWC3	Yamaha	01	New	3.79	2.97	1.55	
Sterndrive1	Schuster	77	Old	50.37	12.97	29.56	
Sterndrive2	Yamaha	98	New	20.45	17.04	10.09	
Sterndrive3	GM	02	New	10.52	12.47	3.66	

In most cases, a clear pattern of deterioration between new and old equipment could not be discerned. Therefore, straight averages of the emission rates were used across the equipment's lifetime. Table 5 lists the estimated emissions for brand new equipment at the zero hour rate (ZHR), the emissions at the useful life

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point (UL), and at the end of the equipment life (END), for all tested equipment types.

Table 5. Basic Evaporative Emission Rates

Equipment Type	Diurnal (g/day)			Resting Loss (g/day)			Hot Soak (g/event)			Running Loss (g/day)		
	ZHR	UL	END	ZHR	UL	END	ZHR	UL	END	ZHR	UL	END
Outboard(G2)	15.83	15.83	15.83	3.80	3.80	3.80	6.14	6.14	6.14			
Outboard(G4)	25.00	25.00	25.00	12.63	12.63	12.63	9.07	9.07	9.07			
PWC	7.91	7.91	7.91	6.88	6.88	6.88	4.83	4.83	4.83			
Stern-drive	27.11	27.11	27.11	14.16	14.16	14.16	14.44	14.44	14.44			

Running loss measurements are performed while the equipment is being operated within the shed. Exhaust emissions are ported out of the enclosure to ensure that only evaporative emissions are being measured. Due to the difficulty associated with measuring running losses, few tests were performed on the LSI fleet.

RVP/Temperature Correction Factors

Evaporative emission rates are impacted by fuel volatility as measured by the Reid Vapor Pressure (RVP) and ambient temperature. Staff utilized the same temperature/RVP correction factors derived from the SORE testing to adjust the LSI emission rates.

Modeling Change

The OFFROAD model will be modified to accept evaporative emission rates for all four processes for all LSI equipment types. The emission rates will take the form of a ZHR with a DR (see Table 6), which is a function of equipment age. Because of lack of data, average emissions will be used across the life of the equipment (DR=0). The equations used are included in the SORE documentation.

Also due to the limited testing, emission rates for the equipment types in this addendum as well as the SORE equipment tested will be used as surrogates for other LSI equipment shown in Appendix A. The surrogates were determined based on similarities in their engine size. The evaporative test results for other off-road engines are listed in Appendix B. The details of the evaporative tests performed in support of this proposed inventory update are presented in a report entitled "Collection of Evaporative Emissions Data From Off-Road Equipment" prepared by Automotive Testing Laboratories, Inc. (ATL), under contract to the Air Resources Board. The document is available on our website at

<http://www.arb.ca.gov/research/abstracts/00-315.htm>

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Table 6. LSI Evaporative Emission Factors

Equipment Type	Diurnal		Resting Loss		Hot Soak		Running Loss	
	ZHR (g/day)	DR (g/day/yr)	ZHR (g/day)	DR (g/day/yr)	ZHR (g/event)	DR (g/event/yr)	ZHR (g/day)	DR (g/day/yr)
Outboard(G2)	15.83	0.00	3.80	0.00	6.14	0.00		
Outboard(G4)	25.00	0.00	12.63	0.00	9.07	0.00		
PWC	3.79	0.00	2.97	0.00	1.55	0.00		
Sterndrive	27.11	0.00	14.16	0.00	14.44	0.00		

