OFFROAD Modeling Change Technical Memo

SUBJECT: ESTIMATION OF THE IMPACT OF ETHANOL ON OFF-ROAD EVAPORATIVE EMISSIONS (Federal 8 HOUR OZONE TEMPERATURE PROFILE)

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Summary

Faced with evidence that methyl tertiary butyl ether (MTBE) found in ground and surface water posed a significant health threat to California citizens, the Air Resources Board (ARB or Board), at the instruction of the Governor, began the phase out its use in 2003.

In order to comply with the federal mandate requiring a two percent oxygen content in commercially dispensed gasoline, ethanol (EtOH) was used as an additive beginning in 2004. This memo proposes modifications to the evaporative emission estimates contained in the OFFROAD model to reflect the impacts of the inclusion of ethanol in gasoline. Tables 1 and 2 present the estimated increases in reactive organic gases (ROG) evaporative emissions attributable to ethanol in gasoline based on the California 8 hour ozone temperature profile. Information on methodology to calculate evaporative emissions for small off-road equipment can be found at http://www.arb.ca.gov/msei/off-road/updates.htm#soreevap. Large off-road and recreational marine evaporative emissions is described in the document: Addendum to Evaporative Emissions for Small Off-Road Engines to Include Large-Spark Ignition Engines.

Table 1. 2002 Off-road Equipment Summer Average ROG Evaporative Emissions Inventory (Federal 8 Hr. Ozone)

Area	Evaporative Emission * (MTBE) Tons/day	Evaporative Emission * (Ethanol) Tons/day	Difference Tons/day
Statewide	111.21	111.21	0.00
South Coast	41.70	41.70	0.00
San Joaquin Valley	10.40	10.40	0.00
Sacramento Region	11.05	11.05	0.00
San Diego	10.45	10.45	0.00
San Francisco Bay Area	18.16	18.16	0.00

* includes emissions from small and large off-road equipment and recreational marine engines. Does not include gas cans.

Table 2. 2015 Off-road Equipment Summer Average ROG Evaporative Emissions Inventory (Federal 8 Hr. Ozone)

Area	Evaporative Emission * (MTBE) Tons/day	Evaporative Emission * (Ethanol) Tons/day	Difference Tons/day
Statewide	91.66	123.72	32.06
South Coast	32.31	43.24	10.93
San Joaquin Valley	8.75	11.78	3.03
Sacramento Region	10.49	14.00	3.51
San Diego	9.06	12.37	3.19
San Francisco Bay Area	14.38	17.90	3.52

* includes emissions from small and large off-road equipment and recreational marine engines. Does not include gas cans.

Methodology

As is the case with the on-road emissions inventory as estimated by EMFAC, the OFFROAD model estimates evaporative emissions associated with four mutually exclusive processes:

- **Diurnal emissions** are those that occur when the ambient temperature is rising and the engine is not running. The driving force in this instance is radiant heat from the sun.

- **Running Losses** are evaporative emissions that occur while the engine is running. The driving force in this instance is the heat of the engine.

- **Hot Soaks** occur immediately after an engine is shut off. These emissions tend to continue until the temperature of the fuel stabilizes with the ambient temperature (assumed to be about 45 minutes in the OFFROAD model).

- **Resting Losses** are those evaporative emissions that occur when the engine is not running and the ambient temperature is either stable or declining.

Information regarding the estimation of the impact of ethanol on the on-road emissions inventory can be found in the document entitled “Increased Evaporative Emissions Due To Ethanol Permeation “ located on ARB’s website at http://www.arb.ca.gov/msei/msei.htm.

In the process of developing the Small Off-Road Engine (SORE) evaporative emissions standards in 2003, five walk-behind lawn mowers were tested by the ARB on fuels containing either MTBE or ethanol. All of the five mowers tested were new and it is these tests that serve as the basis for the estimated change in emissions attributable to ethanol fuel use. Due to the lack of test data for other off-road equipment, it is proposed that impact of ethanol on evaporative emissions derived from the five lawnmower test fleet be applied to all gasoline powered off-road equipment. A description of the five mowers tested is included in Table 3.

Table 3. – Equipment Descriptions

Equipment Manufacturer	Model	Engine Manufacturer	Model	Tank Volume	Tank Type
Toro	20040	Briggs	Intek OHV	0.50	HDPE
Lawn Boy	10363	Tecumseh	Centura	0.38	HDPE
Yard Machine	11A	Briggs	Intek OHV	0.25	HDPE
Craftsman	917379440	Briggs	Intek OHV	0.25	HDPE
Craftsman	917389580	Tecumseh	OHV	0.38	HDPE

The fuel tank volume is expressed in gallons and “HDPE” is high-density polyethylene.

