APPENDIX C
EMISSIONS FROM OFF-ROAD APPLICATIONS: DISCUSSION OF IMPACTS FROM PERMEATION DUE TO ETHANOL BLENDING

Contents

This Appendix presents the staff assessment of the potential impact of the proposed changes on emissions from off-road gasoline engines and portable fuel containers. It also presents projected reductions from fuel property changes that may occur as a result of the proposed changes.

C-1) OFF-ROAD ENGINES AND EMISSIONS

Off-road gasoline exhaust and evaporative emissions are attributable to engines in lawn mowers, string trimmers, airport ground equipment, and recreational equipment (snowmobiles, pleasure craft) among others. Evaporative emissions also occur from gas cans. Off-road gasoline mobile sources and gas cans emitted roughly 30% of the statewide gasoline-powered mobile source and mobile source related HC + NOx exhaust and evaporative emissions in 2005[1]. Although both on-road and off-road emissions are trending downward as a result of State regulations, the off-road percentage contribution to the total gasoline-related mobile source inventory is increasing. With no additional control measures, the off-road percentage is expected to increase to 47% by 2020[1]. This is due to both the projected growth of off-road engine usage and the much more stringent control now being applied to reduce gasoline-powered on-road emissions from cars and heavy duty vehicles.

Unlike on-road vehicles which are dominated by 4-stroke engines, the off-road category includes both 2-stroke and 4-stroke engines. Most off-road gasoline engines are open loop with only some of the larger ones being closed loop. Engines that include feedback controls that process information from the exhaust to aid in engine operation are termed closed loop systems. Engines without feedback controls are called open loop systems and consist of simple carbureted systems on small engines. Open loop systems use a predetermined program of load and speed to determine the engine fuel injection requirements. A certain fuel composition must be assumed to generate the needed fueling pattern. Consequently open loop systems are often more impacted by changes in some aspects of fuel composition. Engines with closed loop systems have computers that use measurements of the oxygen content of the exhaust stream combined with information about the mode of operation (e. g. throttle level and fuel flow) to adjust engine operation for fuel quality. The exhaust stream oxygen concentration allows the computer to determine how much excess air the engine is running. Generally off-road engines have limited exhaust and evaporative controls and produce emissions that have different fuel property sensitivities compared to on-road vehicles. Only a few large engines are now equipped with emission controls such as catalytic converters. Since only CaRFG3 is produced and dispensed within the state, off-road gasoline applications use the same fuel as on-road applications.

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[1] 2006 California Almanac of Emissions and Air Quality (http://www.arb.ca.gov/aqd/almanac/almanac06/almanac06iu.htm)

C-2) EMISSIONS INVENTORY

Estimation of emissions inventory from various off-road sources is performed by staff using the ARB's offroad emissions inventory model, OFFROAD. This model incorporates various aspects of off-road source emissions modeling, such as the effects of adopted and proposed regulations, technology types, and seasonal conditions. Parameters that are used by the model to estimate emissions include activity, population, category and types of engines, emissions factors, growth and scrappage, seasonal and temporal patterns, etc. The 2000 base year equipment population is adjusted for growth and scrappage, producing model-year specific population distributions for specified calendar years from 1970 through 2040. In 2007, the OFFROAD model[2] was updated to include new information on many parameters. The estimates of emissions from the model for the different classes and categories are summarized in Table 1 below for 2010, 2015 and 2020. The table includes emissions from 2 stroke and 4 stroke engines and gas cans. These estimates provide a basis for staff to evaluate future control measures.

Table 1. Summary of Statewide Emission Inventory of Gasoline Powered Off-Road Equipment in tons per day (based on CA 8-hr ozone temperature profile)

	2010			2015			2020		
	2 Stroke	4 Stroke	Gas Cans	2 Stroke	4 Stroke	Gas Cans	2 Stroke	4 Stroke	Gas Cans
ROG (Evap)	48	111	38	48	99	29	51	96	24
ROG (exhaust)	193	72	0	182	64	0	181	62	0
CO	413	2490	0	398	2563	0	401	2705	0
CO as ROG	6	37	0	6	38	0	6	41	0
Total ROG	247	220	38	236	201	29	238	199	24
NOx	14	72	0	16	66	0	19	63	0
ROG total			**505**			**466**			**461**
NOx total			**86**			**82**			**82**

* CO as ROG is calculated by multiplying the CO inventory value by (0.06/4.01) where 0.06 is the Maximum Incremental Reactivity (MIR) for CO and 4.01 is the average MIR for RFG exhaust.