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Appendix A

Equipment Types Tested by ATL as Surrogates for LSI Equipment

OFFROAD Equipment Type	ATL tested equipment
Asphalt Paver	Forklift
Concrete Paver	Forklift
Roller	Forklift
Scraper	Forklift
Paving Equipment	Forklift
Trencher	Forklift
Bore/Drill Rig	Forklift
Excavator	Forklift
Concrete/Industrial Saw	Generator
Crane	Forklift
Grader	Forklift
Off-Highway Truck	Forklift
Crushing/Processing Equipment	Forklift
Rough Terrain Forklift	Forklift
Rubber Tired Loader	Forklift
Rubber Tired Dozer	Forklift
Tractor/Loader/Backhoe	Forklift
Crawler Tractor	Forklift
Skid Steer Loader	Forklift
Off-Highway Tractor	Forklift
Dumper/Tender	Forklift
Other Construction Equipment	Forklift
Aerial Lift	Forklift
Forklift	Forklift
Sweeper/Scrubber	Forklift
Other General Industrial Equipment	Forklift
Other Material Handling Equipment	Forklift
Industrial Tractor	Forklift
Lawn & Garden Tractor	Lawnmower
Commercial Turf Equipment	Lawnmower
Other Lawn & Garden Equipment	Lawnmower
Agricultural Tractor	All Terrain Vehicle
Combine	All Terrain Vehicle
Baler	All Terrain Vehicle
Agricultural Mower	All Terrain Vehicle
Sprayer	All Terrain Vehicle
Tiller >5 HP	All Terrain Vehicle
Swather	All Terrain Vehicle
Hydro Power Unit	Generator
Other Agricultural Equipment	All Terrain Vehicle
Generator Set	Generator
Pump	Generator
Air Compressor	Generator
Gas Compressor	Generator
Welder	Generator
Pressure Washer	Generator
Chainsaw >5 HP	Chainsaw
Shredder>5 HP	Chainsaw
Skidder	Forklift
Feller/Buncher	Forklift
Aircraft Support Equipment	Forklift
Terminal Tractor	Forklift
A/C Tug, Narrow Body	Forklift
A/C Tug, Wide Body	Forklift
Air Conditioner	Generator
Air Start Unit	Generator
Baggage Tug	Forklift
Belt Loader	Forklift
Bobtail	Forklift
Cargo Loader	Forklift
Deicer	Forklift

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(continued)

Equipment Types Tested by ATL as Surrogates for LSI Equipment

OFFROAD Equipment Type	ATL tested equipment
Fuel Truck	Forklift
Ground Power Unit	Generator
Lav Truck	Forklift
Lift	Forklift
Maintenance Truck	Forklift
Other Ground Support Equipment	Forklift
Service Truck	Forklift
Water Truck	Forklift
Transport Refrigeration Unit	Generator
Miscellaneous Portable Equipment	Generator
Off-Road Motorcycle	Dirtbike
All Terrain Vehicle	All Terrain Vehicle
Vessel w/Outboard Engine	Outboard(G2)
Sailboat Auxiliary Outboard Engine	Outboard(G2)
Personal Water Craft	PWC
Vessels w/Inboard Engine	Sterndrive
Vessels w/Outboard Engine	Outboard(G4)
Vessels w/Sterndrive Engine	Sterndrive
Vessels w/Inboard Jet Engine	Sterndrive

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Appendix B

Evaporative Emission Factors for Other Off-Road Equipment

Equipment Type	Diurnal			Resting Loss			Hot Soak			Running Loss		
	Grams per Day			Grams per Day			Grams per Event			Grams per Hour		
	ZHR	DR1	DR2	ZHR	DR1	DR2	ZHR	DR1	DR2	ZHR	DR1	DR2
Chainsaw	0.44	0.010	0.010	0.21	0.004	0.004	0.12	0.044	0.044	0.58	0.000	0.000
Lawnmower	2.05	0.096	0.889	1.15	0.054	0.500	0.65	0.071	0.071	1.71	1.894	1.894
Tractor	5.93	0.343	0.343	3.33	0.194	0.194	1.23	0.123	0.123	1.71	1.894	1.894
ATV	8.14	0.360	0.360	2.43	0.105	0.105	2.40	0.200	0.200	11.3	0.000	0.000
Trimmer/Edger	0.63	0.000	0.000	0.30	0.000	0.000	0.29	0.000	0.000	0.58	0.000	0.000
Leaf Blower	1.07	0.000	0.000	0.51	0.000	0.000	0.15	0.000	0.000	0.58	0.000	0.000
Tiller	2.89	0.000	0.000	1.24	0.000	0.000	0.57	0.000	0.000	1.71	1.894	1.894
Generator/Welder	12.04	0.000	0.000	2.29	0.000	0.000	3.24	0.000	0.000	1.80	1.470	1.470
Forklift	30.61	0.000	0.000	5.40	0.000	0.000	10.5	0.000	0.000	4.61	0.000	0.000