State of California
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DRAFT

Comparison of the Effects of a Fully-Complying Gasoline Blend and a High RVP Ethanol Gasoline Blend on Exhaust and Evaporative Emissions

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Air Resources Board
P.O. Box 2815
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California Environmental Protection Agency
California Air Resources Board

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I. EXECUTIVE SUMMARY

A. Overview

This report presents the results of a test program conducted by the Air Resources Board (ARB) on 12 light-duty vehicles. The test program was initiated in late 1995, to investigate whether a 10 percent ethanol (3.5 weight percent oxygen) gasoline blend with an 8.0 psi Reid vapor pressure (RVP) would provide as good or better emission benefits as a fully complying gasoline blended to be typical of the gasoline used during the summer and meeting a 7.0 psi RVP limit. The purpose of the program is to determine whether an RVP exemption should be provided to 10 percent ethanol blends as provided for in Health and Safety Code Section 43830(g).

To compare the emission effects of these two gasoline blends, the 12 vehicles were tested for exhaust emissions on the federal test procedure (FTP) and REP05 (off-cycle) test procedure[1]. The vehicles were model year 1990-1995 light-duty vehicles with 3-way catalysts and fuel-injection. These control technologies are found in 1986 and newer model year vehicles. 1986 and newer model year vehicles account for about 70 percent of the projected vehicle miles traveled for 1998 and a significant fraction of the emissions in the emissions inventory for light duty vehicles.

Six of the vehicles were also tested for evaporative emissions. Evaporative emissions tests were based on ARB's procedures for the 2-day diurnal and standard 1-hour hot-soak tests. Tests for running loss emissions were not performed because the running loss test facilities were not available at the time. Running loss emissions were estimated with the assistance of General Motors using their vapor generation model[2]. ARB staff also estimated running loss emissions using a draft ARB model for evaporative emissions and the U.S. EPA's model for evaporative emissions.

B. Results

Exhaust and evaporative emissions test data were evaluated for the following: carbon monoxide (CO), oxides of nitrogen (NOx), total hydrocarbons (THC), nonmethane organic gas species (NMOG), ozone-forming potential from NMOG (OFP), ozone-forming potential from NMOG plus carbon monoxide (OFPCO), sum of toxic masses (TOX), and potency-weighted toxics (TOXPW). The four toxic compounds evaluated under this test program include benzene, 1,3-butadiene, formaldehyde, and acetaldehyde.

The data were evaluated to address the following specific questions.

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[1] The REP05 is a test procedure that provides information on how vehicle emission control systems perform at high speeds. For more details refer to the "Final Technical Report on Aggressive Driving Behavior for the Revised Federal Test Procedure, Notice of Proposed Rulemaking. U.S. EPA, Office of Air and Radiation, Office of Mobile Sources, January 31, 1995.

[2] The GM model is proprietary and has not been described in detail in any publication. The Model is based on principles described in SAE Paper No. 861556, "Evaporative Emissions from Gasolines and Alcohol-Containing Gasolines with Closely Matched Volatilities," by S. R. Reddy, October 1986.

- How do the regulated (THC, CO and NOx) emissions from the high RVP ethanol blend compare to those from the fully complying blend?

- How does the ozone forming potential of the emissions from the high RVP ethanol blend compare to that from the fully complying blend?

- How do the emissions of toxic compounds from the high RVP ethanol blend compare to those from the fully complying blend?

The test results were evaluated using arithmetic averages (percent of the means and mean of percents methods) and a more formal statistical methodology to provide a comprehensive examination of the data. The arithmetic averages represent a simple assessment of the data to estimate general trends. The formal method represents a rigorous statistical evaluation of the data that provides refined estimates and allows for evaluation of statistical significance.

The overall percent change in emissions (combined effects of exhaust and evaporative processes) was calculated based on the percent of the means, mean of percents, and the formal methods. Also, individual test modes were examined. *(See Appendix 3 for more discussion on the statistical methodology.)*

A summary of the overall percent change in emissions using each of the methodologies is presented in the following table. As shown in the table, all three methodologies give similar results in the estimate of the percent change in emissions between the high RVP ethanol blend and the complying blend.

The formal method indicates that CO emissions decreased by about 10 percent for the high RVP ethanol blend while NOx emissions increased by 14 percent. For combined exhaust and evaporative emissions, THC increased by 18 percent. Also, combined NMOG emissions were 32 percent higher for the high RVP ethanol blend than for the complying blend.

The results were also assessed for ozone forming potential by performing a reactivity adjusted emissions analysis. We used the Carter maximum incremental reactivity (MIR) factors[3] to calculate the ozone forming potential of both the exhaust and evaporative emissions. The ozone forming potential of the combined exhaust and evaporative emissions is 21 percent higher for the high RVP ethanol blend than for the complying blend. The difference in ozone forming potential is largely due to the higher RVP of the ethanol blend which results in significantly greater evaporative NMOG mass emissions.

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[3] California Non-Methane Organic Gas Test Procedures, Amended June 24, 1996, Monitoring and Laboratory Division, California Air Resources Board.

Table 1

Overall Percent Change in Emissions
(High RVP Ethanol Blend vs. Complying Blend)

Pollutant	Analysis Method		
	Percent of Means	Mean of Percents	Formal Method*
Exhaust Only			
CO	-7%	-7%	-10%
NOx	17%	16%	14%
Exhaust and Evaporative Combined**			
THC	23%	21%	18%
NMOG	35%	35%	32%
OFP	20%	23%	21%
OFPCO***	16%	19%	17%
TOX	14%	15%	13%
TOXPW	9%	6%	5%

* The estimated percent changes under the formal method have likelihoods of 90 percent or higher. For the estimates of percent change based on the arithmetic averages (simple analysis) we don't estimate likelihoods.

** Running loss emissions were estimated using evaporative emissions models.

*** Includes CO as an other species. See Appendix 3 for details of how CO is integrated into the ozone forming potential.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

While CO is generally not included in a reactivity adjusted emissions analysis, any reduction in CO could benefit the exhaust emissions by somewhat reducing the ozone forming potential. However, evaporative emissions are not affected by CO. When CO is included, the ozone forming potential is 17 percent higher for the high RVP ethanol blend than for the complying blend.

Although not shown in Table 1, the specific reactivity, which is a measure of how much ozone would be formed per gram of NMOG, was similar for the high RVP ethanol blend and the complying blend. This was expected given that both test blends were made from the same gasoline base and about equal volumes of oxygenate were added.

Exhaust emissions of the toxic compounds--benzene, 1, 3-butadiene, formaldehyde and acetaldehyde emissions from the high RVP ethanol and complying blends were evaluated on both a mass and cancer potency adjusted basis. The combined emissions of toxics are 13 percent greater for the high RVP ethanol blend than for the complying blend. Also, the combined potency weighted toxics are five percent greater for the high RVP ethanol blend than for the complying blend.

