Appendix 1

Proposed Revision of Section 2296.2

PROPOSED REGULATION ORDER

(Proposed deletions are shown in ~~strike-out type~~. Proposed additions are underlined.)

Amend section 2292.6, Title 13, California code of Regulations, to read as follows:

Section 2292.6 **Specifications for Liquefied Petroleum Gas**

The following standards apply to liquefied petroleum gas (the identified methods are incorporated herein by reference):

Specifications for Liquefied Petroleum Gas

Specification	**Value**	**Test Method**
Propane	85.0 vol. % (min.) a/	ASTM D 2163-87
Vapor Press. at 100° F	208 psig (max.)	ASTM D 1267-89 ASTM D 2598-88 b/
Volatility residue: evaporated temp., 95% or butanes, butenes, and heavier	 -37° F (max.) ~~2.5~~ 5.0 vol. % (max.)	 ASTM D 1837-86
Butenes, pentanes, and heavier	0.5 vol.% (max.)	ASTM D 2163-87
Propene	~~5.0~~ 10.0 vol. % (max.) ~~c/~~	ASTM D 2163-87
Residual matter: residue on evap. of 100 ml oil stain observed.	 0.05 ml (max.) pass ~~d~~ c/	 ASTM D 2158-89 ASTM D 2158-89
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	120 ppmw (max.)	ASTM D 2784-89
Moisture content	pass	ASTM D 2713-86
Odorant	~~e~~ d/	

a/ Propane shall be required to be a minimum of 80.0 volume percent starting on January 1, 1993. Starting on January 1, 1997, the minimum propane content shall be 85.0 volume percent.

b/ In case of dispute about the vapor pressure of a product, the value actually determined by Test Method ASTM D 1267-89 shall prevail over the value calculated by Practice ASTM D 2598-88.

~~c/ The propene shall be limited to 10.0 volume percent starting January 1, 1993. Starting January 1, 1997~~ 1999 ~~, the propene limit shall be 5.0 volume percent.~~

~~d~~ c/ An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper, in 0.1 ml increments and examined in daylight after 2 min. as described in Test Method ASTM 2158-89.

~~e~~ d/ The liquefied petroleum gas upon vaporization at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.

Appendix 2

LPG Task Group Participating Organizations

LPG Task Group Participating Organizations

American Automobile Manufacturers Association
Air Resources Board
ARCO Products Company
California Department of Food and Agriculture - DMS
California Energy Commission
Chevron Products Company
Chrysler Corporation
Clean Air Partners
Cummins Engine Company, Inc.
Detroit Diesel
Engine Manufacturers Association
Equilon Enterprises, LLC
Exxon Company, USA
Ford Motor Company
General Motors
GFI Control Systems, Inc
IMPCO Technologies, Inc
Kohler Corporation
Mutual Liquid Gas
National Propane Gas Association
National Renewable Energy Laboratory
Natural Resources Canada — Canmet Energy Technology Centre
Navistar International
North Western Propane Gas Association
ONAN Corporation
ORTECH
Propane Gas Association of Canada
Propane Vehicle Council
RPM Consulting Group
Sacramento Metropolitan Air Quality Management District
South Coast Air Quality Management District
Southwest Research Institute
Suburban Propane
Texas Railroad Commission — Alternative Fuels Research and Education Division
The Adept Group, Inc.
Tosco Refining Company
Western Propane Gas Association

Appendix 3

LPG Blends Evaluation Test Protocol

State of California

AIR RESOURCES BOARD

LPG Blends Evaluation Test Protocol

Emissions, Performance and Durability Study
of Various LPG Fuel Compositions

February, 9 1998

I. INTRODUCTION

The proposed test program will be used to identify alternative blends of liquefied petroleum gas (LPG) fuels that provide equivalent or better performance than HD-5 in terms of emissions control, engine performance and required durability. This protocol is a general statement of the scope of work to be done as part of the LPG Evaluation Test Program. This protocol will guide the creation of contracts for conducting specific tests. The contracts will be defined and agreed to by the LPG Task Group prior to the project manager awarding the contracts.

II. OBJECTIVE

This test program is to determine if alternative specifications to the adopted ARB standards for motor vehicle grade LPG will provide equivalent or better emissions, performance, and durability in existing engines. The test program will evaluate various LPG blends to determine if there are equivalent specifications that could alleviate supply and distribution concerns for users of LPG motor vehicles.

III. TESTING

A. Overview

To evaluate various blends of LPG fuels in existing engines, a medium duty engine and a light duty vehicle were selected. Engine stand and vehicle dynamometer testing will be conducted. Testing will evaluate emissions, engine performance, and durability characteristics of various LPG fuels in these engines and components.

The LPG Test Program will consist of the following tests:

- Fuel properties
- Emissions
- Performance/combustion
- Durability

Each of the test fuels will be analyzed to verify the supplier's statement of fuel properties. Also, the octane rating of each fuel will be determined. The candidate fuels will be ranked with the first being the most similar to the base fuel based on parameters such as the stoichiometric air/fuel ratio, lower heating value, and octane rating.

The emissions tests will be conducted on the medium duty engine and the light duty vehicle using the appropriate Federal Test Protocol (FTP) procedure. The base fuel will be tested at the beginning and end of the emissions testing, and if time permits, the candidate fuels will be tested in the sequence in which they were ranked. Only the fuels that are deemed equivalent or better than the base fuel from the emissions testing will be considered further. In the event that more than one fuel passes the emissions tests, the LPG Task Group will reconvene and review the test data to decide how the subsequent performance and durability tests should be conducted. If the first candidate fuel fails early in the performance testing process, then tests with the next candidate fuel could be initiated. If a fuel passes the performance evaluation, it will then be tested for durability.

Financial and applicable time constraints will be considered in establishing the detailed protocol for the performance and combustion tests and durability tests.

B. Engine Selection

The medium duty Cummins 6B engine and the Ford F150 bi-fueled pickup (gasoline/LPG) are the only two LPG powered engines/vehicles that are certified to California emissions standards for 1998. The Ford vehicle will be used for emissions testing and the Cummins engine will be used for emissions, performance, and durability testing. The Cummins engine is a lean burn engine and is certified to California low emission vehicle standards and the Ford F150 is a stoichiometric engine and is also certified to the low emission vehicle standards.

C. Fuel Preparation

Table 1 lists the properties and tolerances of the test fuels that will undergo emissions testing. For this study, the base fuel for emissions testing will be California certification fuel. The certification fuel is specified in the California Code of Regulations Title 13 section 2292.6. The primary components of the test fuels are shown in Table 1.