Each mower was tested over a full day diurnal with a temperature profile that ranged from 65 to 105^{o} F. The diurnal test temperature profile is displayed in Figure 1. Data in the form of grams of hydrocarbon were collected for each minute of each test. Each mower was first tested on a fuel containing MTBE and subsequently on a fuel containing ethanol. The fuel tank of each mower was filled to a standard level of 50% before testing. The relative fuel specifications are listed in Table 4.

Table 4. Fuel Specification of Fuel Containing MTBE and Ethanol

METHOD	ASTM 4815-94, GC/FID		ASTM D5580, GC/FID		ASTM D5191	ASTM D86 Automatic		
Sample	**MTBE/EtOH (vol %)**	**Total Oxygen (mass %)**	**Benzene (vol %)**	**Total Aromatics (vol %)**	**RVP (psi)**	**T10 (deg F)**	**T50 (deg F)**	**T90 (deg F)**
Summer 1	10.08 MTBE	1.85	0.63	22.5	7.02	138	201	316
Winter 1	10.19 MTBE	2.06	0.50	21.4	9.92	122	197	310
Summer 2	10.64 MTBE	1.96	0.83	23.4	6.87	140	207	298
Summer 3	10.60 MTBE	1.95	0.83	23.4	6.95	142	207	297
Ethanol	5.95 EtOH	2.07	0.83	26.1	6.90	134	213	296

In addition to the diurnal testing, each mower was operated for 15 minutes and then placed in a sealed enclosure at a stabilized temperature of 95^o F in order to measure their hot soak emissions. Table 5 presents the summary results of each test for the five lawnmowers.

Table 5. – Evaporative Emissions Test Results

	Diurnal			Hot Soak		
Manufacturer	**MTBE**	**EtOH***	**% Diff.**	**MTBE**	**EtOH***	**% Diff.**
	(g/day)	(g/day)		(g/test)	(g/test)	
Toro	5.476	6.983	+28%	0.699	0.738	+6%
Lawn Boy	2.068	3.079	+49%	0.412	0.550	+33%
Yard Machine	2.450	3.222	+32%	0.632	1.116	+77%
Craftsman (1)	2.181	3.135	+44%	0.580	0.823	+42%
Craftsman (2)	2.256	3.155	+40%	0.546	0.650	+19%

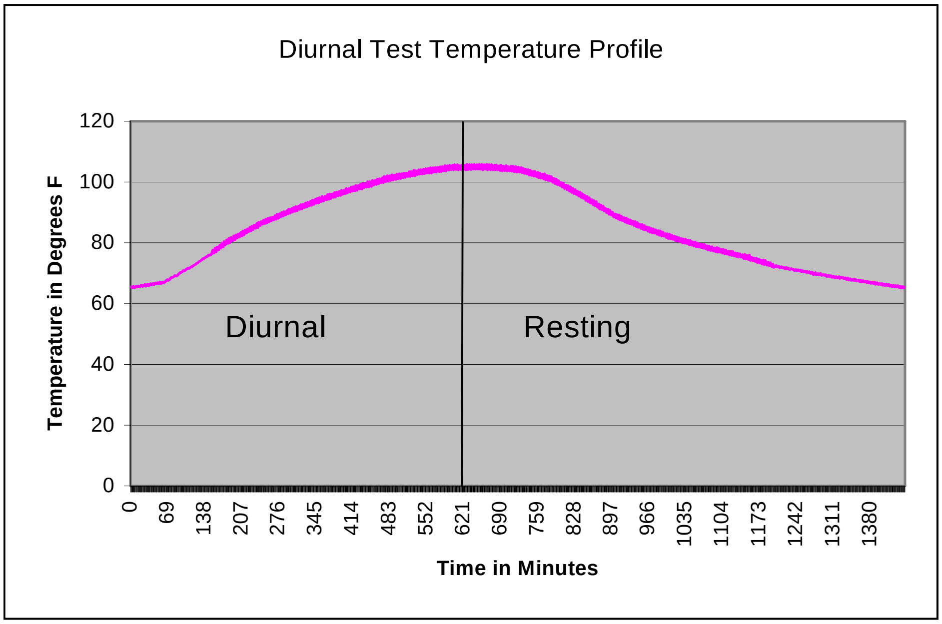
*Corrected SHED results

Rather than use the summary results, staff analyzed the minute by minute test data in order to develop a relationship between the increase due to ethanol and the ambient temperature. This was done to relate the test data to other temperature profiles that are more indicative of the regional and seasonal temperatures encountered by off-road equipment in California.

