Attachment 4

California Environmental Protection Agency
Air Resources Board

Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline

August 2003

State of California
<u>California Environmental Protection Agency</u>

AIR RESOURCES BOARD
Stationary Source Division

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I. EXECUTIVE SUMMARY

A. Introduction

There is an evaporative emissions effect associated with the mixing (or commingling) of a gasoline containing ethanol and a gasoline not containing ethanol. The addition of ethanol to a non-ethanol-blended fuel can increase the Reid vapor pressure (RVP) of the fuel by up to one pound per square-inch (psi). However, this impact is less when a fuel produced without ethanol is commingled with a fuel produced with (already containing) ethanol. This is because the RVP increase from commingling is limited to that which occurs in the fuel produced without ethanol (the RVP increase has already been realized in the ethanol-produced fuel). In this case, the commingling impact is dependent upon the relative proportions of each fuel in the final commingled fuel, as well as the ethanol content of the fuel produced with ethanol. Because of this, for example, the maximum RVP increase of commingling a 6 percent ethanol fuel is about 0.7 psi RVP, based on the addition of ⅔ of a tank of non-ethanol fuel to ⅓ of a tank of ethanol fuel.

Due to the RVP increase associated with commingling, the federal reformulated gasoline (RFG) regulations prohibit the mixing of ethanol blended gasoline and non-ethanol blended gasoline in the distribution and marketing system. However, neither the federal nor the California Phase 3 Reformulated Gasoline (CaRFG3) regulations prohibit the mixing of ethanol-blended gasoline with non-ethanol-blended gasoline in vehicle tanks. To date, since virtually all CaRFG has been made with methyl tertiary butyl ether (MTBE) and little ethanol, this has not been a significant problem in California. However, as MTBE is phased out of California gasoline, the mixing of a non-ethanol-blended fuel and an ethanol-blended fuel in vehicle tanks could result in a significant new source of emissions.

In proposing the CaRFG3 regulations in 1999, staff of the Air Resources Board (ARB/Board) estimated that the potential impacts of commingling CaRFG3 containing ethanol with CaRFG3 not containing ethanol in motor vehicle fuel tanks would result in an average 0.1 psi or less RVP increase in the California gasoline pool. An increase in the RVP of a gasoline has the practical effect of increasing evaporative emissions from motor vehicles. To compensate for the anticipated increase in evaporative emissions due to commingling, the CaRFG3 regulations include a reduced RVP flat limit for gasoline produced using the revised CaRFG3 Predictive Model. However, due to uncertainty in the potential commingling impacts, in approving the CaRFG3 regulations, the Board directed staff to further evaluate the magnitude of the potential real-world commingling impacts. Staff has completed this further evaluation, and this report presents their findings.

In addition, the United States Environmental Protection Agency (U.S. EPA) based its denial of California’s request for a waiver from the federal oxygenate mandate on its belief that California may have underestimated the emissions associated with commingling. As a result, staff's evaluation not only addresses the Board's directive, but also collects data to address U.S. EPA's concerns about the likely emissions due to commingling.

B. Findings

Staff performed both simulation modeling and a field study to carry out the Board's directive to assess the likely magnitude of commingling impacts associated with the switch to CaRFG3. Based on the simulation model and field study, staff estimate that the likely overall RVP increase due to commingling is less than 0.1 psi. As such, the 0.1 psi RVP reduction provided for in the CaRFG3 Predictive Model is sufficiently protective against an increase in commingling evaporative emissions from gasoline powered motor vehicles.

Based on ethanol market share of 25 to 65 percent, the modeling work estimated average RVP increases of 0.06-0.07 psi and 0.06-0.08 psi, for 6 and 7.7 volume percent ethanol blends, respectively. Staff also investigated the sensitivity of the simulation model results by varying the assumptions for consumers purchase propensity toward ethanol fuel. The sensitivity analysis yielded ± 0.01 psi RVP variations to the above estimates. These figures are in good agreement with the field study results that found the likely commingling impacts were a statewide gasoline pool RVP increase of 0.06-0.13 psi, with the most likely statewide impact approximately 0.07psi RVP.

The results of ARB's recent commingling study, based on data collected specific to the California market place, demonstrates that the original ARB estimated commingling impact of no more than 0.1 psi increase in RVP in the California gasoline pool is correct, and that U.S. EPA's denial of California's waiver request was inappropriate.