C. Results of Data Evaluation

In general, the results of the test program are consistent with those previously reported in studies conducted to evaluate the effect of oxygen and RVP on exhaust and evaporative emissions.[4] The data show that the high RVP ethanol blend has a greater ozone forming potential than a fully complying blend even when the additional CO benefits and reactivity are incorporated.

The data collected in this test program show that the high RVP ethanol blend produces lower CO emissions than the complying blend. The data also show that NOx emissions increase significantly for the high RVP ethanol blend. The evaporative emissions data clearly show that the RVP level has an important effect on mass emissions. While evaporative emissions are less reactive than exhaust, the one psi RVP increase from splash blending ethanol results in significantly higher mass emissions of THC and NMOG and associated ozone forming potential.

The results show that there is a likelihood between 90 to 100 percent that emissions of NOx, THC, toxics, and potency weighted toxics are greater with the high RVP ethanol blend than with the fully complying gasoline. The data also show that the likelihood is greater than 95 percent that the ozone forming potential is higher with the high RVP ethanol blend than with the fully complying gasoline. However, for CO, the likelihood is almost 100 percent that emissions are higher with the fully complying gasoline than with the high RVP ethanol blend.

D. Conclusions

In conclusion, the data from the twelve vehicles in the test program indicate that a high RVP ethanol blend significantly increases overall emissions of NOx, THC, NMOG, ozone forming potential, toxics, and potency weighted toxics, and decreases emissions of CO. Additionally, the high level of certainty associated with the results of the test program show that additional testing would not likely change the outcome of this evaluation and that additional tests on 1990 to 1995 model year vehicles and vehicles that employ control technologies similar to these are unnecessary.

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[4] See references 1 through 4.

II. INTRODUCTION

The ARB staff performed a study to compare the emissions from cleaner burning gasoline blended with 10 percent ethanol to the emissions of cleaner burning gasoline that meets all specifications and is typical of the gasoline used during the summer. The test gasoline blends were formulated from the same base gasoline. The key differences between the test blends are the oxygen content and Reid vapor pressure (RVP). The test program was designed to investigate whether 10 percent ethanol blends with an RVP increase of about one psi provide as good or better emission benefits as a fully complying blend. The Health and Safety Code Section 43830(g) provides an RVP exemption to 10 percent ethanol blends unless the ARB determines such blends result in increased ozone forming potential as compared to a complying blend. The study was performed at ARB facilities in El Monte, California. The emissions test program started in late 1995 and was completed in May 1998.

The ARB established a workgroup consisting of representatives from the ethanol industry, the automotive industry, the oil refining industry, the U.S. EPA, ARB staff, and other interested parties (Ethanol Workgroup) to assist in defining the scope of the program. The workgroup's knowledge of fuels and motor vehicle emissions was critical in the development of the test program.

III. SCOPE OF TESTING

Twelve vehicles covering a range of model years 1990 through 1995 were tested for exhaust emissions using the federal test procedure (FTP) and REP05, an off-cycle test procedure that provides information on how vehicle emissions control systems perform at higher speeds.[5, 6] Six of these vehicles were also tested for evaporative emissions using a modified enhanced evaporative test procedure. The evaporative emissions tests included a two-day diurnal test and a one hour hot soak test. Running loss emissions were estimated using an ARB draft evaporative emissions model and the U.S. EPA's evaporative emissions model[7].

Emissions were both quantified and speciated to allow a comparison of the impact of these fuels on evaporative and exhaust emissions of THC and their ozone forming potential, CO, NOx, toxics and potency weighted toxics. Additional details on the test program are presented in Appendix 1.

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[5] U.S. Environmental Protection Agency, 1995 Code of Federal Regulations, Part 68, Subpart B--Emissions Regulations for 1997 and Later Model Year New Light Duty Vehicles and New Light Duty Truck: Test Procedures.

[6] Final Technical Report on Aggressive Driving Behavior for the Revised Federal Test Procedure, Notice of Proposed Rulemaking, U.S. EPA, Office of Air and Radiation, Office of Mobile Sources, January 31, 1995.

[7] Code of Federal Regulations, Part 80, Subpart D, Section 80.45 (c)(3)(ii).

IV. TEST VEHICLES

Twelve late model vehicles were selected for this test program. The tested vehicles used are listed in Table 2, along with their respective engine families, evaporative control systems, and emission control technologies. All vehicles were obtained from the greater Los Angeles area and selected randomly using the California Department of Motor Vehicle's ownership database.

Table 2
Vehicle Descriptions

Veh #	Model Year	Mfg	Model Tested	Engine Family	Evaporative Control System*	Emission Control Systems**	Testing Purpose
1	1995	Nissan	Pathfinder	SNS3.028GEEA	*	HO2S,TWC,WUTWC, MPI,EGR	exh only
2	1993	Mazda	MPV	PTK3.0T5FCC5	*	HO2S,TWC,MPI	exh only
3	1994	Toyota	Camry	RTY2.2VJG2GA	*	O2S,TWC,MPI,EGR	exh only
4	1990	Honda	Integra	LHN1.8V5FXC7	*	O2S,TWC,MPI,EGR	exh only
5	1992	GM	Cutlass	N1G3.1W8XGZ1	*	O2S,TWC,MPI,EGR	exh only
6	1991	Ford	Explorer	MFM4.0T5FAM0	*	HO2S,TWC,MPI	exh only
7	1993	Ford	Escort	PFM1.9V5FCC2	*	HO2S,TWC,MPI,EGR	exh+ evp
8	1991	Chrysler	Caravan	MCR3.3T5FBRX	*	HO2S,TWC,MPI	exh+ evp
9	1995	GM	Grand AM	S1G3.1V8GFEA	*	HO2S,TWC,MPI,EGR	exh+ evp
10	1994	Nissan	Sentra	RNS1.6VJG1EA	*	O2S,TWC,MPI,EGR	exh+ evp
11	1990	Honda	Accord	LHN2.2V5FPC1	*	HO2S,TWC,MPI,EGR	exh+ evp
12	1995	Nissan	Pathfinder	SNS3.028GEEA	*	HO2S,TWC,WUTWC, MPI,EGR	exh only
13	1992	Toyota	Lexus	NTY4.0V5FBB6	*	HO2S,TWC,WUTWC, MPI,EGR	exh+ evp
14	1995	Nissan	Pathfinder	SNS3.028GEEA	*	HO2S,TWC,WUTWC, MPI,EGR	exh only

* All vehicles tested were equipped with an evaporative control system consisting of a vapor control canister, vapor line from the fuel tank to the canister, and a purge line from the canister to the intake manifold.