Table 1
LPG Test Fuels
(Volume %)

Fuel	Propane	Propene [1]	n-Butane [1]
Base	93.5 ± 1.0%	3.8 ± 0.5%	1.9 ± 0.3%
Test Fuel 1	85 ± 1.0%	10 ± 0.5%	5 ± 0.5%
Test Fuel 2	80 ± 1.0%	15 ± 0.5%	5 ± 0.5%
Test Fuel 3	80 ± 1.0%	10 ± 0.5%	10 ± 0.5%
Test Fuel 4	76 ± 1.0%	3.8 ± 0.5%	20 ± 0.5%
1. The propene or n-butane tolerances may be increased to ± 1% to reduce costs.			

D. Emissions Testing Overview

The emissions testing for both the light duty and medium duty will begin with the base fuel. Subsequent tests will proceed in the order of the fuel most similar to the base fuel being first. With each fuel, duplicate emissions tests will be done, except exhaust speciation data will only be collected for one complete test cycle. Triplicate tests will be conducted if the first two tests differ significantly (specified in the data analysis section). The base fuel will be tested once more at the end of the emissions testing to account for any emissions drift.

1. Light Duty Emissions Testing

The light duty testing will done by the standard EPA FTP procedure as specified in Code of Federal Regulations (CFR) Title 40, Part 86, Subpart B. However, as a cost saving measure, the test fuel may be supplied to the vehicle directly from the fuel cylinder.

2. Medium Duty Emissions Testing

The medium duty engine tests will follow the EPA FTP transient cycle as specified in the Code of Federal Regulations (CFR) Title 40, Part 86, Subpart N. The following would be included in the emissions tests:

- A new engine map test for the base fuel (Tests with all fuels will use the same map developed with the base fuel)

- One cold-start and 2 hot-start tests on each fuel (in duplicate)

For each fuel, data on some performance characteristics will be gathered to supplement other available information that could be used to select candidate fuels for subsequent performance and combustion tests.

E. Performance and Combustion Testing

Only the medium duty engine will be used for conducting performance and combustion characteristics testing. Combustion and performance testing will be considered together and can be done with the same engine setup. The engine dynamometer testing will include steady-state tests for performance including the cylinder head being instrumented for in-cylinder pressure measurements. The parameters to be measured are power, torque, air flow, fuel flow, engine boost, intake air temperatures/pressures, exhaust temperatures/pressures, and fuel system control logic parameters. In the combustion testing the characteristics of interest are the combustion pressure, rates of pressure rise, combustion rate/duration, and knock index. They can be measured by taking dynamic combustion pressure measurements and using high speed data gathering equipment. The performance measurements will be compared to the standards used by the manufacturer for the engine; therefore, no base fuel will be tested for a performance comparison.

F. Durability Testing

1. Medium Duty Durability Testing

Medium duty engine durability testing will be 500 hours of testing with the selected candidate fuel followed by a visual inspection of engine components. The testing will provide information on the effect of the candidate fuel on the operating characteristics of the engine in extended operation and will ensure that no apparent damage is done to the engine.

IV. DATA COLLECTION, ANALYSIS AND REPORTING

A. Fuel Analysis Data

In addition to the fuel supplier's analysis, a gas chromatography analysis will be conducted for each fuel to verify the properties of the fuel samples used in each part of the test program.

B. Emissions Testing Data

The exhaust emissions for each candidate fuel will be measured against the exhaust emissions with the base fuel. Equivalency will be based on comparisons of the average composite exhaust emissions for NOx, CO, THC, NMHC or NMOG, and reactivity emissions (ozone forming potential). NMHC will be measured in the medium duty test and NMOG will be measure for the light duty test. Composite emissions results will be calculated according to standard FTP procedures; however the emissions results from the two hot cycle tests in each test run for the medium duty engine will be averaged before applying the standard method. The ozone forming potential will be based on current ARB maximum incremental reactivity values using data from only one entire test cycle on each fuel. The hydrocarbon speciation data for the medium duty engine will be collected on one cold and one hot cycle. For the light duty vehicle, the hydrocarbon speciation data will be gathered according to the standard FTP procedure (3 bag analysis) on one test run.

While the medium duty engine is on the emissions test stand, additional engine performance data will be gathered for later use in evaluating fuels for further testing. The data to be gathered are the following:

- Exhaust temperatures and pressures
- Turbo in and turbo out exhaust temperatures and pressures
- Turbo in and turbo out compressor temperatures
- Pre- and post-catalyst exhaust temperatures
- Oil temperatures and pressures

1. Emissions Criteria

For each emission type, the criterion for determining whether the candidate fuel is equivalent to the base fuel is:

$$X_c \leq X_r (1+2\delta)$$

Where: X_c = Average composite emissions during testing with the candidate fuel.
X_r = Average composite emissions during testing with the reference fuel.
δ = Coefficient of variability (%).

Note that reactivity data will only be collected for one test cycle on each fuel; therefore, the data cannot be averaged.

The coefficient of variation was determined with existing data using the same methodology used in the Auto/Oil study. The coefficients of variation to be used in the LPG Test Program are shown in Table 2. The light duty coefficients of variation are estimated from emissions testing done on LPG vehicles by ARCO, WPGA, and the ARB. Further, evaluation of the Auto/Oil emissions data on a wide variety of light duty gasoline vehicles confirms that the light duty δ values are in the appropriate range. The coefficients of variation for medium duty testing are estimated from data in the Southwest Research Institute report titled Reactivity Comparison of Exhaust Emissions from Heavy-Duty Engines Operating on Gasoline, Diesel, and Alternative Fuels and further supported with other ARB heavy duty engine test data and discussions with representatives from Cummins and ORTECH.

Table 2
Emissions Testing Coefficients of Variation
(δ = % of base fuel mean)

Pollutant	**Light Duty[1], δ**	**Medium Duty [2], δ**
Total Hydrocarbons	7%	4%
Non-Methane Hydrocarbons	---[3]	5%
Non-Methane Organic Gases	9%	---[3]
Carbon Monoxide	8%	5%
Oxides of Nitrogen	17%	2%
Ozone Forming Potential	9%	7%

1. Based on testing with LPG only.
2. Based on testing with various fuels.
3. Not used for engine certification and would not be compared in evaluating fuels.

If the composite emissions test results for the first two runs on a fuel vary by more than $2.77 \cdot \delta$ (or $\sqrt{2} \cdot 1.96 \cdot \delta$) then the task group will decide whether a third test should be run. If the observed differences between two runs exceeds $2.77 \cdot \delta$, one or both of the runs can be assumed, with a 95% confidence, to be inconsistent with testing that complies with the δ values in Table 2.