C-3) OFF-ROAD TEST PROGRAMS FOR FUEL COMPOSITION AND PERMEATION EFFECTS

Experimental data for both exhaust and evaporative emissions effects of fuel properties for off-road gasoline engines is limited compared to on-road gasoline engines. To assess the impact of ethanol blends on emissions from off-road

[2] http://www.arb.ca.gov/msei/offroad/offroad.htm

engines, staff conducted a literature survey on available information in peer-reviewed literature, test program reports and government agency reports. Detailed below are summaries of studies conducted that provide a comparison of emissions from non-oxygenated gasoline to ethanol-blended gasoline. The first part details exhaust testing followed by details of studies of evaporative emissions from off-road engines.

1) Exhaust Emissions

Pollutant impact with ethanol-gasoline blend in a commercial SI Engine: Hsieh et. al[3] studied the effects of 0, 5, 10, 20 and 30 percent ethanol in gasoline blends in a SI engine (not specified as being on or off-road). The engine operated in closed loop mode with no catalytic control of exhaust emissions. The addition of ethanol to gasoline provided higher torque output with a nominal increase in fuel consumption. They reported engine exhaust reductions in hydrocarbons and carbon monoxide resulting from the ethanol blends relative to the reference non-ethanol fuel. Hydrocarbon emissions were lower by 20 to 40 percent and carbon monoxide emissions were lower by 25 to 65 percent when using the 10 percent ethanol blended fuel. Emissions of oxides of nitrogen was dependent on engine operating condition and did not exhibit any specific correlation to oxygen content in the blended fuel.

Snowmobiles with ethanol blend for the Montana Department of Environmental Quality [4]: Tests were conducted on four 4-stroke snowmobiles with a reference gasoline and a 10 percent ethanol (E-10) blend. Hydrocarbon emission reductions using the E-10 ranged from 4 to 40 percent and carbon monoxide reductions reported ranged from 10 to 70 percent for the different vehicle speeds tested. Changes in oxides of nitrogen ranged from -4 to +100 percent depending on the vehicle speed. The report concluded that oxygenates in gasoline provided moderate to significant reductions in exhaust hydrocarbons and carbon monoxide with small to moderate increases in oxides of nitrogen.

Hand-held 2-stroke engines - Impacts on emissions from 10 percent oxygenated blends: A recent U.S. EPA study[5] on 2-stroke off-road engines reported results from testing on twenty three 2-stroke handheld new and in-use spark ignition engines. The engines tested included string trimmers, chain saws, and blowers. Only four of the engines tested had moderate catalyst controls on emissions. A federal gasoline and a 10 percent ethanol blended fuels were used to compare emissions from the use of these two fuels in the engines tested in this study. The study concluded that a 10 percent ethanol blended gasoline provided about a 12

[3] "Engine Performance and Pollutant Emission of a SI Engine using Ethanol-Gasoline Blended Fuels", W. Hsieh, R. Chen, T. Wu, and T. Lin, Atmospheric Environment, 36(2002), 403-410.
[4] "Laboratory Testing of Snowmobile Emissions", C. C. Lela and J. J. White, Report prepared for Yellowstone National Park and the Montana Department of Environmental Quality, July 2002.
[5] "Emissions profile from new and in-use handheld, 2-stroke engines", J. Volckens, J. Braddock, R. F. Snow, and W. Crews, Atmospheric Environment, 41 (2007) 640-649.

percent reduction in hydrocarbons and a 22 percent reduction in carbon monoxide emissions compared to a non-oxygenated fuel. Changes in emissions of oxides of nitrogen were reported to be statistically insignificant when using the oxygenated blend.