** Emission Controls
O2S = oxygen sensor
HO2S = heated oxygen sensor
TWC = three-way catalytic converter
WUTWC = warm-up TWC
EGR = exhaust gas recirculation
MPI = multipoint fuel injection

The vehicles covered a range of model years from 1990 though 1995. The range was chosen because it encompasses vehicles with emission control systems that were typical of at least 50% of the on-road fleet in 1996. Within each model year, engine families were ranked according to sales volume. Taking into consideration all six model years in aggregate, the staff selected the engine family with the highest sales volume, then the next highest, but noting to exclude manufacturers and model years which had already been chosen. This selection was first carried out for the six vehicles to be tested on both exhaust and evaporative emission test procedures. For the six vehicles that were exhaust tested only, the same selection process was followed with the exceptions that: (a) models included in the first six vehicles were not included in the second set of six vehicles; instead, the engine family (within the same manufacturer) with the next highest sales volume was selected, and (b) the sales volume criterion was relaxed in order to introduce additional manufacturer representation. For example, Mazda was chosen since this manufacturer accounts for approximately three percent of annual California sales. Specifically, a Mazda engine family with the highest sales volume for 1990-1995 model year was included. Lastly, none of the test vehicles selected with the above criteria were certified to the enhanced evaporative test procedures (which were phased in beginning with the 1995 model year).

The test vehicles represent vehicles with emission control technologies found in a large segment of the California vehicle fleet. The vehicles tested have three-way catalysts (TWC) and fuel injection. These emission control technologies are found in model year vehicles 1986 and newer. Three-way catalysts were introduced in 1981 and by 1986 almost all vehicles had TWC. The test vehicles are representative of normal and moderate emitting vehicles with TWC and fuel injection, and similar vehicles that are higher emitting due to non-optimal emission control systems but are not considered in disrepair. Vehicles considered “high emitters” which are vehicles generally with faulty emission control systems were not tested because these vehicles are known to have highly variable emissions from test to test on the same fuel. Thus, it would be difficult to detect fuel effects in such highly unstable vehicles.[8]

The categories of vehicles represented by the test vehicles account for an estimated 70 percent of the vehicle miles traveled for 1998. As shown below, these vehicles account for a significant portion of the total estimated light-duty motor vehicle emissions inventory for 1998.

Estimated Percent of Total Light Duty Vehicle Emissions
(1986 and Newer Model Year Vehicles with TWC and Fuel Injection)

Reactive Organic Gas (ROG)	32 percent
Carbon Monoxide (CO)	42 percent
Oxides of Nitrogen (NOx)	48 percent

8 Auto/Oil Air Quality Improvement Research Program Technical Bulletin No. 11: A Study of Fuel Effects on Emissions From High Emitting Vehicles, 1992

V. TEST FUELS

Two gasoline blends were selected for the test program by the Ethanol Workgroup. The test gasolines were created by blending 10 volume percent ethanol and 11 volume percent MTBE using the same gasoline base. The target properties were chosen such that the fully complying gasoline would be a typical summer California gasoline meeting all of the required specifications for cleaner burning gasoline, while the ethanol blend would comply except for oxygen content and RVP. The desired levels of the oxygen and RVP of the ethanol gasoline blend were 3.5 weight percent and 8 psi.

Periodic fuel analyses were conducted in order to ensure fuel integrity throughout the duration of the program. A detailed fuel analysis was performed on the first 4 drums (2 of each fuel) of high RVP ethanol and complying fuels opened for testing. Subsequent detailed analyses were performed on an intermittent basis. These analyses included detailed hydrocarbon speciation as well as the parameters listed in Table 3. The RVP was determined for each drum of fuel opened. Table 3 lists the average values for key fuel properties. The test methods used to analyze the fuel are listed in Appendix 1.

Table 3

Summary of Analysis on the Composition of Test Fuels*

Property	ETOH				MTBE		
	Target	**Blender's Analysis**	**ARB's Average****		**Target**	**Blender's Analysis**	**ARB's Average****
Oxygen (wt%)	3.2 - 3.6	3.5	3.94		1.8 - 2.2	1.97	2.09
Aromatics (vol %)	23.0 - 25.0	23.7	26.46		23.0 - 25.0	23.0	23.39
Olefins (vol%)	4.0 - 6.0	4.9	5.17		4.0 - 6.0	4.4	5.20
Benzene (vol%)	0.5 - 1.0	0.8	0.82		0.5 - 1.0	0.8	0.81
RVP (psi)	7.7 - 8.0	8.0	7.81		6.7 - 7.0	7.0	6.88
T10 (deg F)	130 - 140	133	129		130 - 140	139	134
T50 (deg F)	190 - 210	195	186		190 - 210	199	197
T90 (deg F)	280 - 300	297	297		280 - 300	297	296
Sulfur (ppmw)	30 - 40	30.30	33.19		30 - 40	30.31	31.76

* See Appendix 1 for more details.

** Only ARB analytical results were used to calculate the average. Where replicates samples were taken, the mean was used for the analysis.

VI. EMISSIONS TEST PROTOCOLS

A. Test Procedures/Sequence

Vehicles in this program were tested using the standard FTP and the REP05 test procedure and the ARB's enhanced evaporative test procedures with some modifications. A total of 14 vehicles were tested with 12 having valid data. Vehicles #1 and #12 were deleted from the data set because the data were deemed invalid.

Vehicle #1 exhibited an inordinate number of problems regarding the disposition and validity of the data. Vehicle #1 experienced many problems regarding alcohol analysis and hydrocarbon speciation for the FTP exhaust tests. Another reason for excluding Vehicle #1 test data is that it was tested prior to the establishment of the protocol regarding the use of a target canister weight. Thus, each FTP conducted on this vehicle began with a canister loaded to a different weight. This may have introduced additional variability in the test data. Given these problems, it was deemed that the most prudent course of action was to exclude the reporting of all test data obtained from Vehicle #1 and to re-test a vehicle of identical engine family and model year.

Vehicle #12, the replacement for Vehicle #1, was the second vehicle to exhibit several testing problems. These included: a) dynamometer testing using the hand brake due to interaction of the dynamometer with the anti-lock braking system on the vehicle, b) an undiagnosed problem resulting in excessively hot exhaust, and c) the presence of an unidentified contaminant in the speciation profile for hydrocarbons. It was deemed appropriate to replace vehicle #12 rather than attempt to repair the vehicle, identify the contaminant, and re-run all tests. Vehicle #14 was the replacement for Vehicle #1.