C. Engine Performance (Medium Duty)

1. Performance/Combustion Criteria

Performance, combustion, and durability test results with the candidate fuel will be compared to acceptable engine standards and tolerance criteria specified by the engine manufacturer. Some standards for combustion characteristics are kept confidential by the manufacturer and will be provided to Adept and the ARB on a confidential basis. Table 3 lists the engine parameters and the acceptability criteria that will be used to evaluate the test fuel during the performance and combustion testing.

Table 3
Performance and Combustion Testing Criteria
(for Medium Duty Cummins 6B Engine)

Test Parameter	Acceptability Criteria *	
	Mean	Range
Maximum Power	195 hp	- 5%
Maximum Torque	420 lb.-ft	- 5%
Air Flow	Confidential	
Fuel Flow	Confidential	
Engine Boost	Confidential	
Intake Air Temperature	Confidential	
Intake Air Pressure	Confidential	
Exhaust Temperature	Confidential	
Exhaust Pressure	Confidential	
Fuel System Control Logic Parameters	Confidential	
Ignition Delay	Confidential	
Rate of Combustion	Confidential	
Maximum Combustion Pressure	Confidential	
Rate of Pressure Rise	Confidential	
Knock Index	Confidential	

* Cummins will provide the acceptable ranges to Adept and the ARB on a confidential basis.

D. Durability Criteria

1. Medium Duty Durability

During the durability testing, the engine operating characteristics will be evaluated to ensure that they remain within the acceptable design limits. The candidate fuel will be deemed acceptable if the engine completes the test without problems and power cylinder component measurements remain within design guidelines. Acceptability ranges will be provided to Adept and the ARB on a confidential basis by the engine manufacturer. Results from this test will be analyzed and a recommendation to the LPG Task Group will be made.

Appendix 4

Test Data and Laboratory Results

Emissions Test Results

Cummins B-5.9 LPG Engine

Test Date	Fuel ID	Engine Hours	THC g/bhp-hr	NMHC g/bhp-hr	CO g/bhp-hr	NOx g/bhp-hr	CO2 g/bhp-hr	NMOG g/bhp-hr	Ozone g/bhp-hr
5/20/98	Base	257.0	0.884	0.849	0.418	2.78	670	---	---
5/21/98	Base	258.3	0.847	0.811	0.329	2.77	680	0.82	1.156
5/22/98	Base	260.1	1.083	1.045	0.369	2.92	675	---	---
6/8/98	Base	271.7	0.899	0.863	0.367	2.95	677	---	---
6/19/98	Base	282.6	0.723	0.690	0.424	2.95	677	0.72	0.999
6/22/98	Base	283.9	0.742	0.701	0.518	3.02	680	---	---
7/17/98	Base	289.3	0.712	0.680	0.455	2.96	675	0.72	1.068
8/12/98	Base	296.6	0.870	0.842	0.308	2.96	672	---	---
8/17/98	Base	303.1	0.878	0.842	0.281	2.90	662	---	---
	Average		**0.848**	**0.814**	**0.385**	**2.91**	**674**	**0.75**	**1.074**
5/28/98	Fuel 1	263.1	0.726	0.694	0.409	3.07	666	0.76	1.215
5/29/98	Fuel 1	264.8	0.762	0.730	0.451	3.16	662	---	---
7/20/98	Fuel 1	290.7	0.619	0.587	0.360	3.31	674	0.62	1.072
	Average		**0.702**	**0.670**	**0.407**	**3.18**	**667**	**0.69**	**1.144**
6/3/98	Fuel 2	267.3	0.711	0.673	0.572	3.25	668	---	---
6/4/98	Fuel 2	270.0	0.765	0.733	0.416	3.20	669	0.85	1.338
7/3/98	Fuel 2	286.2	0.655	0.619	0.557	3.34	687	---	---
7/21/98	Fuel 2	292.0	0.564	0.531	0.569	3.18	676	---	---
8/14/98	Fuel 2	298.9	0.655	0.624	0.332	3.32	669	---	---
	Average		**0.670**	**0.636**	**0.489**	**3.26**	**674**	**0.85**	**1.338**
6/10/98	Fuel 3	274.6	0.833	0.791	0.623	3.16	676	---	---
6/11/98	Fuel 3	276.1	0.878	0.839	0.613	3.30	674	0.83	1.360
	Average		**0.856**	**0.815**	**0.618**	**3.23**	**675**	**0.83**	**1.360**
6/16/98	Fuel 4	278.6	0.795	0.744	0.789	3.04	675	0.78	1.237
6/17/98	Fuel 4	279.9	0.769	0.728	0.844	3.02	685	---	---
	Average		**0.782**	**0.736**	**0.816**	**3.03**	**680**	**0.78**	**1.237**
8/13/98	Fuel 5	297.1	0.606	0.579	0.324	3.57	671	0.52	1.068
8/17/98	Fuel 5	300.3	0.640	0.608	0.324	3.70	677	---	---
	Average		**0.623**	**0.594**	**0.324**	**3.63**	**674**	**0.52**	**1.07**

Emissions Test Results

Ford F-150 Bi-Fuel Pickup

Test Date	Fuel ID	Odometer miles	THC g/mi	CO g/mi	NOx g/mi	NMOG g/mi	Ozone g/mi	CO2 g/mi	Fuel Econ. mpg
6/16/98	Base	6699	0.057	2.064	0.031	0.036	0.047	540	10.6
6/17/98	Base	6739	0.047	1.714	0.028	0.029	0.037	544	10.6
7/30/98	Base	7197	0.045	1.114	0.055	0.033	0.040	554	10.4
8/5/98	Base	7278	0.053	2.071	0.045	0.034	0.043	564	10.2
9/16/98	Base	7533	0.066	3.105	0.045	0.044	0.073	555	10.3
9/23/98	Base	7572	0.061	2.101	0.034	0.041	0.049	551	10.4
	Average		**0.055**	**2.028**	**0.040**	**0.036**	**0.048**	**551**	**10.4**
7/1/98	Fuel 1	6821	0.047	1.324	0.044	0.032	0.047	556	10.4
7/7/98	Fuel 1	6936	0.049	2.340	0.033	0.026	0.040	561	10.3
8/12/98	Fuel 1	7329	0.054	2.465	0.035	0.045	0.061	554	10.5
	Average		**0.050**	**2.043**	**0.037**	**0.035**	**0.050**	**557**	**10.4**
7/2/98	Fuel 2	6861	0.060	2.002	0.048	0.041	0.062	557	10.4
7/3/98	Fuel 2	6904	0.054	2.148	0.038	0.036	0.073	557	10.4
	Average		**0.057**	**2.075**	**0.043**	**0.038**	**0.068**	**557**	**10.4**
7/15/98	Fuel 3	7012	0.045	0.994	0.048	0.030	0.047	556	10.5
7/16/98	Fuel 3	7052	0.060	1.990	0.044	0.040	0.059	556	10.5
8/26/98	Fuel 3	7370	0.051	1.751	0.060	0.035	0.057	566	10.3
	Average		**0.052**	**1.578**	**0.051**	**0.035**	**0.054**	**559**	**10.4**
7/24/98	Fuel 4	7116	0.080	3.507	0.044	0.053	0.074	556	10.6
7/28/98	Fuel 4	7157	0.064	2.603	0.021	0.042	0.063	556	10.6
8/27/98	Fuel 4	7411	0.066	2.214	0.056	0.047	0.063	553	10.7
	Average		**0.070**	**2.775**	**0.040**	**0.047**	**0.067**	**555**	**10.6**
8/28/98	Fuel 5	7451	0.046	3.014	0.040	0.034	0.059	552	10.5
9/4/98	Fuel 5	7492	0.031	1.143	0.066	0.027	0.059	546	10.7
9/25/98	Fuel 5	7613	0.048	2.256	0.042	0.039	0.062	548	10.6
	Average		**0.042**	**2.138**	**0.049**	**0.033**	**0.060**	**549**	**10.6**