Lawnmower Diurnal and Resting Loss

The analysis performed to determine the temperature related impact of ethanol required the separation of the minute by minute test data into two groups. The diurnal was defined as the data collected when the temperature in the enclosure was increased from 65 to 105^o F. Resting Loss was defined as the data collected when the temperature in the enclosure was decreased from 105^o F to 65^o F.

Figure 1. – Diurnal Test Temperature Profile



Staff analyzed the minute by minute data to determine the percent increase in the gram per minute emission rate of the equipment on ethanol compared to MTBE. Because all of the tested equipment was new, staff combined the results of the five mowers to derive the average increase in emissions due to ethanol.

Some data cleaning was performed as emissions tended to spike during testing. Immediately following such an event, the readings tended to go negative while the instruments attempted to stabilize. A moving average was used to smooth the data, regardless of fuel type tested, to minimize the impact of these events. The resulting data for diurnal and resting loss emissions were averaged by temperature and are shown in Figures 2 and 3.

Figure 2. Impact of Ethanol on Lawnmower (Diurnal)

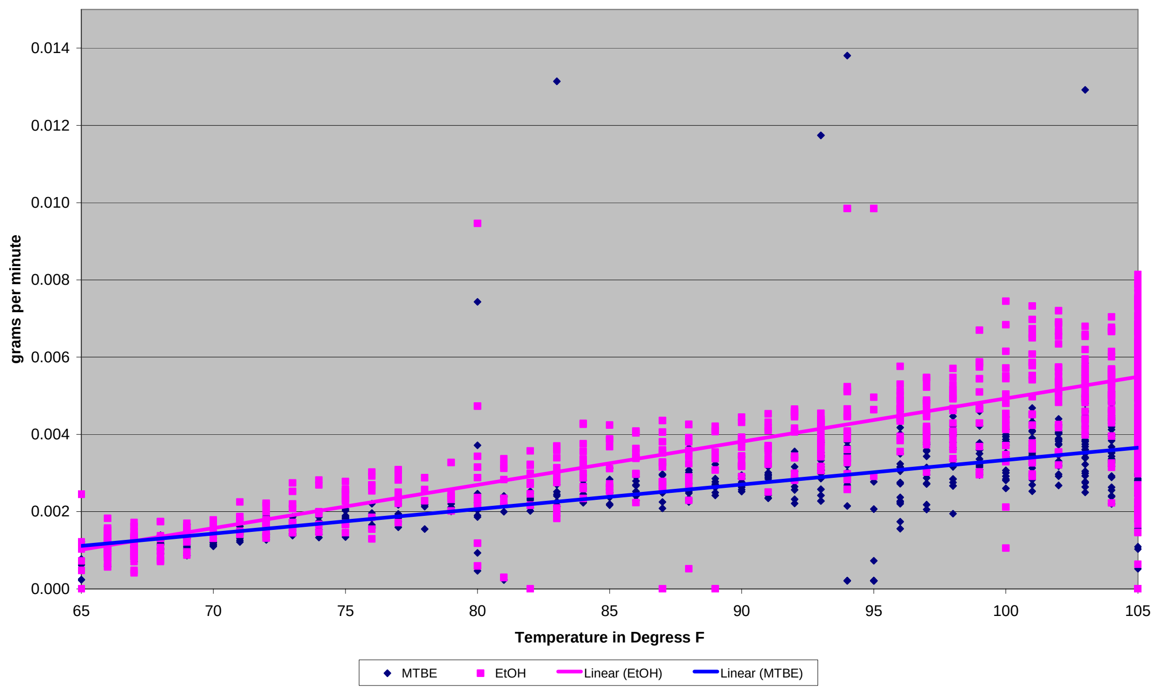
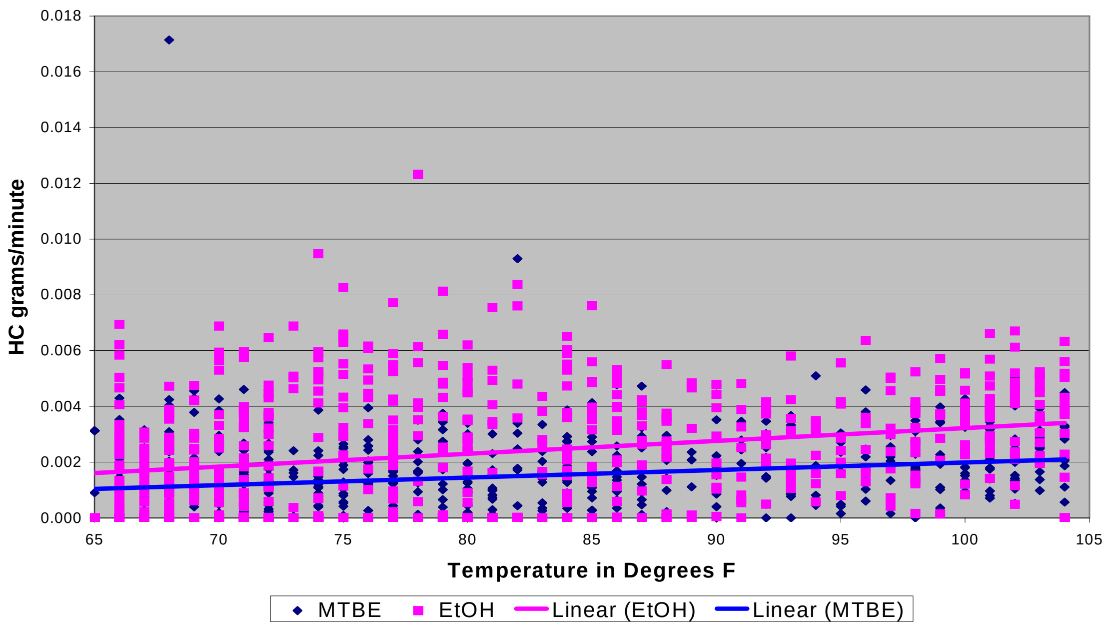