Fuel, Lubricant, and Emission measurement issues from small engines: A study conducted by White and Hare[6] tested a 4-stroke walk-behind-mower and a 2-stroke moped to compare the effects of four different gasoline formulations on emissions. The objective was to study the potential for changes in fuel formulation alone to lower emissions as compared to changes in engine or fuel delivery systems. They used four types of formulations in their study: an industry average, MTBE blended, ethanol blended and a straight non-oxygenated aliphatic gasoline. The results indicated that using the 10 percent ethanol blend, hydrocarbons were reduced by 3 to16 percent and carbon monoxide by 10 to 42 percent. Emissions of oxides of nitrogen were unchanged for the 4-stroke engine while it was 63 percent higher for the 2-stroke engine.

2-Stroke motorcycle engines[7]: A study by Wang et. al studied the impact of different fuel oxygenates on emissions from 2-stroke 50 cc. motorcycle engines. The oxygenates reported in the study were methanol, ethanol, MTBE, benzene and isopropyl ether. The oxygenate content varied from 0 to 15 percent by volume for the tests conducted. The authors reported reductions of 10 percent for hydrocarbons and 14 percent for carbon monoxide by utilizing 10 percent ethanol blends compared to a non-oxygenated fuel in such engines. For oxides of nitrogen, they did not provide specific data for the ethanol blend.

4-Stroke motorcycle engines: Using a 4-stroke uncontrolled motorcycle engine, Jia et. al[8] compared the emissions between a baseline unleaded non-oxygenated gasoline and a 10 percent ethanol blended with the baseline fuel. They reported greater than 30 percent reductions in hydrocarbons and carbon monoxide with no measurable increase in oxides of nitrogen by utilizing the 10 percent ethanol blend.

2) Evaporative Emissions

The use of ethanol in California gasoline resulted in an increase in evaporative hydrocarbon emissions compared to non-oxygenated or MTBE containing fuel because of increased permeation through fuel system components. Experimental studies applications that examined permeation effects are limited. Discussed below are studies that were available to staff.

[6] "Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues", C. T. Hare and J. J. White, SAE Paper 911222, 1991

[7] "Effect of Oxygenates on Exhaust Emissions from Two-Stroke Motorcycles", C. Wang, S. Lin, and H. Chang, J. of Environmental Science and Health, Part A, Vol. A37(9) (2002) 1677-1685.

[8] "Influence of Ethanol-Gasoline Blended Fuel on Emission Characteristics from a Four-Stroke Motorcycle Engine", L. Jia, M. Shen, J. Wang, and M. Lin, Journal of Hazardous Materials, A123 (2005) 29-34.

Permeation from Automotive Systems: The Coordinating Research Council completed a study[9] on fuel permeation effects from fuel systems in model year 2000-2005 automobiles. The results indicated a 173 percent increase in the diurnal permeation rate when a 10 percent oxygenated fuel was compared to a base non-oxygenated non-ethanol fuel.

Permeation from Fuel Hoses and Gas Tanks: In a communication with staff, the USEPA provided a draft report on the effects of ethanol on non-road fuel hoses and tanks [10]. Use of a 10 percent ethanol blend enhanced permeation emissions in fuel hoses by 82 percent to 200 percent at 73 F. For tanks, permeation emissions were enhanced by 10 percent to 100 percent at 84 F.

ARB Monitoring and Laboratory Division staff studies on lawn mowers: A study was conducted on five lawnmowers followed by a study on six lawnmowers. Table 2 below shows the results from a five lawnmower data set that was used to estimate off-road emissions inventory[11].