C. Field Study

The first part of staff's evaluation consisted of a field study to collect fuel samples from in-use vehicle fuel tanks to provide information on the RVP of the gasoline before fueling. After fueling, a second sample was obtained to provide information on the increase in RVP due to commingling.

The general approach to obtaining these samples was to have sampling teams present at retail gasoline stations as consumers arrived to fuel their vehicles. Once permission from the vehicle operator was obtained, fuel samples were then taken from vehicle fuel tanks both before and after the vehicles were fueled. In order to determine the properties of the fuel being used for fueling the vehicles, morning and afternoon fuel samples were obtained from the gasoline station dispensers. During the sampling, descriptive information (such as initial vehicle fuel tank level, amount of fuel purchased, vehicle type, etc) specific to each fueling event was also collected. The fuel samples were then analyzed for RVP, oxygenate concentration, and total oxygen content to determine the actual impacts associated with commingling.

During the months of August and September 2001 staff implemented the fuel sampling protocol in three regions of the state: Lake Tahoe, the Bay Area, and Los Angeles. Sampling was performed at a total of 19 different gasoline stations resulting in data collection for 396 observed fueling events. Four of the 19 stations were dispensing ethanol-blended fuel. As anticipated, staff was unable to successfully obtain fuel samples from every vehicle due to various fill-pipe configuration constraints. Of the 396 observed fuelings, 254 complete sets of fuel samples were obtained for an overall sampling success rate of 64 percent. The model year of vehicles in the sample is representative of the 2001 statewide passenger car and light-duty truck population.

D. Consumer Fueling Habits

The second part of staff's evaluation included gathering information on California consumer fueling habits. Fueling habits are a critical factor in the evaluation of commingling impacts. Therefore, it was essential to collect current information specific to California consumers.

Data collected during the field study portion of staff's evaluation allow observation of several fueling habits critical to estimating commingling impacts. To supplement the field information, staff requested gasoline marketers to provide additional information on motorists fueling habits. Based on the information provided by California gasoline marketers, staff believes that the fueling data collected in the field study are sufficiently representative of California consumers for use in a commingling analysis.

E. Simulation Model

In addition to documenting actual impacts of commingling on individual vehicle fuel tanks from data of the field study, a simulation model was used to estimate the potential commingling impacts. The simulation model used was developed by Dr. David M. Rocke, University of California, Davis.

The actual impact on emissions of commingling depends on many variables associated with the gasoline marketplace and on consumer behavioral patterns. These include ethanol market penetration, brand loyalty, fuel tank levels prior to fueling, fillup vs. non-fillup preference, and quantity of fuel purchased. For staff's modeling analysis, the potential future ethanol market share was assumed to vary from 25 percent to 65 percent of the gasoline market pool.

The field study data drive the simulation model with the following input parameters:

- overall, almost 50 percent of consumers purchase the same gasoline brand as their previous fuel purchase;
- about 80 percent of consumers fuel when there is ¼ tank of gasoline or less remaining in their tanks, with more than 40 percent registering nearly an empty tank;
- more than 50 percent of consumers opt for fillup, and;
- non-fillup consumers purchase on average 7 gallons of fuel, about 1/3 to ½ of an average tank, assuming most tanks have a capacity between 14 and 20 gallons.

These figures are consistent with data identified in previous commingling studies, including those by the U.S. EPA staff.[1]

F. Analysis of U.S. EPA Denial of California's Waiver Request

On April 12, 1999, Governor Davis requested a waiver from the U.S. EPA from the federal oxygen requirement for federal reformulated gasoline areas. Additional information supporting the waiver request was submitted to the U.S. EPA as necessary. The justification for a waiver request was based on the fact that the use of oxygenates, such as ethanol, increases emissions of oxides of nitrogen (NOx). As a result, the federal oxygen requirement interferes with the ability of California to meet the national ambient air quality standards (NAAQS) for ozone and particulate matter (PM), where NOx is a precursor to both ozone and PM. The CaRFG3 Predictive Model clearly demonstrates that non-oxygenated fuels can be produced which provide additional NOx reductions for the state.