Duplicate back-to-back exhaust and evaporative tests were performed on all vehicles for each fuel type. The order of fuels tested was not randomized because previous studies have shown that ethanol is difficult to purge from the canister and may confound the emission results of subsequent tests. The fully complying gasoline was the first fuel tested on each vehicle. Additionally, to the extent possible, the same driver, same dynamometer, and same evaporative test enclosure were used.

B. Exhaust Tests

Of the 14 vehicles tested in this program, vehicles # 1, 2, 3, 4, 5, 6, 12, and 14 were tested for exhaust emissions and vehicles # 7, 8, 9, 10, 11, and 13 were tested for exhaust and evaporative emissions. Exhaust tests consisted of the FTP and the REP05 with some modifications to the preconditioning sequence in order to ensure purging of the fuel system and evaporative control system as well as resetting of the adaptive learn memory.

Criteria were established for conducting a third FTP test where the duplicate tests exhibited a large difference. This determination was based on the difference between the two tests, using the criteria established in the Auto/Oil Air Quality Improvement Research Program study. Specifically, the third test was performed if the ratio of emission measurements (as defined by the higher/lower measurement) exceeded the value of 1.33 for THC, 1.70 for CO and 1.29 for NOx. Where a triplicate test was performed, all three values were deemed valid.

Tests using the REP05 cycle were conducted following the completion of each FTP fuel/replicate test sequence. This is a 2-bag test with the second bag being on the order of three minutes duration. The short second bag required an increased sample flow rate in order to collect sufficient sample for hydrocarbon speciation. It was necessary to perform this test on a single roll dynamometer (i.e., the 48" dynamometer in Dyno #1) due to the extreme speeds and accelerations specified in this test cycle.

C. Evaporative Emissions Tests

Evaporative emission tests are based on ARB's recently adopted test procedures for the "Supplemental" 2-day diurnal and hot-soak tests.[9] In the evaporative emissions tests, special steps were required in the canister handling and loading. Evaporative canisters were removed only if necessary for purposes of purging and loading. In some cases, it was necessary to adjust the position of the canister. However, the new position of the canister, once established, remained fixed throughout the test sequence in order to provide test-to-test consistency. In many cases, a canister was found to have vapor leaks. It was necessary to seal such leaks in order to adequately purge and load the canister.

For the 2-day diurnal test, three speciation samples were taken, at 0 hours, 24 hours, and 48 hours. The 1-hour hot soak test required two speciation samples, one at the start and one at the end of the test. In addition, double bags were taken for each hydrocarbon speciation sample in diurnal, hot-soak and exhaust tests. This was done in order to avoid repeating tests in the event that a bag sample was later deemed invalid. Double samples were not taken for aldehydes and alcohol. Response factors for MTBE and ethanol were determined for the FIDs (flame ionization detector) used for both exhaust and evaporative emission measurements.

The test program did not include tests for running loss emissions because the facilities required to measure running loss were not available. General Motors provided the ARB staff estimates of running loss emissions based on their vapor generation model.[10] The GM estimates of running loss are in Appendix 1. Running loss emissions of THC were also estimated using an ARB draft evaporative emissions model and the U.S. EPA's evaporative emissions model used in their reformulated gasoline program. In order to estimate the ozone forming potential of the estimated THC running loss emissions, we used the ratio of the ozone forming potential to the THC for the hot soak emissions.

[9] Air Resources Board, Mail-Out #96-31.

[10] The GM model is a proprietary and has not been described in detail in any publication. The Model is based on principles described in SAE Paper No. 861556, "Evaporative Emissions from Gasolines and Alcohol-Containing Gasolines with Closely Matched Volatilities," by S. R. Reddy, October 1986.

D. Emission Measurements and Reporting

The following exhaust and evaporative emissions were measured and reported using the reference test methods listed in Appendix 1:

Exhaust:

- THC
- non-methane hydrocarbons (NMHC)
- NMOG
- CO
- CO2
- NOx
- THC speciation
- aldehyde speciation (acetaldehyde and formaldehyde)
- alcohol speciation (ethanol and methanol)
- MTBE, Reactivity - both ozone/mile and ozone/NMOG
- fuel economy

Evaporative:

- THC
- NMHC
- NMOG
- THC speciation (diurnal and hot soak)
- alcohol speciation (ethanol and methanol)
- MTBE, and Reactivity - ozone/gram and ozone/test (diurnal and hot soak).

VII. TEST DATA RESULTS

The individual test results are presented in Appendix 1.

Tables 4 and 5 present the average exhaust emissions for THC, CO, NOx, ozone forming potential (OFP), and potency-weighted toxics (TOXPW) for each vehicle for the FTP composite and REP05 composite, respectively.

Table 6 presents the average evaporative emissions for THC, ozone forming potential, and potency-weighted toxics for the hot soak, and one and two day diurnals. The results in Tables 4, 5 and 6 were calculated by use of arithmetic averages.

Table 4-A
Exhaust Emission Summary by Vehicle by Test Mode*
(Arithmetic Averages for FTP Composite)

Vehicle	CO (g/mi)		NOx (g/mi)	
	E	C	E	C
2	3.82	3.91	0.28	0.25
3	1.46	1.23	0.27	0.25
4	2.91	3.53	0.29	0.28
5	6.46	4.60	0.35	0.24
6	3.38	3.39	0.62	0.61
7	1.76	2.14	0.15	0.11
8	4.56	4.64	0.62	0.56
9	1.79	2.13	0.35	0.33
10	2.32	2.73	0.33	0.23
11	4.02	4.16	0.19	0.19
13	2.00	1.91	0.20	0.18
14	2.17	3.22	0.37	0.32

* E = ethanol blend and C=complying blend

Table 4-B
Exhaust Emission Summary by Vehicle by Test Mode*
(Arithmetic Averages for FTP Composite)

Veh	THC (g/mi)		NMOG (mg/mi)		OFP (mg/mi)		OFPCO (mg/mi)		TOX (mg/mi)		TOXPW (mg/mi)	
	E	C	E	C	E	C	E	C	E	C	E	C
2	0.43	0.29	453.94	296.69	1659.92	1130.27	1866.12	1341.47	25.60	17.76	5.45	3.89
3	0.10	0.07	100.25	65.19	344.13	232.03	422.72	298.22	5.48	4.24	1.01	0.76
4	0.23	0.21	217.37	181.31	739.04	636.61	896.38	827.32	14.39	11.85	2.35	2.15
5	0.42	0.29	378.54	272.10	1176.19	882.17	1524.85	1130.62	28.36	20.68	4.75	3.91
6	0.18	0.19	171.67	182.98	575.82	641.83	758.33	824.78	10.97	11.20	1.80	1.97
7	0.09	0.10	78.60	88.39	265.41	293.94	360.30	409.53	6.56	7.00	1.10	1.29
8	0.34	0.36	305.07	329.88	1065.75	1127.53	1312.21	1377.85	20.02	18.47	3.13	3.47
9	0.15	0.19	135.72	175.39	462.48	577.74	559.19	692.91	8.58	9.57	1.53	1.79
10	0.17	0.16	168.97	161.48	635.26	576.63	760.80	723.89	11.49	9.34	1.78	1.76
11	0.18	0.16	154.98	134.18	551.64	510.52	768.97	734.92	11.92	10.47	2.02	1.97
13	0.17	0.16	162.34	156.17	603.56	553.44	711.42	656.66	9.75	8.47	1.80	1.75
14	0.14	0.20	136.01	197.74	490.23	731.88	607.47	905.71	9.43	10.83	1.28	1.75