Place Holder for Fuel Certificates of Analysis

Appendix 5

Linear Baseline Drift Analysis

Emissions Drift Analysis
for the LPG Task Group Emissions Test

The emissions data for the base fuel on both engines was analyzed with linear regression against time to determine if part of the variability in the emissions results was attributable to emissions drift (increase or decrease in exhaust emissions over time). If drift effects were evident, then adjustments to the data could be made to separate these effects from the random error effects. Because the test fuel sequence was not randomized, this was a precaution the LPG Task Group thought should be made.

Statistically significant results in a linear model (above a 90 percent confidence) were seen versus hour of operation for NOx emissions when using the base fuel in the Cummins engine and were also evident versus odometer reading for NMOG on the Ford F-150 pickup. NOx emissions on the Cummins engine increased slightly from the beginning to the end of the test program, and the NMOG emissions for the Ford F-150 decreased through the duration of the test program. However, any adjustments to the data accounting for emissions drift do not affect the staff recommendation. The SAS results and data follow.

Regressions for Evaluating Emissions Drift -- Cummins B5.9 LPG Engine

General Linear Models Procedure
Class Level Information

Class	Levels	Values
FUEL	1	Base

Number of observations in data set = 9

Dependent Variable: NOX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.02294933	0.02294933	4.70	0.0668
Error	7	0.03416823	0.00488118		
Corrected Total	8	0.05711756			

R-Square	C.V.	Root MSE	NOX Mean
0.401791	2.400232	0.06986541	2.91077778

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.02294933	0.02294933	4.70	0.0668

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.045150422	5.11	0.0014	0.39989494
HOUR	0.003112523	2.17	0.0668	0.00143546

Dependent Variable: CO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00092146	0.00092146	0.14	0.7154
Error	7	0.04473676	0.00639097		
Corrected Total	8	0.04565822			

R-Square	C.V.	Root MSE	CO Mean
0.020182	20.74061	0.07994352	0.38544444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.00092146	0.00092146	0.14	0.7154

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	0.5588986398	1.22	0.2615	0.45757990
HOUR	-.0006236867	-0.38	0.7154	0.00164252

Dependent Variable: NMHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01876173	0.01876173	1.53	0.2562
Error	7	0.08590227	0.01227175		
Corrected Total	8	0.10466400			

R-Square	C.V.	Root MSE	NMHC Mean
0.179257	13.61466	0.11077795	0.81366667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.01876173	0.01876173	1.53	0.2562

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	1.596343340	2.52	0.0399	0.63406971
HOUR	-0.002814259	-1.24	0.2562	0.00227605

Dependent Variable: THC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01987534	0.01987534	1.62	0.2440
Error	7	0.08598466	0.01228352		
Corrected Total	8	0.10586000			

R-Square	C.V.	Root MSE	THC Mean
0.187751	13.05943	0.11083106	0.84866667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.01987534	0.01987534	1.62	0.2440

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	1.654236632	2.61	0.0350	0.63437370
HOUR	-0.002896576	-1.27	0.2440	0.00227714

Dependent Variable: NXNMHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00016932	0.00016932	0.01	0.9229
Error	7	0.11783068	0.01683295		
Corrected Total	8	0.11800000			

R-Square	C.V.	Root MSE	NXNMHC Mean
0.001435	3.481446	0.12974187	3.72666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.00016932	0.00016932	0.01	0.9229

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	3.652312383	4.92	0.0017	0.74261525
HOUR	0.000267355	0.10	0.9229	0.00266568

Dependent Variable: OZONE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00799941	0.00799941	1.82	0.4057
Error	1	0.00438526	0.00438526		
Corrected Total	2	0.01238467			

R-Square	C.V.	Root MSE	OZONE Mean
0.645912	6.163942	0.06622128	1.07433333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HOUR	1	0.00799941	0.00799941	1.82	0.4057

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.138527744	2.71	0.2250	0.78886066
HOUR	-0.003846486	-1.35	0.4057	0.00284795

Regressions for Evaluating Emissions Drift -- Ford F-150 Pickup

General Linear Models Procedure
Class Level Information

Class	Levels	Values
FUEL	1	Base

Number of observations in data set = 6

Dependent Variable: NOX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00013349	0.00013349	1.33	0.3132
Error	4	0.00040185	0.00010046		
Corrected Total	5	0.00053533			

R-Square	C.V.	Root MSE	NOX Mean
0.249353	25.26821	0.01002306	0.03966667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ODOM	1	0.00013349	0.00013349	1.33	0.3132

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.0584090286	-0.69	0.5306	0.08518128
ODOM	0.0000136793	1.15	0.3132	0.00001187

Dependent Variable: CO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.37706918	0.37706918	0.87	0.4027
Error	4	1.72532566	0.43133141		
Corrected Total	5	2.10239483			

R-Square	C.V.	Root MSE	CO Mean
0.179352	32.38187	0.65675826	2.02816667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ODOM	1	0.37706918	0.37706918	0.87	0.4027

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-3.184414995	-0.57	0.5988	5.58148252
ODOM	0.000727033	0.93	0.4027	0.00077759