In June 2001, the U.S. EPA denied California's waiver request. In denying the waiver, the U.S. EPA acknowledged the NOx benefits of non-oxygenated fuels, but believed that there was too much uncertainty regarding potential increases in volatile organic compound (VOC) evaporative emissions. The U.S. EPA associated this uncertainty with uncertainty concerning the magnitude of emissions increase due to fuel commingling in vehicle fuel tanks, especially in the South Coast Air Quality Management District (SCAQMD).

The ARB field study data of California consumer fueling habits (brand loyalty, initial tank level, and frequency of fillup) are similar to the information possessed by the U.S. EPA. However, in their analysis of commingling U.S. EPA staff modified the data, because of a stated lack of confidence that the data adequately represent actual fueling habits. This modification produced lower brand loyalty, lower percent of fillups, and higher initial fuel tank levels. Each of these changes leads to a higher commingling effect. Moreover, there is a distinct difference between the ARB's and U.S. EPA's analysis in the way "brand-loyal" consumers (those who always purchase one brand of gasoline) are handled. While the ARB assumed negligible commingling effects from this group of consumers, the U.S. EPA assumed the group would contribute to commingling.

[1] In-Use Volatility Impact of Commingling Ethanol and Non-Ethanol Fuels", Peter Caffrey and Paul Machiele, U.S. EPA, Society of Automotive Engineers (SAE) Paper 940765

Cumulatively, these factors produced an over estimation of potential commingling impacts by the U.S. EPA staff, at least, by a factor of two.

II. INTRODUCTION

This chapter provides information on the current requirements for gasoline sold in California, the State's phase out of MTBE, and California's request for a waiver from the federal oxygen mandate for federal RFG.

A. Current Requirements for California Gasoline

Both state and federal regulations govern California gasoline production.

1. California Regulations

The California Phase 2 Reformulated Gasoline (CaRFG2) regulations were adopted by the ARB in 1991 and were implemented in 1996. These regulations established a comprehensive set of specifications, including limits for eight gasoline properties, including:

- Reid vapor pressure
- Sulfur content
- Benzene content
- Aromatics content
- Olefins content
- 50 percent distillation point (T50)
- 90 percent distillation point (T90)
- Oxygen content

The CaRFG2 regulations have provided very significant reductions in ozone and particulate matter precursor emissions and toxic air pollutants. The emission benefits of the program have been equivalent to removing 3.5 million vehicles from California's roads.

2. Federal Regulations

California gasoline production is also governed by federal RFG regulations enacted by the U.S. EPA. Nationally, about 30 percent of the gasoline produced must meet these requirements. These regulations impose emission performance standards in conjunction with specific requirements for oxygen content (year-round average of 2.0 percent by weight), and limits on benzene content. The federal requirements were implemented in two phases. The first phase began in 1995 and the second phase began in December 1999. In the September 15, 1999 Federal Register, the U.S. EPA made the finding that the emission reduction benefits of California gasoline are at least as great as those from federal Phase II RFG.

For California, the federal RFG regulations were first implemented in 1995 in the South Coast and San Diego and in 1996 in the Sacramento Metropolitan Region. The South Coast, San Diego, and Sacramento areas of the State account for about 70 percent of the gasoline sold in California. Further, the San Joaquin Valley was recently reclassified by the U.S. EPA as a "severe" ozone non-attainment area and this region has used federal RFG since December 10, 2002. With the San Joaquin Valley included in the federal RFG program, approximately 80 percent of the gasoline sold in California will need to meet both the federal and the more stringent state gasoline requirements.

Because of the 1990 federal Clean Air Act Amendments (CAAA) requirement that mandated the use of a minimum oxygen content, the use of oxygenates in California, and MTBE in particular, has grown significantly.

B. California Phase 3 Reformulated Gasoline

Because of concerns regarding the use of MTBE, on March 25 1999, Governor Gray Davis issued Executive Order D-5-99 which, among other things, called for the phase-out of MTBE no later than December 31, 2002. The Governor's Executive Order also directed the ARB to adopt CaRFG3 regulations that will provide additional flexibility in lowering or removing the oxygen content requirement while maintaining the emissions and air quality benefits of CaRFG2, and that the U.S. EPA be requested to provide a waiver from the federal oxygen mandate in California.

In December 1999, the ARB approved the CaRFG3 regulations. These regulations were designed to prohibit the use of MTBE in the production of California gasoline while preserving the benefits of the CaRFG2 program. They were also designed to provide additional flexibility to refiners to produce California gasoline. The CaRFG3 specifications are shown in Table II-1.