* E = ethanol blend and C=complying blend

Table 5-A
Exhaust Emission Summary by Vehicle by Test Mode*
(Arithmetic Averages for REP05 Composite)

Vehicle	CO (g/mi)		NOx (g/mi)	
	E	C	E	C
2	7.48	9.00	0.12	0.11
3	4.42	6.93	0.32	0.37
4	8.51	8.75	0.30	0.29
5	22.78	26.57	0.22	0.26
6	4.46	6.17	1.59	1.31
7	1.67	2.49	2.20	1.18
8	6.15	5.27	0.77	0.69
9	4.32	4.77	0.62	0.66
10	3.67	4.86	0.15	0.13
11	8.29	8.37	0.19	0.16
13	1.19	1.55	0.21	0.21
14	6.68	6.43	0.07	0.09

* E = ethanol blend and C=complying blend

Table 5-B
Exhaust Emission Summary by Vehicle by Test Mode*
(Arithmetic Averages for REP05 Composite)

Veh	THC (g/mi)		NMOG (mg/mi)		OFP (mg/mi)		OFPCO (mg/mi)		TOX (mg/mi)		TOXPW (mg/mi)	
	E	C	E	C	E	C	E	C	E	C	E	C
2	0.06	0.07	33.24	40.93	126.89	155.54	531.01	641.34	6.39	7.50	1.23	1.47
3	0.04	0.06	25.10	34.78	103.74	142.68	342.64	516.70	2.61	3.45	0.57	0.78
4	0.13	0.13	89.84	89.54	351.68	353.16	811.34	825.73	10.14	9.27	2.20	2.31
5	0.36	0.37	283.23	292.64	841.93	934.10	2071.81	2369.13	29.69	29.48	5.62	5.78
6	0.05	0.06	30.54	35.18	122.93	143.83	363.85	476.88	3.94	4.63	0.79	0.87
7	0.04	0.04	27.91	47.91	97.08	120.29	187.43	254.72	2.97	3.52	0.50	0.68
8	0.13	0.11	95.47	80.19	349.61	285.83	681.83	570.36	7.82	5.78	1.49	1.22
9	0.04	0.05	29.41	29.30	89.67	83.36	323.19	340.97	5.69	5.61	0.94	0.94
10	0.06	0.08	41.64	63.07	126.17	188.13	324.47	450.36	5.72	8.77	1.12	1.71
11	0.10	0.10	65.59	67.68	265.12	267.94	713.00	719.94	7.51	6.91	1.74	1.74
13	0.02	0.02	10.02	9.51	31.50	30.59	95.71	114.43	1.04	1.18	0.16	0.19
14	0.09	0.07	61.26	48.41	208.91	159.03	569.60	506.24	11.43	9.88	2.23	1.88

* E = ethanol blend and C=complying blend

Table 6
Evaporative Emissions Summary by Vehicle by Test Mode*

VEH	TEST PHASE	THC (g/test)		NMOG (mg/test)		OFP (mg/test)		TOX (mg/test)		TOXPW (mg/test)	
		E	C	E	C	E	C	E	C	E	C
7	0-24 hr	10.00	8.53	11417.33	9316.29	23420.38	19941.55	281.42	240.69	47.84	40.92
8	0-24 hr	7.44	3.14	8186.25	3366.60	10047.42	4587.96	38.87	26.14	6.61	4.95
9	0-24 hr	2.01	1.59	2173.25	1767.93	4200.89	2646.78	61.31	21.68	10.42	3.69
10	0-24 hr	15.79	7.43	17213.94	8019.48	31152.83	15663.20	287.64	210.56	48.90	35.80
11	0-24 hr	1.17	0.89	1518.05	1090.81	2996.68	2093.09	44.02	30.03	7.48	5.11
13	0-24 hr	1.61	1.50	2149.03	1672.96	3103.08	2026.32	28.02	10.23	4.76	1.74
7	24-48 hr	15.22	10.29	16123.82	11185.39	26078.66	19391.02	250.49	221.15	42.58	37.60
8	24-48 hr	19.00	9.80	19273.04	10488.16	26630.80	14102.57	32.97	22.31	5.60	3.99
9	24-48 hr	4.39	2.88	4829.44	2444.95	6784.69	3226.80	47.18	17.80	8.02	3.03
10	24-48 hr	17.52	7.99	18558.95	8619.35	31386.30	13942.08	243.40	135.89	41.74	23.10
11	24-48 hr	6.29	1.91	6637.19	2102.42	8396.81	3048.85	39.82	26.13	6.77	4.44
13	24-48 hr	3.80	2.68	3839.77	2795.90	4647.56	3235.65	19.39	8.05	3.30	1.37
7	Hot Soak	0.30	0.22	341.79	253.67	942.28	730.89	8.79	7.64	1.49	1.30
8	Hot Soak	0.06	0.04	83.03	47.17	184.10	107.94	2.19	1.41	0.37	0.24
9	Hot Soak	0.14	0.08	226.16	80.24	521.44	212.83	5.60	2.63	0.95	0.45
10	Hot Soak	0.51	0.29	642.27	329.86	1720.64	941.95	15.22	9.85	2.59	1.67
11	Hot Soak	0.06	0.04	88.35	49.95	194.72	124.85	2.35	1.77	0.40	0.30
13	Hot Soak	0.11	0.06	175.89	61.49	394.43	165.78	4.27	1.80	0.73	0.31

* E = ethanol blend and C=complying blend

VIII. RESULTS OF ANALYSES

Evaluation of the test results are based on comparing the differences in the emissions response of the high RVP ethanol blend to the fully complying blend. The percent difference between the two fuels was calculated by subtracting the emissions from the fully complying gasoline from the emissions from the ethanol gasoline blend and then dividing by the emissions from the fully complying blend [(ethanol - fully complying)/fully complying]. Because running loss tests could not be performed, two scenarios were analyzed: (1) assuming no difference in running loss emissions between the two fuels, and (2) using estimated running loss emissions based on evaporative emissions models.