Figure 3. Impact of Ethanol on Lawnmower (Resting Losses)



As can be seen in the figures, the impact due to ethanol appears to increase with increasing temperature for diurnal emissions. The EtOH/MTBE ratio data was best curve fitted to obtain a relationship between temperature range of the diurnal/resting loss cycle, the starting temperature, and emissions change. In order to find the EtOH/MTBE correction factor over different temperature range, temperature correction had to be applied to the EtOH/MTBE ratio. Staff calculated at each starting temperature the corresponding change in the emission due to EtOH/MTBE ratio and the delta temperature change. For example one data point would be starting temperature of 65F, the delta temperature would be 5F, and the EtOH/MTBE ratio would be (EtOH/MTBE @70F)/(EtOH/MTBe@65F). With the dataset, a multi-variable regression analysis was perform to determine the relationship between the starting temperature, the delta temperature and the corresponding changes in the EtOH/MTBE ratio. The final equations are shown below :

Diurnal EtOH/MTBE = 0.00634(Delta Temp) + 0.00725(Starting Temp) + 0.66099

where Delta Temp = Highest temperature (F) – lowest temperature (F) during the diurnal process

Starting Temp = Lowest temperature (F) of the diurnal process

Resting Loss EtOH/MTBE = Diurnal EtOH/MTBE + 0.001309(Delta Temp) + 0.004824

where Delta Temp = Highest temperature (F) – lowest temperature (F) during the resting loss process

Lawnmower Hot Soak and Running Loss

No running loss tests were performed on the lawn mower fleet using fuels containing ethanol and hot soak tests were only performed at 95^{o} F. For modeling purposes, hot soak and running loss evaporative emissions will be modeled as a diurnal with the fuel temperature hotter than ambient. The fuel temperature will be modeled as a function of ambient temperature and engine running time. The equation is based on on-road vehicle test data.

Fuel Temperature (% increase) = 0.006336(ΔTime) + 0.000856

where ΔTime = Change in time (minutes)

The impact of ethanol on evaporative emissions will vary depending on the temperature profile experience by the equipment. Table 6 lists examples of different temperature profile and their effect on evaporative emission increases using ethanol.

Table 6. Ethanol Effect of Different Temperature Profile on Evaporative Emission

Temperature Profile	EtOH/MTBE Factor
State Summer 65-105F	1.38
State Summer Average	1.27
State Winter Average	1.19
State Annual Average	1.24

Fuel Tank Composition – Plastic/Metal Tank

Staff assumes that ethanol-blended fuel will have less effect on the evaporative emission of equipment with metal fuel tanks. Table 7 lists the plastic and metal tank composition by equipment category. The table was compiled using various sources such as manufacturer's website and previous surveys performed by ARB on lawn and garden equipment (http://www.arb.ca.gov/msei/off-road/techmemo/Lawn_and_Garden_Activity.doc).