Table 2. Evaporative Emissions from Off-Road Sources based on the Five Lawnmower Study

	Diurnal		
Manufacturer	MTBE	EtOH*	% Diff.
	(g/day)	(g/day)	
Toro	5.5	7.0	+28%
Lawn Boy	2.1	3.1	+49%
Yard Machine	2.5	3.2	+32%
Craftsman #1	2.2	3.1	+44%
Craftsman #2	2.3	3.2	+40%
Average	2.9	3.9	+36%

The second study on six different lawnmowers was conducted in the summer of 2001 with CaRFG2 fuel and data was presented in a staff report[12]. Subsequently, these six lawnmowers were fitted with different equipment representing different phases of emission control strategies. After each modification, the lawnmowers were tested with CARFG2 as follows:

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[9] "Fuel Permeation from Automotive Systems: E0, E6, E10, E20 and E85", CRC Report No. E-65-3, 2006.
[10] Personal Communication with Craig Harvey, U.S. EPA, OTAQ, Assessment and Standards Division, 2006.
[11] Estimation of the Impact of Ethanol on Off-Road Evaporative Emissions, Technical Memo, Air Resources Board, June 2006.
[12] "Initial Statement of Reasons for Proposed Rulemaking Public Hearing to Consider the Adoption of Exhaust and Evaporative Emission Control Requirements for Small Off-Road Equipment and Engines Less Than or Equal to 19 Kilowatts", Staff Report, August 8, 2003.

Phase 1 : Original baseline testing with CaRFG2
Phase 2 : Test with fluorinated tank
Phase 3 : Test with fluorinated tank plus PermBlok fuel line
Phase 4 : Test with fluorinated tank plus PermBlok fuel line plus controlled venting

After the controlled tests were concluded in 2002, staff tested the same six lawnmowers with CaRFG3 to estimate the effects of ethanol blending on evaporative emissions. Data from these six lawnmowers were however not used in the development of the fuel correction factors for evaporative emissions in the OFFROAD model. This was because of concerns that there existed possibilities that the components of the tanks and fuel lines exchanged during testing of the different control technologies were not placed back to their original conditions or specifications. As shown in Table 3, the percent difference in diurnal emissions ranged from -11 percent to 51 percent and such high variation was another reason that the six lawnmower dataset was not used to support the OFFROAD model.

Table 3. Evaporative Emissions from Off-Road Sources based on 6 Lawnmower Study

	Diurnal		
Manufacturer	MTBE (g/day)	EtOH* (g/day)	% Diff.
Briggs & Stratton #1	2.9	3.0	4%
Briggs & Stratton #2	2.6	3.4	31%
Tecumseh #1	3.3	3.4	5%
Tecumseh #2	3.5	3.1	-11%
Honda #1	2.5	3.0	17%
Honda #2	2.5	3.8	51%
Average	2.9	3.3	+14%

C-4) EVALUATION OF TEST RESULTS

1) ARB Staff Evaluation

a) Application of 5 and 6 Lawnmower study[1,11] data to estimate increases in permeation hydrocarbon emission increases:

Staff has now used the five and six lawnmower data to calculate a range of possible changes in evaporative hydrocarbons attributable to permeation from the entire off-road gasoline category. The five lawnmower study indicates an estimated increase of about 42 tons/day attributable to permeation for 2010 for the entire off-road category. This was calculated from the projected increase of 36 percent in evaporative emissions as shown in Table 2. The second lawnmower study, results of which are shown in Table 3 however, indicate only a 14 percent increase in evaporative emissions attributable to permeation. Staff used the ratio of 14 percent to 36 percent (projected increases from Table 3 and 2 respectively) multiplied by 42 tons/day to calculate a lower range of projected increase attributable to permeation. This lower range is calculated to be 16 tons/day. Staff therefore has estimated that increases in evaporative emissions attributable to permeation are in the range of about 16 to 42 tons/day in 2010. This is shown in Table 4 for 2010. Similar estimates were calculated for 2015 and 2020. Table 4 therefore provides a possible range of values for the potential increase of evaporative hydrocarbon emissions from blending ethanol in gasoline from off-road gasoline applications.

Table 4. Estimation of the increase in Permeation Emissions Associated with Ethanol in Gasoline based on Two Different Studies

OFFROAD	5 Lawnmower Study	6 Lawnmower Study
	Permeation ROG (tons/day)	Permeation ROG (tons/day)
2010	42	16
2015	39	15
2020	39	15

b) Estimate of changes in emissions resulting from proposed fuel property changes:

To address concerns related to off-road emissions, staff has considered the impacts of fuel property changes on emissions from both 4-stroke and 2-stroke applications. Currently, a 5.7% ethanol blended CaRFG3 is used in off-road engines. The CaRFG3 Predictive Model[13] allows the production of different fuel blends that are essentially ‘ozone’ neutral by proper selection of fuel properties.