The test results were evaluated using arithmetic averages and a more formal statistical methodology to provide a comprehensive examination of the data. The individual test modes were examined to determine the percent change in emissions. The overall percent change in emissions (combined effects of exhaust and evaporative processes) was calculated based on the percent of the means and mean of percents as well as the formal statistical evaluation *(see Appendix 3 for more discussion on the statistical methodology)*. We used the ARB emissions inventory to determine the appropriate weights used in combining exhaust and evaporative emissions.

A summary of the results of the analyses are presented in sections A and B. More details are found in Appendix 2 and Appendix 4.

A. Arithmetic Averages

1. Arithmetic Average by Test Mode

The data were evaluated by calculating arithmetic averages (simple analysis) for each of the modes tested. In the simple analysis, the mean difference in emissions between the high RVP ethanol blend and the fully complying blend was calculated. This was performed for each pollutant of interest. Table 7 presents a summary of the average emissions difference by test mode for exhaust and evaporative emissions. A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower. Additional information on a vehicle by vehicle basis and the individual bag data is presented in Appendix 2.

Table 7

Summary of Percent Change in Emissions by Test Mode
(Arithmetic Averages of the Emissions)

	Exhaust		Evaporative		
Pollutant	**FTP Composite**	**REP05 Composite**	**Hot Soak**	**Diurnal**	
				0-24 Hr	24-48 Hr
CO	-2%	-13%	na	na	na
NOx	13%	24%	na	na	na
THC	9%	-3%	58%	65%	86%
NMOG	10%	-5%	89%	69%	84%
OFP	9%	-5%	73%	60%	82%
OFPCO	5%	-11%	73%	60%	82%
TOX	16%	-1%	53%	37%	47%
TOXPW	6%	-5%	53%	37%	47%

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

2. Combined Arithmetic Averages Using Emission Inventory Weights (Percent of the Means Method)

In order to combine the individual test modes (FTP, REP05, hot soak, and diurnal) to assess the overall impact of the test fuels on total emissions (exhaust and evaporative), we used the inventory and information from the U.S. EPA[11] to defined "inventory processes" for both exhaust and evaporative emissions. See Appendix 3 for a more detailed discussion of the inventory processes.

The exhaust and evaporative emissions were combined using weight factors for the respective processes according to their share in the motor vehicle emissions inventory. The weights for each inventory process (start exhaust[12], running exhaust[13], diurnal combined[14], hot soak, and running loss) were derived from the Motor Vehicle Emissions Inventory Version 7G (MVEI 7G). The inventory weighting varied for each pollutant of interest. For example, combined THC emissions are made up (weighted) by exhaust emissions (69%) and evaporative emissions (31%). Of the exhaust emissions, 55% are start exhaust and 45% are running exhaust.

11 Because the REPO5 test procedure is not part of the California motor vehicle inventory, we relied on information from the U.S. EPA in determining the contribution of FTP and REPO5 on running exhaust.

12 Start Exhaust = FTP bag 1 - FTP bag 3

13 Running Exhaust = 0.72*[(FTP bag 2*3.9 + FTP bag 3*3.6)/(7.5)] + 0.28*$REP05_{composite}$

14 Diurnal Combined= 0.79*Day 1 + 0.21*Day 2. Diurnal Combined contains resting loss.

Evaporative emissions are also proportioned by diurnal (28%), hot soak (13%), and running loss (59%). A more detailed discussion on the weight methodology is presented in Appendix 3.

Table 8 presents a summary of the average percent difference for exhaust and evaporative emissions and the combined percent difference. The results in Table 8 were calculated by averaging the mass emissions for each vehicle and calculating the percent difference. (Note: calculations were made assuming the difference in running loss emissions is zero and with the difference in running loss emissions estimated using the evaporative models.)

Table 8

Percent Change in Exhaust and Evaporative Emissions*
(High RVP Ethanol vs. Complying Blend)
(Percent of Means Method)

Pollutant	Process	Emission Proportions	Percent Change in Emissions (RL=0)**	Percent Change in Emissions (RL=non zero)***
CO	Exhaust	1.00	-7%	-7%
NOx	Exhaust	1.00	17%	17%
THC	Exhaust	0.69	8%	8%
	Evaporative	0.31	27%	55%
Combined Total		1.00	14%	23%
NMOG	Exhaust	0.64	8%	8%
	Evaporative	0.36	32%	82%
Combined Total		1.00	17%	35%
OFP	Exhaust	0.73	7%	7%
	Evaporative	0.27	23%	54%
Combined Total		1.00	11%	20%
OFPCO	Exhaust	0.76	4%	4%
	Evaporative	0.24	23%	54%
Combined Total		1.00	8%	14%
TOX	Exhaust	0.83	13%	13%
	Evaporative	0.17	13%	44%
Combined Total		1.00	13%	18%
TOXPW	Exhaust	0.84	4%	4%
	Evaporative	0.16	13%	35%
Combined Total		1.00	5%	9%

* Exhaust emissions consist of FTP and REP05 weighted according the fraction of daily driving associated with each cycle, based on a U.S. EPA study. Evaporative Emissions consist of hot soak, diurnal and running loss weighted according to MVEI7G fractions. The emission proportions are based on the MVEI7G fractions.

** Assumes running loss (RL) is zero

*** Includes an estimate of running loss (RL) based on ARB's MVEI and U.S. EPA evaporative emissions model.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

3. Combined Arithmetic Averages Using Emissions Inventory Weights (Mean of Percents Method)

Table 9 shows a summary of the emission differences derived by first calculating the percent emission difference for each vehicle then averaging the percent differences for all 12 vehicles.

Table 9
Percent Change in Exhaust and Evaporative Emissions*
(Mean of Percents Method)

Pollutant	Process	Emission Proportions	Percent Change in Emissions (RL=0)	Percent Change in Emissions (RL=non zero)
CO	Exhaust	1.00	-7%	-7%
NOx	Exhaust	1.00	16%	16%
THC	Exhaust	0.69	5%	5%
	Evaporative	0.31	26%	54%
	Combined Total	1.00	12%	21%
NMOG	Exhaust	0.64	7%	7%
	Evaporative	0.36	34%	84%
	Combined Total	1.00	17%	35%
OFP	Exhaust	0.73	5%	5%
	Evaporative	0.27	26%	72%
	Combined Total	1.00	11%	23%
OFPCO	Exhaust	0.76	2%	2%
	Evaporative	0.24	26%	72%
	Combined Total	1.00	8%	19%
TOX	Exhaust	0.83	9%	9%
	Evaporative	0.17	21%	42%
	Combined Total	1.00	11%	15%
TOXPW	Exhaust	0.84	-1%	-1%
	Evaporative	0.16	22%	43%
	Combined Total	1.00	3%	6%

* Exhaust emissions consist of FTP and REP05 weighted according the fraction of daily driving associated with each cycle, based on a U.S. EPA study. Evaporative Emissions consist of hot soak, diurnal and running loss weighted according to MVEI7G fractions. The emission proportions are based on the MVEI7G fractions.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

B. Overall Percent Difference in Emissions for Individual Vehicles (Combined Across Inventory Processes)

The overall percent difference in emissions for each vehicle was calculated by combining the exhaust and evaporative (when available) emissions change using inventory weights derived for each model year. For a description of this approach, please see Appendix 3. Table 10 summarizes the results of this analysis. Details are provided in Appendix 4, Attachment B, Tables 1 through Table 8. This approach differs from the previous in that the inventory processes (starts exhaust, running exhaust, hot soak, diurnal, and running loss) are combined on a vehicle by vehicle basis.