Dependent Variable: NMOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00008170	0.00008170	4.73	0.0954
Error	4	0.00006913	0.00001728		
Corrected Total	5	0.00015083			

R-Square	C.V.	Root MSE	NMOG Mean
0.541666	11.49479	0.00415728	0.03616667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ODOM	1	0.00008170	0.00008170	4.73	0.0954

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.0405618611	-1.15	0.3149	0.03533082
ODOM	0.0000107018	2.17	0.0954	0.00000492

Dependent Variable: THC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00009949	0.00009949	1.74	0.2581
Error	4	0.00022934	0.00005734		
Corrected Total	5	0.00032883			

R-Square	C.V.	Root MSE	THC Mean
0.302563	13.80911	0.00757199	0.05483333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ODOM	1	0.00009949	0.00009949	1.74	0.2581

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.0298384044	-0.46	0.6670	0.06435085
ODOM	0.0000118097	1.32	0.2581	0.00000897

Dependent Variable: OZONE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00027214	0.00027214	1.93	0.2373
Error	4	0.00056469	0.00014117		
Corrected Total	5	0.00083683			

R-Square	C.V.	Root MSE	OZONE Mean
0.325205	24.66770	0.01188161	0.04816667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ODOM	1	0.00027214	0.00027214	1.93	0.2373

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.0918696805	-0.91	0.4144	0.10097626
ODOM	0.0000195318	1.39	0.2373	0.00001407

Appendix 6

Derivation of Emissions Allowances

Derivation of Accepted Test Variation (Delta)

Prior to beginning the LPG Task Group emission tests ARB staff determined the coefficients of variation expected from the emissions testing described in the test protocol. These coefficients of variation were included in the test protocol to establish a criteria for comparing the test fuels to the base fuel and as a reference point to determine if additional tests should be conducted because of higher than expected test variation.

<u>Ford F-150</u>

The coefficient of variation (delta) used for comparing the emissions of the test fuels with the base fuel for the Ford F-150 was determined with existing data external to the test program. The methodology used is the same as the methodology established from the Auto/Oil Air Quality Improvement study. The coefficients of variation for each pollutant were estimated from published emissions test data on vehicles operating on various LPG blends. The reports were published by ARCO, WPGA, and the ARB. The data set contains emissions results for 12 light duty vehicles operating on 12 LPG blends The data, SAS code, and the results follow.

ARB staff, through further evaluation of the Auto/Oil emissions data on a wide variety of light duty gasoline vehicles confirmed that the light duty δ values determined from the available LPG data are in the appropriate range. The root mean squared error is the approximate estimate of variation in the log metric (with small variation, the variation in the log and normal metric is nearly the same).

<u>Cummins B5.9</u>

ARB staff originally estimated the coefficients of variation for the Cummins B5.9 engine from data in the Southwest Research Institute report titled <u>Reactivity Comparison of Exhaust Emissions from Heavy-Duty Engines Operating on Gasoline, Diesel, and Alternative Fuels</u>. The report contained emissions test data for medium and heavy duty engines on various fuel types. However, it only contained emissions results for one engine using LPG. Staff estimated the expected test variability with the available data and compared the results with other ARB heavy duty engine test data and discussions with representatives from Cummins and ORTECH.

However, because there were more data from the Cummins engine tests than were available prior to test program and the test data variability was not too high, the coefficient of variation (delta) used to compare the test fuels to the base fuel was determined from the Cummins emissions test data. The methodology for calculating the coefficient of variability delta is the same as discussed above. The emissions test data from the Cummins engine tests, the SAS code, and the results follow.

Light Duty Vehicle Emissions Test Variability Results
General Linear Models Procedure
Class Level Information

Class	Levels	Values
VEHICLE	12	c1500 caravan century century2 grandam k2500 lumina lumina93 olds88 regal taurus taurus93
FUELID	13	100 100bu 10butene 10ibu 10pent 20 40ibu 50 80 hd10 hd30 hd5 lpg

Number of observations in data set = 54

Dependent Variable: LNNOX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	117.20975473	5.86048774	231.37	0.0001
Error	33	0.83586962	0.02532938		
Corrected Total	53	118.04562435			

R-Square	C.V.	Root MSE	LNNOX Mean
0.992919	-6.289622	0.15915207	-2.53039165

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VEHICLE	11	113.09032088	10.28093826	405.89	0.0001
FUELID	8	3.95154088	0.49394261	19.50	0.0001
VEHICLE*FUELID	1	0.16789296	0.16789296	6.63	0.0147

Dependent Variable: LNTHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	95.71350870	4.78567544	862.24	0.0001
Error	33	0.18315874	0.00555026		
Corrected Total	53	95.89666744			

R-Square	C.V.	Root MSE	LNTHC Mean
0.998090	-6.738179	0.07450010	-1.10564152

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VEHICLE	11	95.51201400	8.68291036	1564.41	0.0001
FUELID	8	0.20026952	0.02503369	4.51	0.0009
VEHICLE*FUELID	1	0.00122517	0.00122517	0.22	0.6416

Dependent Variable: LNCO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	24.16580050	1.20829002	172.56	0.0001
Error	33	0.23107586	0.00700230		
Corrected Total	53	24.39687636			

R-Square	C.V.	Root MSE	LNCO Mean
0.990528	22.24570	0.08367974	0.37616135

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VEHICLE	11	18.22128642	1.65648058	236.56	0.0001
FUELID	8	5.92145439	0.74018180	105.71	0.0001
VEHICLE*FUELID	1	0.02305969	0.02305969	3.29	0.0787

NOTE: Due to missing values, only 30 observations can be used in this analysis.

Dependent Variable: LNOZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	7.44710832	0.82745648	114.01	0.0001
Error	20	0.14514938	0.00725747		
Corrected Total	29	7.59225770			

R-Square	C.V.	Root MSE	LNOZ Mean
0.980882	-4.584032	0.08519078	-1.85842481

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VEHICLE	9	7.44710832	0.82745648	114.01	0.0001
FUELID	0	0.00000000	.	.	.
VEHICLE*FUELID	0	0.00000000	.	.	.

NOTE: Due to missing values, only 30 observations can be used in this analysis.