With the approval of the CaRFG3 regulations, ethanol is the only oxygenate approved to replace MTBE in California. Therefore, the phase out of MTBE is expected to result in large-scale replacement of MTBE with ethanol to comply with the federal RFG oxygen requirement. The addition of ethanol to gasoline results in a non-linear increase in the fuel's RVP. An RVP increase also results when ethanol blended gasoline is added to non-ethanol blended gasoline. This is called commingling, and the resulting RVP increase is called the commingling impact. In general, commingling results in an increase in evaporative VOC emissions from motor vehicles. In order to maintain the emissions and air quality benefits of the CaRFG2 program, the ARB included a reduction in the CaRFG3 Predictive Model[2] RVP fuel specification of 0.1 psi to offset the anticipated impacts associated with commingling.

[2] The Predictive Model is a mathematical set of equations that relate emission rates of certain pollutants to the values of the eight regulated gasoline properties. To date, most gasoline produced from refineries in California has been produced according to the Predictive Model.

Table II-1:
California Reformulated Gasoline Phase 3 Specifications

Property	*Units*	*Flat Limits*	*Averaging Limits*	*Cap Limits*
Reid Vapor Pressure[1]	psi	7.00 or 6.90[2]	Not Applicable	6.40 –7.20
Sulfur Content	ppmw	20	15	60[3] 30[3]
Benzene Content	Volume %	0.80	0.70	1.10
Aromatics Content	Volume %	25.0	22.0	35.0
Olefins Content	Volume %	6.0	4.0	10.0
T50	^{o}F	213	203	225
T90	^{o}F	305	295	335
Oxygen Content	Weight %	1.8 - 2.2	Not Applicable	0 – 3.7

1 The Reid vapor pressure standards apply only during the summer months.
2 The 6.90 psi standard applies only when a producer or importer is using the evaporative emissions model element of the CaRFG Phase 3 Predictive Model.
3 The CaRFG Phase 3 sulfur content cap limits of 60 and 30 parts per million are phased in starting December 31, 2002, and December 31, 2004, respectively.

However, due to uncertainty in the potential commingling impacts, in approving the CaRFG3 regulations, the Board directed staff to further evaluate the real-world impacts of commingling. Staff's efforts to evaluate these impacts are described in Chapters III through VII.

C. California's Waiver Request

On April 12, 1999, Governor Davis requested a waiver from the U.S. EPA from the federal oxygen requirement for federal reformulated gasoline areas. Additional information supporting the waiver request was submitted to the U.S. EPA as necessary. The justification for a waiver request was based on the fact that the use of oxygenates, such as ethanol, increases emissions of NOx from gasoline powered motor vehicles. As a result, the federal oxygen requirement interferes with the ability of California to meet the NAAQS for ozone and PM, where NOx is a precursor to both ozone and PM. The CaRFG3 Predictive Model demonstrates that non-oxygenated fuels can be produced which provide additional NOx reductions for the state.

In June 2001, the U.S. EPA denied California's waiver request. In denying the waiver, the U.S. EPA acknowledged the NOx benefits of non-oxygenated fuels, but believed that there was too much uncertainty regarding potential increases in VOC evaporative emissions from commingling in vehicle fuel tanks, especially in the SCAQMD. Staff's evaluation and analysis of U.S. EPA's denial of California's waiver request is provided in Chapter VIII.

D. Executive Order D-52-02

Because of the U.S. EPA's decision to deny California's waiver request, between 750 and 900 million gallons of ethanol will need to be imported into the state each year as soon as the ban on MTBE is implemented. The California Energy Commission (CEC) and independent consultants have questioned whether the necessary quantity of ethanol could be efficiently transported to and distributed within California by 2003. In February 2002, an independent study commissioned by the CEC advised that price spikes of up to 100 percent are likely if MTBE is phased out with an inadequate supply of ethanol available and ready for distribution. The independent study also emphasized that even with an adequate supply of ethanol available and ready for distribution, phasing out MTBE next year could result in a five to ten percent shortage of gasoline. In 1999, California experienced a supply reduction of similar magnitude due to major fires and facility outages at two California refineries, and the price of gasoline nearly doubled.