Table 10
Percent Change in Emissions by Vehicles
(Using the calculations approach described in Appendix 3)

Veh	THC			CO	NOx	OFP			TOXPW		
	Exh (1)	Evap (2)	Comb (3)			Exh (1)	Evap (2)	Comb (3)	Exh (1)	Evap (2)	Comb (3)
2	18%	nt	na	-11%	14%	31%	nt	na	22%	nt	na
3	26%	nt	na	-6%	1%	34%	nt	na	17%	nt	na
4	13%	nt	na	-11%	3%	16%	nt	na	8%	nt	na
5	41%	nt	na	19%	33%	26%	nt	na	12%	nt	na
6	-6%	nt	na	-12%	8%	-11%	nt	na	-8%	nt	na
7	-8%	9%	-2%	-22%	65%	-9%	7%	-3%	-13%	5%	-10%
8	-4%	43%	8%	4%	11%	-3%	34%	4%	-6%	15%	-4%
9	-15%	17%	-2%	-12%	-5%	-17%	27%	0%	-9%	33%	0%
10	0%	40%	16%	-20%	47%	6%	29%	14%	-8%	16%	-2%
11	10%	32%	17%	-6%	4%	6%	25%	12%	1%	15%	4%
13	5%	16%	8%	-14%	10%	7%	29%	13%	-5%	33%	1%
14	-18%	nt	na	-10%	11%	-26%	nt	na	1%	nt	na

(1) Exhaust emissions consist of FTP and REP05 weighted according the fraction of daily driving associated with each cycle, based on a U.S. EPA study.
(2) Evaporative Emissions consist of hot soak, diurnal and running loss weighted according to MVEI7G fractions for each vehicle model year.
(3) Exhaust and evaporative emissions are combined according to the MVEI7G fractions for each vehicle model year.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

C. Analysis Using the Formal Method

The percent difference in the emissions response of the high RVP ethanol blend to the complying blend was also calculated by conducting a more in-depth statistical analysis. This analysis also determined the likelihood that the direction of the change in emissions would apply to a much larger fleet of vehicles similar to these represented in the test sample. The fundamental statistical analyses were carried out using the PROC MIXED module found in industry-standard *SAS* statistical software[15] ("mixed effects" analysis), and the results are appropriate for inferences to more extensive real world populations of vehicles. Additional details regarding the statistical analysis can be found in Appendix 3. Complete results of the analysis are presented in Appendix 4. The uncertainty estimates show that there is a high level of certainty in the direction of the emission differences between the two fuels. The exhaust and evaporative emissions were combined using the same weight factors as in Section A (Table 8). Table 11 presents a summary of the percent change in emissions which includes estimated running loss emissions based evaporative emissions models. Table 12 presents a summary of the percent change in emissions assuming no emissions difference for running loss emissions.

D. Comparisons of Results Based on Arithmetic Averages and Formal Method

Table 13 presents the same information for the case where running loss emissions are estimated using the ARB and EPA evaporative emissions models. Table 14 shows a summary of the results from the simple averages and the formal statistical analyses for the case where running loss emissions are assumed to be zero. A complete presentation of the results are contained in Appendix 2 and Appendix 4. As shown in the tables, the choice of methodology (simple or mixed effects model) does not affect the final assessment. All analyses indicate that emissions on the high RVP ethanol blend are higher than those on the MTBE blend, except for emissions of CO. Additionally, as shown in Tables 11 and 12, the results of the formal analysis show a high level of certainty in the direction of the emission differences between the two fuels.

[15] SAS Statistical Software, Version 6.12

Table 11
Percent Change in Exhaust and Evaporative Emissions
(High-RVP Ethanol Blend vs. Complying Blend)

(Standard Errors and Likelihoods Using the Formal Method with Non-Zero Values for Running Loss)

Pollutant	**Inventory Process**	**Emission Proportion**	**Percent Change in Emissions**	**Standard Error**	**Likelihood that High-RVP > Complying Fuel**	**Likelihood that Complying Fuel > High-RVP**
Carbon Monoxide	Exhaust	1.00	-10%	4%	0%	100%
Nitrogen Oxides	Exhaust	1.00	14%	6%	99%	1%
Total Hydrocarbons	Exhaust	0.69	3%	5%	69%	31%
	Evap.	0.31	52%	6%	100%	0%
	Total	*1.00*	*18%*	*4%*	*100%*	*0%*
Nonmethane Organic Gases	Exhaust	0.64	3%	6%	72%	28%
	Evap.	0.36	83%	6%	100%	0%
	Total	*1.00*	*32%*	*4%*	*100%*	*0%*
Ozone-Forming Potential from NMOG	Exhaust	0.73	3%	5%	71%	29%
	Evap.	0.27	71%	4%	100%	0%
	Total	*1.00*	*21%*	*4%*	*100%*	*0%*
Ozone-Forming Potential from NMOG + CO	Exhaust	0.76	0%	4%	52%	48%
	Evap.	0.24	71%	4%	100%	0%
	Total	*1.00*	*17%*	*4%*	*100%*	*0%*
Toxics	Exhaust	0.83	7%	4%	94%	6%
	Evap.	0.17	41%	4%	100%	0%
	Total	*1.00*	*13%*	*4%*	*100%*	*0%*
Potency-Weighted Toxics	Exhaust	0.84	-2%	4%	29%	71%
	Evap.	0.16	41%	5%	100%	0%
	Total	*1.00*	*5%*	*3%*	*92%*	*8%*

* Exhaust emissions consist of FTP and REP05 weighted according the fraction of daily driving associated with each cycle, based on a U.S. EPA study. Evaporative Emissions consist of hot soak, diurnal and running loss weighted according to MVEI7G fractions. The emission proportions are based on the MVEI7G fractions.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