Although not designed to predict how fuel property changes affect emissions from off-road engines, elements of the Predictive Model can be applied to gain insight on the potential impact. For purposes of this evaluation, the Tech3 portion of the predictive model was used to estimate the change in emissions due to fuel property changes. The Tech 3 class portion of the model was used since this class most closely represents emission responses associated with off-

[13] http://www.arb.ca.gov/fuels/gasoline/premodel/pmdevelop.htm

road four-stroke engines. The fuel property changes used were to change the ethanol content while holding other properties constant. Ethanol was increased from the current 5.7 percent ethanol blended gasoline to a 10 percent ethanol blended gasoline.

Using the Tech 3 portion of the Predictive Model to evaluate changes in emissions associated with increasing ethanol content provides the percent change in emissions which are given in Table 5. For evaporative emissions, benefit (or disbenefit) was calculated by utilizing a 0.1 psi reduction of RVP, the most that RVP is expected to change.

Table 5. Estimated Changes for Four-Stroke Engines when Increasing Oxygen from 2.0% to 3.5%

Change in Evap HC	- 1.43%
Change in exhaust HC	- 3.15%
Change in CO	- 8.03%
Change in NOx	+ 1.83%

2) U. S. EPA Staff Evaluation

A recent study[5] conducted by the U.S. EPA investigated the effects of summer gasoline and 10 percent ethanol blended gasoline (non-CARFG RVP) on exhaust emissions from hand-held two-stroke engines (chainsaws, string trimmers and blowers). Twenty three two-stroke engines were tested which included pre-control (pre 1997), Phase-1 (1997-2001) and Phase-2 (after 2002) engines. Four of the engines tested had some level of catalytic mitigation of exhaust emissions. The authors summarized that ethanol blending reduced average HCs by 12.5 percent and CO by 22.5 percent. Emissions of oxides of nitrogen did not show any statistically significant downward or upward trend for the fuels tested in this study. Since the EPA study compared non-oxygenated to a 10 percent ethanol blend, staff has proportioned the projected reduction to assess the reduction going from the current 5.7 percent blend to a 10 percent future blend (ratio of 4.3/10). The predicted changes are shown in the Table 6 below. As with 4-stroke engines in Table 5, for evaporative emissions, benefit (or disbenefit) was calculated by utilizing a 0.1 psi reduction of RVP

Table 6. Estimated Changes for Two-Stoke Engines when Increasing Oxygen from 2.0% to 3.5%

Change in Evap HC	- 1.43%
Change in exhaust HC	- 5.28%
Change in CO	- 9.67%
Change in NOx	+ 0.00%

A comparison of values in Table 5 which was derived from the ARB Predictive Model for 4-stroke engines with values in Table 6 calculated for 2-stroke engines from the U.S. EPA study[5] shows similarity for the two different engine classes from two independent studies.

The USEPA[14] assessed fuel oxygenate impacts on off-road 4-stroke engines by extrapolating current available data for on-road vehicles predicted changes in exhaust emissions. The U. S. EPA results are comparable directionally with results from Table 5. It predicted reductions in hydrocarbons and carbon monoxide and moderate increases in oxides of nitrogen by utilizing ethanol blends relative to non-oxygenated blends.

A U.S. EPA technical memorandum[15] compared the impacts of a base fuel and two oxygenated fuels (2.7 and 3.5 percent) on emissions. The nonroad engines included four 4-stroke lawnmowers and one 2-stroke moped. The effect of fuel oxygen was calculated to be proportional to oxygen content. Staff used this to estimate changes in hydrocarbon, carbon monoxide and oxide of nitrogen emissions when fuel oxygenate is changed from 2.0 percent to 3.5 percent and the estimates are presented in Table 7 below. The estimated changes were calculated from emission factors in g/kW-hr for both the 4-stroke and 2-stroke engines.