Dependent Variable: LNNMOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.40010232	0.37778915	50.38	0.0001
Error	20	0.14997089	0.00749854		
Corrected Total	29	3.55007320			

R-Square	C.V.	Root MSE	LNNMOG Mean
0.957756	-3.822923	0.08659414	-2.26512894

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VEHICLE	9	3.40010232	0.37778915	50.38	0.0001
FUELID	0	0.00000000	.	.	.
VEHICLE*FUELID	0	0.00000000	.	.	.

```
************************************************************************;
**                                                                    **;
**              Various Light Duty Vehicle Emissions Data             **
**                        and SAS Program                             **;
**                  To Estimate Test Variability                     **;
**                                                                    **;
************************************************************************;

data lpg ;
input vehicle $ fuel $ fuelid $ nmog co nox ozone thc nmhc fecon ;
cards ;
olds88   LPG 100         .     0.73100 0.07700  .      0.14000 0.115 14.93
olds88   LPG 100         .     0.78300 0.08200  .      0.14100 0.114 14.90
olds88   LPG 80          .     0.76100 0.07400  .      0.14500 0.118 15.19
olds88   LPG 80          .     0.83800 0.08599  .      0.15100 0.120 15.08
olds88   LPG 50          .     1.31400 0.04900  .      0.15300 0.120 15.72
olds88   LPG 50          .     1.17400 0.05300  .      0.14800 0.113 15.74
grandam  LPG 100bu       .     1.70400 0.00899  .      0.07600  .      17.48
grandam  LPG 100bu       .     1.86800 0.01500  .      0.08799  .      17.65
grandam  LPG 100         .     0.32300 0.04800  .      0.06000  .      16.61
grandam  LPG 100         .     0.31500 0.04600  .      0.05400  .      16.42
grandam  LPG 50          .     0.60800 0.01500  .      0.07199  .      16.93
grandam  LPG 50          .     0.69299 0.01900  .      0.05700  .      17.01
grandam  LPG 40ibu       .     1.54600 0.01200  .      0.08000  .      17.34
grandam  LPG 40ibu       .     1.61900 0.00800  .      0.07600  .      17.78
grandam  LPG 20          .     1.30400 0.01100  .      0.06300  .      17.67
grandam  LPG 20          .     1.24000 0.01500  .      0.07800  .      17.62
grandam  LPG 10butene    .     1.51000 0.01100  .      0.06700  .      18.09
grandam  LPG 10butene    .     1.58400 0.01100  .      0.06800  .      18.26
grandam  LPG 10pent      .     2.17800 0.02100  .      0.08599  .      18.02
grandam  LPG 10pent      .     1.92500 0.01300  .      0.07000  .      18.04
grandam  LPG 10ibu       .     1.70900 0.00700  .      0.08100  .      19.73
grandam  LPG 10ibu       .     1.61300 0.01200  .      0.06100  .      17.80
lumina   LPG lpg      0.08799 1.05000 0.19200 0.15400 1.75000  .        .
lumina   LPG lpg      0.09900 1.16000 0.22600 0.15700 1.58600  .        .
lumina   LPG lpg      0.10100 1.23000 0.20200 0.16400 1.62400  .        .
taurus   LPG lpg      0.08500 2.22000 0.09900 0.12800 1.50600  .        .
taurus   LPG lpg      0.08000 2.20000 0.10000 0.11600 1.45000  .        .
taurus   LPG lpg      0.10100 2.61000 0.09800 0.15700 1.55400  .        .
taurus   LPG lpg      0.08599 2.46000 0.10200 0.12100 1.40700  .        .
century  LPG lpg      0.09100 1.06000 0.21000 0.12800 1.40700  .        .
century  LPG lpg      0.11100 1.08000 0.18000 0.14500 1.30600  .        .
century  LPG lpg      0.09300 1.21000 0.19900 0.12300 1.32300  .        .
century  LPG lpg      0.10000 1.06000 0.20500 0.13100 1.31000  .        .
lumina93 LPG lpg      0.09400 1.88000 0.14400 0.14500 1.54300  .        .
lumina93 LPG lpg      0.09300 1.68000 0.17000 0.13200 1.41900  .        .
lumina93 LPG lpg      0.10800 1.79000 0.21900 0.15800 1.46300  .        .
century2 LPG lpg      0.10000 2.20000 0.10300 0.12300 1.23000  .        .
century2 LPG lpg      0.10300 2.65000 0.12200 0.14600 1.41700  .        .
century2 LPG lpg      0.10200 2.83000 0.12600 0.14500 1.42200  .        .
taurus93 LPG lpg      0.07400 0.51000 0.09200 0.09500 1.28400  .        .
taurus93 LPG lpg      0.07500 0.53000 0.09400 0.09700 1.29300  .        .
taurus93 LPG lpg      0.08400 0.54000 0.10200 0.11700 1.39300  .        .
regal    LPG lpg      0.07400 1.40000 0.02500 0.11500 1.55400  .        .
regal    LPG lpg      0.07900 1.28000 0.03100 0.11400 1.44300  .        .
regal    LPG lpg      0.07500 1.17000 0.03800 0.11000 1.46700  .        .
caravan  LPG hd10     0.13800 3.61800 0.13400 0.15100 0.15200 0.120 13.33
caravan  LPG hd10     0.11100 2.77400 0.16200 0.15300 0.14000 0.108 14.43
caravan  LPG hd10     0.10200 2.52000 0.16700 0.13900 0.13500 0.104 14.61
c1500    LPG hd5      0.14000 1.45500 0.81499 0.25400 0.17400 0.139 12.43
c1500    LPG hd5      0.14300 1.32500 0.74800 0.24800 0.17300 0.138 12.66
c1500    LPG hd5       .      1.40500 0.82500 .       0.17100 0.136 12.81
k2500    LPG hd30     0.33800 9.03700 2.77500 0.90900 0.40400 0.333  8.38
k2500    LPG hd30     0.29400 8.24900 2.81800 0.81299 0.37000 0.301  8.57
k2500    LPG hd30      .      7.67300 2.77700  .      0.36500 0.297  8.51
 ;


 data lpg ; set lpg ;
  lnnox=log(nox) ; lnnmc=log(nmhc) ; lnthc=log(thc) ; lnco=log(co) ;
  lnoz=log(ozone) ; lnnmog=log(nmog) ;
  if fuel = 'LPG' ;

  proc glm ;
  class vehicle fuelid;
```

```
model lnnox = vehicle fuelid vehicle*fuelid / ss1 ; run ;

proc glm ;
class vehicle fuelid ;
model lnnmhc = vehicle fuelid vehicle*fuelid / ss1 ; run ;

proc glm ;
class vehicle fuelid ;
model lnthc = vehicle fuelid vehicle*fuelid / ss1 ; run ;

proc glm ;
class vehicle fuelid ;
model lnco = vehicle fuelid vehicle*fuelid / ss1 ;  run ;

proc glm ;
class vehicle fuelid ;
model lnoz = vehicle fuelid vehicle*fuelid / ss1 ; run ;

proc glm ;
class vehicle fuelid ;
model lnnmog = vehicle fuelid vehicle*fuelid / ss1 ; run ;
```