As a result, on March 15, 2002, Governor Davis issued Executive Order D-52-02 that directs the ARB, by no later than July 31,2002, to provide California refineries an additional twelve months for the transition from MTBE to ethanol in gasoline. Under the newly announced timeline, the MTBE phase-out will be accomplished no later than December 31, 2003. Individual refineries may continue to make the transition to ethanol earlier than December 2003.

In July 2002, the ARB approved the amendments to the CaRFG3 regulations. The amendments include a postponement of the prohibition of MTBE and other oxygenates use in California gasoline, other than ethanol, supplied by refiners and importers from December 31, 2002 to December 31, 2003.

III. DESIGN AND IMPLEMENTATION OF THE FIELD STUDY AND OTHER DATA COLLECTION EFFORTS

In better defining the impacts of commingling in California markets, ARB conducted both a field study and simulation modeling. This chapter describes the design and implementation of the ARB field study to evaluate the real-world impacts of commingling, including staff's efforts to collect specific information on California consumer fueling habits.

A. ARB Field Study

The first component of staff's evaluation of the real-world impacts of commingling CaRFG3 was the implementation of a field study. The field study was intended to collect real-world information regarding commingling in vehicle fuel tanks, as well as specific information on consumer fueling habits.

1. Establishment of ARB/Industry Working Group

In developing the scope and mission of a field study, staff formed an ARB/industry working group in April 2001. This working group was comprised of representatives from the ARB staff and the oil, ethanol and automotive industries. A list of the companies and organizations represented in the working group is provided in Appendix A. Between April and November 2001 the working group met four times.

Staff also used the working group to provide technical comments regarding staff's analysis. In April 2002, staff provided a preliminary draft version of staff's analysis to the working group for comment and feedback. Staff then made appropriate changes to the analysis based on the working group's comments. Appendix B contains the comments received from the working group by staff.

2. Development of Field Study Protocol

Staff's goal in conducting a field study was to collect fuel samples from motorist's fuel tanks to estimate base fuel RVP as well as verify the estimated increase in RVP due to commingling. In developing a field study, staff was interested in collecting the following information:

- Initial RVP of vehicle fuel tank (prior to fueling).
- RVP of dispensed fuel.
- Final RVP of vehicle fuel tank (after fueling).
- Total oxygen content of each fuel sample.
- Oxygenate types and concentration for each fuel sample.

- Consumer information (such as initial vehicle fuel tank level, amount of fuel purchased, vehicle type, etc).

Fuel Sampling Protocol: Staff's initial efforts to implement a field study began with the development of fuel sampling protocol. The general approach to obtaining these samples was to have sampling teams present at retail gasoline stations as consumers arrived to fuel their vehicles. Fuel samples collected through a chilling apparatus were then taken from vehicle fuel tanks both before and after the vehicles were fueled. In order to determine the properties of the fuel being used for fueling the vehicles, morning and afternoon fuel samples were obtained from the gasoline station dispensers. During the sampling, descriptive information (such as initial vehicle fuel tank level, amount of fuel purchased, vehicle type, etc) specific to each fueling event was also collected and noted on field data sheets. The fuel samples were then analyzed for RVP, oxygenate concentration and total oxygen content to determine the actual impacts associated with commingling.

While the field study was conceptually straightforward, due to the unique nature of such a fuel-sampling program, a standardized approved sampling protocol did not exist. Therefore, the primary focus of the first three working group meetings was the development of an appropriate protocol. By using various components of existing American Society of Testing and Materials (ASTM) and ARB fuel sampling test methods, staff was able to develop an effective fuel sampling protocol that was accepted by the working group for final implementation.

Samples from the vehicle tanks and the station's underground tanks were obtained using ASTM D 5842-95, "Standard Practice for Sampling and Handling of Fuels for Volatility Measurement". Since vehicle tanks are not mentioned in the ASTM sampling method, staff utilized the tank tap portion of ASTM D 5842-95, modified using apparatus that ARB has successfully used for some time to obtain diesel samples from vehicle tanks to check for presence of red dye. Special care, including cooling the sample line and sample container in an ice bath, was taken to ensure that minimal evaporation took place during the sampling process so that accurate RVP results were obtained.