Table 7. Impact on Exhaust Emissions when going from a 2.0% to a 3.5% Oxygenate Fuel[15]

	4-Stroke	2-Stroke
Hydrocarbons	-7%	-1%
Carbon Monoxide	-9%	-19%
Oxides of Nitrogen	+17%	+28%

Volkens et. al[5] indicated a 15 percent variability for hydrocarbons but a much larger 47 percent for oxides of nitrogenfor 2-stroke engines. The uncertainty is larger in the oxides of nitrogen given that the average emission factors for oxides of nitrogen (< 4 g/hp-hr) are typically much smaller than hydrocarbon values (~ 85 g/hp-hr). One of the general conclusion from the study is that changes in fuel oxygenate levels from 2.0 to 3.5 percent has the potential to reduce hydrocarbon and carbon monoxide with attendant increases in oxides of nitrogen. Due to limited data available to asses specific effects of oxygenate levels in off-road engines and given the attendant uncertainty as shown from studies above, rough estimates are possible, but more testing is necessary before reliable estimates can be made.

[14] Personal Communication with the Laboratory Group of the USEPA in Ann Arbor, MI, USA, (2007).
[15] "Exhaust Emission Effects of Fuel Sulfur and Oxygen on Gasoline Nonroad Engines", USEPA Memo No. EPA420-R-05-016, December 2005.

C-5) ESTIMATION OF FUEL PROPERTY CHANGES ON EMISSIONS

1) Emission Estimates and Uncertainty in the Estimates

Based on the two lawnmower evaporative emissions studies, staff has estimated the increase in evaporative hydrocarbons, due to increased permeation, could range between 16 and 42 tons/day. These estimates were derived from two lawnmower studies conducted by ARB described earlier.

To calculate an estimate of reductions in emissions of hydrocarbons, carbon monoxide and oxides for nitrogen, staff applied projected changes in pollutant emissions from the fuel property changes, presented earlier. The Predictive Model was used to represent the 4-stroke off-road category and the 2-stroke U.S. EPA emissions study[5] was used to represent the 2-stroke gasoline engines. For 2010, the estimated reduction in exhaust hydrocarbons achievable could range between 16 and 22 tons/day*. There could be from none to about 20 tons/day of evaporative emissions left to be mitigated. As for oxides of nitrogen, the estimated increase could range between 1 and 2 tons/day[#]. These are detailed in Table 8. Similar projections are shown for 2015 and 2020 in Tables 9 and 10 respectively.

A drawback using such an approach is using percentage reductions for one type of off-road engines and then extrapolating it to the entire off-road category. A study by Frey and Bammi[16] attempted to quantify the variability and uncertainty in emission factors for lawn and garden equipment. They analyzed data available from testing on lawn and garden equipment from different projects. They reported that uncertainty for emission factors for off-road engine total hydrocarbons and oxides of nitrogen could range between -33 to +46 percent and from -45 to +75 percent for hydrocarbons and oxides of nitrogen respectively. Frey and Bammi also indicate that emission factors are significantly influenced by the choice of equipment, fuels, and test conditions.

Due to the large uncertainties in emissions from off-road applications, projected reductions from fuel effects presented here can only be used as a guide to mitigate enhancements related to permeation. A larger robust data set that includes representative engines and applications from the entire off-road

[16] "Quantification of Variability and Uncertainty in Lawn and Garden Equipmet NOx and Total Hydrocarbon Emission Factors", H. C. Frey and S. Bammi, J. Air & Waste Management Association, 52, 435-448 (2002).

* This has been calculated by using a 15 percent uncertainty in hydrocarbon emissions adopted from Volkens et. al[5] and applying it to the projected 19 tons/day reductions calculated for the off-road category. It is to be noted that the 15 percent value has been assigned to both exhaust and evaporative emissions from both 2-stroke and 4-stroke engines.

For oxides of nitrogen, Volkens et. al[5] assigns a 47 percent uncertainty which when applied to oxides of nitrogen provides a range of 0.5 to 1.5 tons/day increase due to fuel oxygenate change. The increase has been round off to 1.0 to 2.0 tons/day.

category is necessary to experimentally verify projected changes due to changes in fuel oxygen.