Cummins B5.9 LPG Engine Emissions Tests Variability Results

General Linear Models Procedure

Class Level Information

Class	Levels	Values
FUEL	6	Base Fuel1 Fuel2 Fuel3 Fuel4 Fuel5

Number of observations in data set = 23

Dependent Variable: LOGTHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.30947094	0.06189419	4.81	0.0064
Error	17	0.21894892	0.01287935		
Corrected Total	22	0.52841986			

R-Square	C.V.	Root MSE	LOGTHC Mean
0.585653	-40.78748	**0.11348722**	-0.27824034

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.30947094	0.06189419	4.81	0.0064

Dependent Variable: LOGCO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.43693822	0.28738764	8.52	0.0003
Error	17	0.57358710	0.03374042		
Corrected Total	22	2.01052532			

R-Square	C.V.	Root MSE	LOGCO Mean
0.714708	-22.52465	**0.18368565**	-0.81548715

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	1.43693822	0.28738764	8.52	0.0003

Dependent Variable: LOGNOX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.10434785	0.02086957	26.85	0.0001
Error	17	0.01321244	0.00077720		
Corrected Total	22	0.11756029			

R-Square	C.V.	Root MSE	LOGNOX Mean
0.887611	2.454594	**0.02787835**	1.13576190

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.10434785	0.02086957	26.85	0.0001

Dependent Variable: LOGNMHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.32405377	0.06481075	4.64	0.0074
Error	17	0.23723428	0.01395496		
Corrected Total	22	0.56128804			

R-Square	C.V.	Root MSE	LOGNMHC Mean
0.577340	-36.21129	**0.11813110**	-0.32622726

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.32405377	0.06481075	4.64	0.0074

Dependent Variable: LOGNXNMH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.03415004	0.00683001	8.45	0.0004
Error	17	0.01374743	0.00080867		
Corrected Total	22	0.04789747			

R-Square	C.V.	Root MSE	LOGNXNMH Mean
0.712982	2.110263	**0.02843716**	1.34756499

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.03415004	0.00683001	8.45	0.0004

Dependent Variable: LOGNXTHC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.03312484	0.00662497	8.27	0.0004
Error	17	0.01362659	0.00080156		
Corrected Total	22	0.04675143			

R-Square	C.V.	Root MSE	LOGNXTHC Mean
0.708531	2.086766	**0.02831190**	1.35673609

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.03312484	0.00662497	8.27	0.0004

NOTE: Due to missing values, only 9 observations can be used in this analysis.

Dependent Variable: LOGOZONE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.07563141	0.01512628	2.45	0.2456
Error	3	0.01851844	0.00617281		
Corrected Total	8	0.09414985			

R-Square	C.V.	Root MSE	LOGOZONE Mean
0.803309	52.33317	**0.07856725**	0.15012896

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	5	0.07563141	0.01512628	2.45	0.2456

```
*******************************************************************************;
**                                                                           **;
**                                                                           **;
**                 Cummins B5.9 LPG Engine Emissions Test Data               **
**                And SAS Program to Calculate Test Variability               **;
**                      LPG Task Group Test Data (1998)                       **;
**                                                                           **;
*******************************************************************************;


data lpg ;
input
Date $     Fuel $   NMHC     THC      CO       NOx    NOxTHC NOxNMHC  NMOG    Ozone;
cards ;

5/20/98    Base    0.849    0.884    0.418    2.779    3.663  3.628    .       .
5/21/98    Base    0.811    0.847    0.329    2.765    3.612  3.576   0.82   1.156
5/22/98    Base    1.045    1.083    0.369    2.921    4.003  3.966    .       .
 6/8/98    Base    0.863    0.899    0.367    2.946    3.844  3.808    .       .
6/19/98    Base    0.690    0.723    0.424    2.948    3.670  3.637   0.72   0.999
6/22/98    Base    0.701    0.742    0.518    3.015    3.757  3.716    .       .
7/17/98    Base    0.680    0.712    0.455    2.961    3.673  3.641   0.72   1.068
8/12/98    Base    0.842    0.870    0.308    2.959    3.829  3.801    .       .
8/17/98    Base    0.842    0.878    0.281    2.903    3.781  3.745    .       .
5/28/98    Fuel1   0.694    0.726    0.409    3.067    3.793  3.761   0.76   1.215
5/29/98    Fuel1   0.730    0.762    0.451    3.157    3.919  3.887    .       .
7/20/98    Fuel1   0.587    0.619    0.360    3.310    3.929  3.897   0.62   1.072
 6/3/98    Fuel2   0.673    0.711    0.572    3.245    3.956  3.918    .       .
 6/4/98    Fuel2   0.733    0.765    0.416    3.204    3.970  3.937   0.85   1.338
 7/3/98    Fuel2   0.619    0.655    0.557    3.338    3.993  3.957    .       .
7/21/98    Fuel2   0.531    0.564    0.569    3.179    3.743  3.710    .       .
8/14/98    Fuel2   0.624    0.655    0.332    3.316    3.971  3.940    .       .
6/10/98    Fuel3   0.791    0.833    0.623    3.164    3.998  3.956    .       .
6/11/98    Fuel3   0.839    0.878    0.613    3.303    4.181  4.141   0.83   1.360
6/16/98    Fuel4   0.744    0.795    0.789    3.037    3.832  3.781   0.78   1.237
6/17/98    Fuel4   0.728    0.769    0.844    3.015    3.784  3.743    .       .
8/13/98    Fuel5   0.579    0.606    0.324    3.570    4.176  4.149   0.52   1.068
8/17/98    Fuel5   0.608    0.640    0.324    3.695    4.335  4.303    .       .
;
     data lpg2; set lpg ;
        proc sort; by fuel;
        data lpg3; set lpg2;


  LOGthc=LOG(thc) ; LOGco=LOG(co) ; LOGnox=LOG(nox) ; LOGnmhc=LOG(nmhc) ;
  LOGozone=LOG(ozone); LOGnxthc=LOG(noxthc); LOGnxnmh=LOG(noxnmhc);


 proc glm ;
  class fuel ;
  model LOGthc=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
  model LOGco=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
  model LOGnox=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
  model LOGnmhc=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
  model LOGnxnmh=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
  model LOGnxthc=fuel  / ss1 ; run ;

  proc glm ;
  class fuel ;
```

```
model LOGozone=fuel  / ss1 ; run ;
```

Appendix 7

Analysis of Test Data for Effects of Variables

Cummins Engine Data

Table 7-2 shows for the Cummins engine the deviations of each fuel's average emission results from the baseline emissions on a grid of the propene and butane contents in the test program. (Although there were six fuels tested, two had essentially the same propene content and another two had essentially the same butane content.) There are two analyses reflected in the table: one in which the baseline, per the test protocol, is the mean of all runs on the base fuel and one in which the each test fuel datum is separately compared to a prediction of the base fuel emissions at the time (hours of operation) when the particular test fuel run was made. The second analysis was done because of the variability of the base fuel results for some pollutants through the course of the study, especially for the Ford. (See Figures 7-1 and 7-2.)