Prior to the final implementation of the fuel sampling protocol, a trial run was performed to evaluate the efficacy of the protocol and to provide sampling staff the opportunity to gain experience and familiarity with the sampling procedure. Staff spent two days in the field conducting sampling operations at six different gas stations. Based on the trial run efforts, minor revisions were incorporated into the fuel sampling protocol.

The final fuel sampling protocol is provided in Appendix C.

Fuel Sample Analysis: Fuel sample analysis was performed by laboratory staff of the ARB. To minimize the amount of handling and the duration of sample storage prior to RVP analysis, the fuel samples were analyzed for RVP within 24 hours in the ARB's mobile laboratory that was located in the general vicinity of the stations participating in the field study. All samples were analyzed for RVP using ARB's "Test Method for the

Determination of the Reid Vapor Pressure Equivalent Using an Automated Vapor Pressure Test Instrument" (California Code of Regulation (CCR) Title 13 §2297).

After analysis for RVP in the ARB's mobile laboratory, the fuel samples were transported to the ARB's laboratory facilities in El Monte, California. There, the fuel samples were analyzed for the volumetric amount and type of oxygenate (MTBE, tertiary amyl methyl ether (TAME), and ethanol) as well as total oxygen content, by ASTM D 4815-94, "Standard Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C1 to C4 Alcohols in Gasoline by Gas Chromatography".

Table III-1 provides a summary of the fuel properties analyzed and the analysis method used.

Table III-1:
Methodology for Fuel Sample Analysis

Fuel Property	*Units*	*Analysis Method*
RVP	psi	CCR, Title 13 §2297[1]
Oxygen Content	Weight %	ASTM D 4815-94
Ethanol Content	Volume %	ASTM D 4815-94
MTBE Content	Volume %	ASTM D 4815-94
TAME Content	Volume %	ASTM D 4815-94

[1] Paragraph (d)(1.0) which specifies a CCR, Title 13 sampling method will be replaced with ASTM D 5842 sampling method which allows for the use of either 32-oz or 4-oz bottles.

3. Field Study Areas, Sampling Sites, and Field Sampling

This section describes the areas selected for inclusion in the field study, the sampling sites selected (including station brand and location) and a discussion of staff's field sampling experience.

Field Study Areas: The production, distribution, and marketing of gasoline in California is essentially divided into two regions, north and south. Refineries in the Los Angeles area supply the majority of the gasoline used in southern California, and most of the gasoline used in northern California is supplied by refineries in the Bay Area. These two large metropolitan areas also account for a large portion of the regional demands. It was therefore decided that the field study would include each of these areas.

Although at the time there were ethanol-blended fuels being marketed throughout California, they represented only a small fraction of the total statewide supply. However, due to the voluntary early phase out of MTBE, ethanol blended fuels were much more prevalent in the Lake Tahoe area. Therefore, in order to increase the number of potential commingling events observed during the field sampling, it was decided this area would also be included in the field study.

Sampling Sites: In identifying potential sampling sites (gas stations) to include in the field study, California gasoline marketers were asked to provide staff access to stations in each area. Participation in the field study was purely voluntary on the part of each gasoline marketer. However, in selecting sampling sites, staff attempted to include stations dispensing ethanol-blended fuels and non-oxygenated fuels.

In the Lake Tahoe area, nine stations were selected for participation in the field study. Four sampling sites in the Lake Tahoe area were dispensing ethanol-blended fuels, and five stations were dispensing non-oxygenated fuels. The following fuel brands were included as part of the field study in the Lake Tahoe area:

- **Lake Tahoe Area** (Kings Beach and South Lake Tahoe)
  - Beacon (2 different stations)
  - Chevron
  - Shell (2 different stations)
  - USA Gasoline (2 different stations)
  - Fox Gasoline
  - United Gasoline

In the Bay Area, six stations were selected for participation in the field study. Because of the voluntary approach to the field study, staff was unable to secure any sampling sites dispensing ethanol-blended fuels. However, two stations were dispensing non-oxygenated regular and mid-grade gasoline. The following fuel brands were included as part of the field study in the San Francisco Bay area:

- **The Bay Area** (Campbell, Los Gatos, San Jose, Sunnyvale, and Cupertino)
  - ARCO
  - Chevron (2 different stations)
  - Shell (2 different stations)
  - Valero