Table 12
Percent Change in Exhaust and Evaporative Emissions
(High-RVP Ethanol Blend vs. Complying Blend)
(Standard Errors and Likelihoods Using the Formal Method with Running Loss Set to Zero)

Pollutant	Inventory Process	Emission Proportion	Percent Change in Emissions	Standard Error	Likelihood that High-RVP > Complying Fuel	Likelihood that Complying Fuel > High-RVP
Carbon Monoxide	Exhaust	1.00	-10%	4%	0%	100%
Nitrogen Oxides	Exhaust	1.00	14%	6%	99%	1%
Total Hydrocarbons	Exhaust	0.69	3%	5%	69%	31%
	Evap.	0.31	25%	6%	100%	0%
	Total	*1.00*	*10%*	*4%*	*99%*	*1%*
Nonmethane Organic Gases	Exhaust	0.64	3%	6%	72%	28%
	Evap.	0.36	32%	6%	100%	0%
	Total	*1.00*	*14%*	*4%*	*100%*	*0%*
Ozone-Forming Potential from NMOG	Exhaust	0.73	3%	5%	71%	29%
	Evap.	0.27	25%	4%	100%	0%
	Total	*1.00*	*9%*	*4%*	*99%*	*1%*
Ozone-Forming Potential from NMOG + CO	Exhaust	0.76	0%	4%	52%	48%
	Evap.	0.24	25%	4%	100%	0%
	Total	*1.00*	*6%*	*4%*	*96%*	*4%*
Toxics	Exhaust	0.83	7%	4%	94%	6%
	Evap.	0.17	20%	4%	100%	0%
	Total	*1.00*	*9%*	*4%*	*99%*	*1%*
Potency-Weighted Toxics	Exhaust	0.84	-2%	4%	29%	71%
	Evap.	0.16	19%	5%	100%	0%
	Total	*1.00*	*1%*	*3%*	*65%*	*35%*

* Exhaust emissions consist of FTP and REP05 weighted according the fraction of daily driving associated with each cycle, based on a U.S. EPA study. Evaporative Emissions consist of hot soak, diurnal and running loss weighted according to MVEI7G fractions. The emission proportions are based on the MVEI7G fractions.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

Table 13

Percent Change in Exhaust and Evaporative Emissions*
High RVP Ethanol vs. Complying Blend
(Non-Zero Values for Running Loss)

Pollutant	Test Mode	Analysis Method		
		Percent of Means	Mean of Percents	Formal Method
CO	Exhaust	-7%	-7%	-10%
NOx	Exhaust	17%	16%	14%
THC	Exhaust	8%	7%	3%
	Evaporative	55%	54%	52%
	Combined Total	23%	21%	18%
NMOG	Exhaust	8%	7%	3%
	Evaporative	82%	84%	83%
	Combined Total	35%	35%	32%
OFP	Exhaust	7%	5%	3%
	Evaporative	54%	72%	71%
	Combined Total	20%	23%	21%
OFPCO	Exhaust	4%	2%	0%
	Evaporative	54%	72%	71%
	Combined Total	16%	19%	17%
TOX	Exhaust	13%	9%	7%
	Evaporative	44%	42%	41%
	Combined Total	18%	15%	13%
TOXPW	Exhaust	4%	-1%	-2%
	Evaporative	35%	43%	41%
	Combined Total	9%	6%	5%

* Includes an estimate of running loss based on ARB's Preliminary Evaporative Emissions Model and the U.S. EPA evaporative emissions model.

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

Table 14
Percent Change in Exhaust and Evaporative Emissions*
High RVP Ethanol vs. Complying Blend
(Running Loss Set to Zero)

Pollutant	Test Mode	Analysis Method		
		Percent of Means	**Mean of Percents**	**Formal Method**
CO	Exhaust	-7%	-7%	-10%
NOx	Exhaust	17%	16%	14%
THC	Exhaust	8%	7%	3%
	Evaporative	27%	26%	25%
	Combined Total	14%	13%	10%
NMOG	Exhaust	8%	7%	3%
	Evaporative	32%	14%	32%
	Combined Total	17%	9%	14%
OFP	Exhaust	7%	5%	3%
	Evaporative	23%	26%	25%
	Combined Total	11%	11%	9%
OFPCO	Exhaust	4%	2%	0%
	Evaporative	23%	26%	25%
	Combined Total	8%	8%	6%
TOX	Exhaust	13%	9%	7%
	Evaporative	13%	21%	20%
	Combined Total	13%	11%	9%
TOXPW	Exhaust	4%	1%	-2%
	Evaporative	13%	22%	19%
	Combined Total	5%	4%	1%

* Assumes the running loss emissions difference is zero

Note: A positive number indicates that there was an increase in emissions associated with using the ethanol blend. A negative number indicates the opposite; emissions using the ethanol blend were lower.

IX. REFERENCES

1. Air Resources Board, Research Division, *Effect of Use of Low Oxygenate Gasoline Blends upon Emissions from California Vehicles*, Final Report, February 1994, Contract Number A932-159.

2. Auto/Oil Air Quality Research Program, *Effects of Oxygenated Fuels and RVP on Automotive Emissions,* SAE Paper 920326, 1992.

3. American Petroleum Institute, *Effects of Fuel RVP and Fuel Blends on Emissions at Non-FTP Temperatures, Volume I: Interim Summary Report,* July 1991.

4. American Petroleum Institute, *Effects of Fuel RVP and Fuel Blends on Emissions at Non-FTP Temperatures, Volume II: Compilation of Test Data and Laboratory Procedures,* June 1991.

5. U.S. EPA, Office of Air and Radiation, Office of Mobile Sources, *Final Technical Report on Aggressive Driving Behavior for the Revised Federal Test Procedure, Notice of Proposed Rulemaking*, January 31, 1995.

6. SAE Paper No. 861556, *Evaporative Emissions from Gasolines and Alcohol-Containing Gasolines with Closely Matched Volatilities,* by S. R. Reddy, October 1986.

7. California Air Resources Board, Monitoring and Laboratory Division, *California Non-Methane Organic Gas Test Procedures*, Amended June 24, 1996,

8. U.S. Environmental Protection Agency, *Emissions Regulations for 1997 and Later Model Year New Light Duty Vehicles and New Light Duty Truck: Test Procedures*,1995 Code of Federal Regulations, Part 68, Subpart B.

9. Code of Federal Regulations, Part 80, Subpart D, Section 80.45 (c)(3)(ii).

10. Auto/Oil Air Quality Improvement Research Program, Technical Bulletin No. 11: *A Study of Fuel Effects on Emissions From High Emitting Vehicles, 1992.*

11. Air Resources Board, Mail-Out #96-31.