By going downward in a grid, one can look for an effect of increasing propene; by going rightward, one can look for the effect of increasing butane. However, the data are few and the experimental design is unbalanced. As a result, visual examination is not always reliable. Therefore, we entered all the data for each pollutant into a regression analysis using this model:

$$emissions = a + b*propene + c*butane + d*hours + e*hours\ \hat{}2$$

("Hours" is the cumulative time elapsed since the first emission test was conducted (in a centered and normalized metric)). The quadratic form of the time dependency was assumed from examining the plots of base fuel data versus time. (See Figure 7-1.) The regressions all had "r-squares" between 0.61 and 0.91, indicating that the data were reasonably "well-behaved" and handled reasonably by the regression equation. The regression parameters are in Table 7-1.

Table 7-1. Regression Parameters for Cummins Data
E = a + b*propene + c*butane (plus time terms)

	Coefficient			Significance ( )		R-Sq.
	const.	propene	butane	propene	butane	
NMHC	.789	-.0111	.00057	.002	.89	.61
THC	.824	-.0114	.00120	.002	.77	.61
CO	.405	.00073	.0201	.76	<.001	.85
NOx	2.83	.0337	.0038	<.001	.33	.91
NMOG	.787	-.00067	-.00079	.85	.85	.89
OFP	1.04	.0132	.0080	.03	.18	.83

Cummins data grids

With the aid of the regression analyses, the following observations can be made for the Cummins engine tests.

NMHC and THC: Increasing the **propene** content **decreased** emissions. This effect is highly statistically significant (= .002 *). The data in Table III-3 (in the main report) show that the propene effect was substantial. There was no effect of butane.

CO: Increasing the **butane** content **increased** emissions. This effect is highly statistically significant (< .01), and (per Table III-3) it was substantial. There was no effect of propene.

NOx: Increasing the **propene** content **increased** emissions (< .01). The data in Table III-8 show that the propene effect was substantial. No butane effect is apparent.

NMOG: No identifiable effects (> .83 for propene and butane).

OFP: Increasing the **propene** content **increased** emissions. This effect is statistically significant (= .03). From Table III-8, it appears to be large for propene up to 15%. However, the fuel with very high propene, fuel 5, did not show greater OFP than the base fuel. This is because of the very low NMOG emissions in the single test on fuel 5. Butane may have increased emissions, but the effect was only marginally significant (= .18). These observations are summarized in Table 7-3. They are generally consistent with the results for the Cummins engine in the equivalency analysis.

Table 7-3. Effects of Propene and Butane Contents--Cummins Engine

	Increasing Propene	**Increasing Butane**
NMHC	reduced emissions	no effect seen
THC	reduced emissions	no effect seen
CO	no effect seen	*increased* emissions
NOx	*increased* emissions	no effect seen
NMOG	no effect seen	no effect seen
OFP	*increased* emissions	*maybe increased*

* " " is the probability that the apparent variable effect does not actually exist.

Ford Truck Data

Table 7-4 shows the same display of the Ford truck results as shown in Table 7-1 for the Cummins engine tests. Again, to help interpret the gridded results, the individual test data were regressed against the propene and butane contents of the fuels plus a quadratic time function. The model was:

$$emissions = a + b*propene + c*butane + d*odom + e*odom^2$$

("Odom" is the odometer reading at the start of a test (in a centered and normalized metric)). However, the regressions were poor, with r-squares from .18 to .55, indicating that the results were largely not relatable to the measured compositions. (Regressions using propene x butane as a variable also were poor.)

As a result, even though individual fuels show large deviations from the base fuel on some pollutants, the only consistent effects of the propene or butane content in the Ford truck test data are for THC (for which r-square = .55) and OFP (r-square = .41). For THC, there was a statistically significant **decrease** in emissions with increasing **propene** content (= .04) and an **increase** with increasing **butane (** = .02). The regression equation is THC = .052 - .00072*propene +.00095*butane (plus odometer terms). For OFP, there was a statistically significant **increase** with increasing **butane** (= .02). The equation is OFP = .0405 +.000647*propene + .0011*butane (plus odometer terms)

The decrease in THC with propene and the increase in OFP with butane are consistent with the Cummins regression results. However, no butane effect on THC (or NMHC) was seen in the Cummins data.

1996 WPGA Emission Data

Three 1995 light-duty vehicles were converted to dual-fuel (LPG and gasoline) operation and then tested on Indolene (federal certification gasoline) and on seven LPGs, including a base fuel with five percent propene and 2.5 percent butane (HD-5). The propene contents of the six test LPGs ranged from 5 to 20 percent, and the butane contents ranged from 2.5 to 40 percent. The organic gas emissions were speciated for determining the ozone-forming potential (OFP) of the emissions. (Reference 3 describes the study in more detail.)

The data clearly show a by-vehicle effect on emissions of all the pollutants. To reduce this vehicle effect, the staff divided each emission datum for a pollutant by the corresponding vehicle's emission datum on the base fuel. These normalized data were then regressed against two models:

normalized emission rate = a + b * propene + c * butane
normalized emission rate = a + b * propene + c * butane + d * date of test

Ford Grids

The resulting regressions were highly successful for NOx, with "r-squared" values of .89. The regressions for CO and OFP were moderately successful, with "r-squared" values of about 0.7 and 0.5, respectively. The NMHC regressions had "r-squared" values of only about 0.25. Adding the date variable did not improve the results noticeably, although it did have a statistically significant coefficient in the CO regression..

Statistically significant effects were found for propene and/or butane for NMHC, NOx, CO, and OFP. Regression parameters are shown in the following table.

Table 7-5. Regression Parameters for WPGA Data
(ARB staff analysis of E/E_{HD5})

	Coefficient			Significance ( )		R-Sq.
	const.	propene	butane	propene	butane	
NMHC	1.02	-.00261	.00569	.60	.06	.24
NOx	.857	.0224	-.0110	.00	.00	.89
CO	1.42	-.013	.0248	.13	.00	.73
OFP	.859	.0240	.0121	.00	.00	.54

Ford Grids