In the Los Angeles area, four stations were selected for participation in the field study. Staff had originally planned to include six stations in their assessment. However, because the planned sampling schedule included September 11, 2001, staff was unable to perform field sampling on that day. Similar to the Bay Area sampling, due to the voluntary approach to the field study, staff was unable to secure any sampling sites dispensing ethanol-blended fuels. All of the Los Angeles area stations were dispensing oxygenated fuels containing MTBE. The following fuel brands were included as part of the field study in the Los Angeles area:

- **Los Angeles Area** (Hacienda Heights, Azusa, and Glendora)
  - ARCO
  - Chevron
  - Mobil
  - Texaco

Field Sampling: During the months of August and September 2001 staff implemented the fuel sampling protocol in the three areas of the state: Lake Tahoe, the Bay Area, and Los Angeles. Sampling was performed at a total of 19 different gasoline stations resulting in data collection for 396 observed fuelings. Four of the 19 stations were dispensing ethanol-blended fuel. In general, consumers were very willing to participate in the field study program. However, as anticipated, staff was unable to successfully obtain fuel samples from every vehicle due to various fill-pipe configuration constraints. Of the 396 vehicles participating in the field study, fuel samples were obtained from 254 vehicles (before and after fueling samples from the vehicle fuel tank) for an overall statewide sampling success rate of 64 percent. This information is shown in Table III-2.

Table III-2:
Field Sampling Results by Region

Region	No. of Stations				Number of Vehicles Participating	Number of Vehicles Sampled
	Oxy/MTBE[1]	Non-Oxy	Ethanol	Total		
Lake Tahoe	0	5	4	9	175	121
The Bay Area	4	2[2]	0	6	121	79
Los Angeles	4	0	0	4	100	54
Statewide Total	8	7	4	19	396	254

1 Some of fuel dispensed from stations identified as MTBE also contained TAME.

2 These stations only sold non-oxygenated fuel in their regular and mid-grade gasoline. Their premium grade of gasoline was oxygenated with MTBE.

B. Data Collection on California Consumer Fueling Habits

The second part of staff's evaluation of the real-world impacts of commingling CaRFG3 included gathering information on California consumer fueling habits. Fueling habits are a critical factor in the evaluation of commingling impacts. Data available on consumer fueling habits prior to the start of the field study were either dated and/or not specific to

California consumers. Therefore, it was essential to collect current information specific to California consumers.

Data collected during the field study portion of staff's evaluation allowed estimation of California motorists fueling habits. Information collected included:

- Whether the consumer purchased the same brand of gasoline during their previous fueling
- Initial fuel tank level
- Whether the fueling event was a "fillup" or not
- Volume of fuel purchased
- Dollar amount of fuel purchased

To supplement the field information, staff requested gasoline marketers to provide additional information on motorists fueling habits. Based on the information provided by California gasoline marketers, staff believes that the fueling data collected in the field study are sufficiently representative of California consumers for use in the commingling evaluation.

C. Data Handling and Quality Control

In collecting the field study data, staff established uniform data handling procedures to ensure no losses in the data collected. In addition, thorough data quality assurance and quality control procedures were utilized during all phases of the evaluation to ensure the accuracy and completeness of the data.

1. Data Handling

In conducting the field study, two sets of data were collected. The first set of data, referred to as the field data sheets, contained the information collected in the field. These data consisted of the specific vehicle fueling information that was documented as well as information to identify specific fuel samples (before and after fueling) to a particular vehicle fueling. The field data collected were key data entered into a spreadsheet at the completion of the fieldwork.

The second data set was the results of the fuel analysis performed by the ARB laboratory staff. Data from the RVP fuel analysis were provided as paper printouts generated by the analytical equipment, with each data set identifying the fuel sample number, as referenced on the field data sheet. These data were key data entered into a spreadsheet for use in staff's analysis of the field study data results. The data generated from the oxygen and oxygenate fuel analysis were provided by the ARB laboratory staff in a spreadsheet format, also referenced by fuel sample number. Once all the fuel sample analysis data were received, these data were merged with the field data collected into a single main data file.

2. Data Quality Assurance/Quality Control

Data quality assurance and quality control were practiced in the field during the implementation of the field study, in the laboratory during analysis of the fuel samples, and during key data entry of the field data.