Table 7. Plastic vs. Metal Tank Composition by Category

Category	Equipment	Residential/ Commercial	Plastic Tank	Metal Tank
Agriculture	All		0%	100%
Airport Ground Support	All		0%	100%
Construction	All		0%	100%
Industrial	All		0%	100%
Lawn and Garden	Chainsaw	Residential	85%	15%
	Chipper/Shredder	Residential	40%	60%
	Lawnmower	Residential	73%	27%
	Leafblower	Residential	97%	3%
	Riding Lawnmower	Residential	100%	0%
	Tiller	Residential	55%	45%
	Tractor	Residential	71%	29%
	Trimmer/Edger	Residential	76%	24%
	Chipper/Shredder	Commercial	40%	60%
	Lawnmower	Commercial	63%	37%
	Leafblower	Commercial	80%	20%
	Riding Lawnmower	Commercial	77%	23%
	Tiller	Commercial	55%	45%
	Tractor	Commercial	63%	38%
	Trimmer/Edger	Commercial	70%	30%
	Snowblower	All	33%	67%
	Wood Splitter	All	14%	86%
	Other	All	86%	14%
Light Commercial	Generator		50%	50%
	Compressor		0%	100%
	Pressure Washer		0%	100%
	Pump		0%	100%
	Welder		0%	100%
Pleasure Craft	All		100%	0%
Recreational Vehicle	All		100%	0%

ARB staff performed testing on a new lawnmower in support of the Off-Road Equipment Fuel Tank (OREFT) regulation in 2003-2004 to determine approximately what the different components of the plastic fuel tank system contributed in regards to its evaporative emissions. Staff determined that approximately 30% were attributed to the plastic fuel tank and the rest of the fuel system (fuel hoses and carburetor) accounted for the evaporative emissions of the lawnmower. Therefore, staff assumes that 70% of the metal fuel tank system will have evaporative emission increases similar to equipment with plastic tanks using ethanol fuel.

Gas Can Emissions

An additional significant source of off-road evaporative emissions is portable fuel containers. The emissions from this source were first included in the OFFROAD model in 1999. Documentation on the development of the gas can inventory can be found at http://www.arb.ca.gov/msei/off-road/pubs/msc9925.pdf.

In September 1999, the ARB adopted standards to control the emissions of hydrocarbons from portable fuel containers. In preparing the regulations for Board review, several gas can were tested for relative emissions when filled with gasoline containing MTBE compared to emissions when filled with gasoline containing ethanol. Table 8 (below) presents a description of the containers tested and their relative emission rates.

Table 8. Portable Fuel Container Emissions Test Results

ID	Manufacturer	Volume	Treatment	MTBE g/gal/day	EtOH g/gal/day	% Diff
C6W1	Wedco	6.60	Untreated	1.09	1.44	+32%
CW3	Wedco	5.00	Untreated	1.41	2.17	+54%
CSF1	B & S	2.50	Untreated	1.46	1.27	-13%
CB1	Blitz	2.06	Untreated	1.88	2.29	+22%
CB2	Blitz	2.06	Untreated	1.95	2.52	+29%
CV1	Vemco	1.25	Untreated	1.51	3.44	+128%
CW1	Wedco	5.00	Untreated	1.39	3.34	+140%
F3W1	Wedco	5.00	Fluorination	0.21	0.70	+233%
F3W2	Wedco	5.00	Fluorination	0.49	0.77	+57%
F3B1	Blitz	2.06	Fluorination	0.53	0.95	+79%
F3B2	Blitz	2.06	Fluorination	0.54	0.80	+48%
SW1	Wedco	5.00	Sulfonation	1.28	2.02	+58%
SB1	Blitz	2.06	Sulfonation	1.81	2.31	+28%
SB2	Blitz	2.06	Sulfonation	1.84	2.36	+28%

Each can was filled to a standardized level (40% of tank capacity), sealed, and allowed to sit for several days. The emissions were calculated by comparing the initial weight of the container and fuel to the resulting weight of the container and fuel.

Tests were performed on untreated cans, as well as can that received treatment to reduce permeation, either fluorination or sulfonation. On average, untreated containers experienced an increase of 54% when containing ethanol compared to MTBE. For fluorinated containers, the average increase was 82% and for sulfonated containers, the average increase was 28%.

In the OFFROAD model, the proper increase will be applied to the appropriate portion of the fleet assumed to be untreated, sulfonated or fluorinated. No adjustment will be assumed for open containers and spillage emissions.

Impact on the Inventory (Using Federal 8-hr Ozone Temperature Profile)

The impacts on the inventory attributable to the proposed changes described above are both regional and seasonally specific. Table 2 describes the impact of ethanol on evaporative emissions from off-road equipment such as small-off-road engines, large-spark ignited engines, and pleasure craft using the Federal 8 hour ozone temperature profile in calendar year 2015. Note that the emission impact on portable gas can is not estimated as it is being updated and will be finalized soon.