Table 8. Projected Impacts of Fuel Property Changes on Exhaust and Evaporative Emissions from Off-Road 2-Stroke and 4-Stroke Engines and Gas Cans in 2010 (tons/day)

	Projected Emissions Inventory	Contribution from Permeation	Range of Emissions Inventory	Fuel Effects (Phase 3 Update)	With Fuel Effects Included
Gas Cans	38	1	38	0	38
Two-Stroke					
Evaporative	48	5 to 12[a]	41 to 48[b]	-1	40 to 47
Exhaust	199	0	199	-11	188
NOx	14	0	14	0	14
Four-Stroke					
Evaporative	111	11 to 29[a]	93 to 111[b]	-2	91 to 109
Exhaust	109	0	109	-5	104
NOx	72	0	72	+1	73
Total					
Evap ROG	197	16 to 42[a]	171 to 197[b]	-3	168 to 194
Exhaust ROG	308	0	308	-16	292
Total ROG	505	16 to 42	479 to 505	-19	460 to 486
NOx	86	0	86	+1	87
		Estimated ROG Increase from Permeation			16 to 42
		Estimated Reduction in ROG from Fuel Effects			-16 to -22
		Net Change in ROG from Permeation plus Fuel Effects			0 to 20
		Net NOx Increase with Fuel Effects			1 to 2

Note: Exhaust CO has been incorporated as hydrocarbon ROG by adjusting the MIR equivalents of CO (0.06) and exhaust hydrocarbons (4.01).

[a] The two lawnmower studies were used to estimate a range for permeation emissions from both two and four stroke engines. For 2010, the range inclusive of two strokes, four strokes and gas cans was calculated to be between 16 and 42 tons/day.

[b] Total evaporative emissions include contributions from permeation emissions plus other evaporative processes.

Table 9. Projected Impacts of Fuel Property Changes on Exhaust and Evaporative Emissions from Off-Road 2-Stroke and 4-Stroke Engines and Gas Cans in 2015 (tons/day)

	Projected Emissions Inventory	Contribution from Permeation	Range of Emissions Inventory	Fuel Effects (Phase 3 Update)	With Fuel Effects Included
Gas Cans	29	0.4	29	0	29
Two-Stroke					
Evaporative	48	5 to 13[a]	40 to 48[b]	-1	39 to 47
Exhaust	188	0	188	-11	177
NOx	16	0	16	0	16
Four-Stroke					
Evaporative	99	10 to 26[a]	83 to 99[b]	-1	82 to 98
Exhaust	102	0	102	-5	97
NOx	66	0	66	+1	67
Total					
Evap ROG	176	15 to 39[a]	152 to 179[b]	-2	150 to 177
Exhaust ROG	290	0	290	-16	274
Total ROG	466	15 to 39	442 to 466	-18	424 to 448
NOx	82	0	82	+1	83
		Estimated ROG Increase from Permeation			15 to 39
		Estimated Reduction in ROG from Fuel Effects			-15 to -21
		Net Change in ROG from Permeation plus Fuel Effects			0 to 18
		Net NOx Increase with Fuel Effects			1 to 2

Note: Exhaust CO has been incorporated as hydrocarbon ROG by adjusting the MIR equivalents of CO (0.06) and exhaust hydrocarbons (4.01).

[a] The two lawnmower studies were used to estimate a range for permeation emissions from both two and four stroke engines. For 2015, the range inclusive of two strokes, four strokes and gas cans was calculated to be between 15 and 39 tons/day.

[b] Total evaporative emissions include contributions from permeation emissions plus other evaporative processes.

Table 10. Projected Impacts of Fuel Property Changes on Exhaust and Evaporative Emissions from Off-Road 2-Stroke and 4-Stroke Engines and Gas Cans in 2020 (tons/day)

	Projected Emissions Inventory	Contribution from Permeation	Range of Emissions Inventory	Fuel Effects (Phase 3 Update)	With Fuel Effects Included
Gas Cans	24	0.3	24	0	24
<u>Two-Stroke</u>					
Evaporative	51	5 to 13[a]	43 to 51[b]	-1	42 to 50
Exhaust	187	0	187	-11	176
NOx	19	0	19	0	19
<u>Four-Stroke</u>					
Evaporative	96	10 to 26[a]	80 to 96[b]	-1	79 to 95
Exhaust	103	0	103	-5	98
NOx	63	0	63	+1	64
<u>Total</u>					
Evap ROG	171	15 to 39[a]	147 to 171[b]	-2	145 to 169
Exhaust ROG	290	0	290	-16	274
Total ROG	461	15 to 39	437 to 461	-20	419 to 443
NOx	82	0	82	+1	83
		Estimated ROG Increase from Permeation			15 to 39
		Estimated Reduction from Fuel Effects			-15 to -21
		Net Change in ROG from Permeation plus Fuel Effects			0 to 18
		Net NOx Increase with Fuel Effects			1 to 2

Note: Exhaust CO has been incorporated as hydrocarbon ROG by adjusting the MIR equivalents of CO (0.06) and exhaust hydrocarbons (4.01). Evaporative emission totals include permeation emissions.

[a] The two lawnmower studies were used to estimate a range for permeation emissions from both two and four stroke engines. For 2020, the range inclusive of two strokes, four strokes and gas cans was calculated to be between 15 and 39 tons/day.

[b] Total evaporative emissions include contributions from permeation emissions plus other evaporative processes.

C-6) SUMMARY OF EFFECTS OF PROPOSED FUEL PROPERTY CHANGES ON EMISSIONS INVENTORY

Table 11 summarizes the estimated reductions possible resulting from the fuel property changes discussed earlier in the report. For 2010, the proposed fuel property changes has the potential to significantly offset permeation ROG emissions. The changes that could result from the proposed Predictive Model update could have the potential to offset from about 50 percent to all of the increases in emissions related to permeation from ethanol blended fuels in 2010. It is a similar case for 2015 and 2020.

Table 11. Summary of Proposed Fuel Property Impacts on Net ROG Increase from Permeation

	2010	2015	2020
Increase in ROG due to Permeation (tons/day)	16 to 42	15 to 39	15 to 39
Potential offset due to fuel property change (tons/day)	16 to 22	15 to 21	15 to 21
Net estimated ROG emissions (tons/day)	0 to 20	0 to 18	0 to 18

However, given the uncertainties in calculating the estimated increases in permeation emissions from the two lawnmower studies and the uncertainties in the projected reductions in exhaust emissions from the fuel oxygenate change, at this time it is not possible to accurately estimate either the increase in evaporative emissions from the use of ethanol or the impact on exhaust emissions. A program being initiated to provide data from a wide class of off-road engines is expected to significantly enhance the data available for staff to derive better estimates in the future. Staff will at that time make assessments to determine if the proposed fuel property changes provide the necessary emission benefits to offset increases due to permeation for the entire off-road category.

C-7) PROPOSED ACTIVITIES BEING INITIATED BY ARB TO REFINE IMPACTS OF FUEL PROPERTY CHANGES ON EMISSIONS FROM OFF-ROAD APPLICATIONS

The current estimates of permeation calculated from the two lawnmower studies detailed earlier in this chapter, has only limited applicability to the entire off-road category. Recognizing that different categories of off-road equipment likely have different ethanol permeation rates and the need for additional evaporative test data, ARB is proposing to significantly expand the existing database of evaporative and exhaust emissions data for off-road equipment. Impacts on permeation due to ethanol blending, engine exhaust emissions, changes due to increased oxygenates, benefits of catalysts on reducing engine emissions, etc. will be studied. Such information will be used to refine existing emission inventory estimates, resulting in effective strategies for improving air quality.

A proposed program is being developed that will be conducted in two phases. The first phase will be conducted at a Southwest Research Institute with a report made available within a year. The second phase will be conducted in-house by ARB staff and is expected to be completed in a longer time frame (2-3 years). This project will expand the number and types of engines being tested.

C-8) REFERENCES

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