Field Work: In conducting the field study, various techniques were employed to assure the quality of the field operations. All staff involved in the field operations were thoroughly trained in the proper implementation of the fuel sampling protocol. As part of this training, staff spent several hours practicing the fuel sampling procedure on state-owned vehicles located at the Department of General Services garage in Sacramento. Additional experience was obtained by conducting a two-day trial run in the Bay Area. During the trial run, three sampling teams were deployed, conducting sampling operations at six different gasoline stations. The two-day trial provided invaluable experience, not only in actual vehicle fuel tank sampling, but also in how to successfully approach private vehicle owners to obtain their voluntary participation. Obtaining volunteers in a timely fashion was critical in the conduct of the field operations.

During the field operations, all sampling team members met on a daily basis to discuss the previous day's activities. The composition of each sampling team was varied by rotating individual team members on a daily basis. As resources allowed, an additional member of the field staff performed oversight activities at all sampling sites. Oversight activities included helping individual teams with any sampling equipment needs (such as maintenance or misplaced tools) in addition to critiquing individual team performance. All field data sheets were reviewed at the end of each day for consistent proper completion; any resultant questions or concerns were discussed immediately with associated team members.

Laboratory Analysis: All quality assurance procedures were followed as described in the applicable ASTM methods. Also, ARB laboratory staff followed appropriate sampling and analytical quality control procedures, as contained in the Standard Operating Procedures (SOPs) for the fuel methods as described below. Data on the quarterly quality control activities of the ARB laboratories are available.

Reid Vapor Pressure Equivalent (SOP MLD 125): At the beginning of each analysis day, a standard material (usually 2,3-dimethylbutane) was analyzed on each vapor pressure instrument. The absolute vapor pressure of the standard material must not differ from the published value by more than 0.15 psi.

Oxygenates in Gasoline (SOP MLD 115): Quality control for this test method occured in three areas:

1. A quality control standard of known composition was analyzed at the beginning and end of each day's analyses. The QC standard was also run after every 10 samples if more than 10 samples were being analyzed at one time. The QC standard's measured concentrations of MTBE, TAME, and ethanol must not differ

from the known concentrations by more than twice the published repeatability of ASTM D4815.

2. A blank sample was run at the beginning of each day's analyses. The measured concentrations of MTBE, TAME, and ethanol in the blank sample must not be higher than 0.1 mass percent.

3. One sample out of every 10 was analyzed twice in succession. The difference in oxygenate concentrations measured in the two runs must not exceed the repeatability of ASTM D4815.

Data Entry: All hard copy of data was reviewed for any apparent errors prior to key data entry. Once key data entry was complete, the electronic data file was spot checked against the original hard copy for correctness. After all the data were entered into one master spreadsheet file, various additional methods (such as filtering, sorting, and statistical analysis) were used to further audit the data quality.

IV. FIELD STUDY DATA AND CONSUMER FUELING HABITS

This chapter discusses staff's observations in the field study. It includes information on the field study data, the representativeness of the sampled vehicles, and the range of gasoline specifications observed. Also included is staff's findings regarding California consumer fueling habits. These fueling habits include information on brand loyalty, initial fuel tank levels, fillup frequency, and grade purchasing propensity.

A. Field Study Data

A complete set of the field study data is contained in Appendix D. This data set includes both the individual information compiled from the field data sheets, as well as the fuel analysis information provided by ARB laboratory staff. The two data sets have been paired so that the fuel analysis information is associated with the information collected on a particular field data sheet. However, based on deliberations in the working group, gasoline brand information is not presented in the field study data contained in Appendix D.

B. Representativeness of Sampled Vehicles

In evaluating the field study data, staff was interested in determining if the age of the sampled vehicles was representative of the statewide vehicle population. This comparison is important to ensure that the vehicles observed in the field study are representative of the increasingly sophisticated emission control equipment found on more modern vehicles.

To perform this evaluation, staff compared the relative age of the sampled vehicle in the field study to that of the 2001 California passenger car and light-duty truck population, as contained in the ARB motor vehicle emission inventory model, EMFAC 2000 (version 2.02) that was based on California Department of Motor Vehicle (DMV) registration data. Three observations involving two motorcycles and a ski boat were excluded. This comparison is shown in Table IV-1, with vehicle age represented in five-year increments. As can be seen, the vehicle model years observed in each region are comparable to each other. The overall sample population is very similar to the statewide vehicle population as contained in EMFAC 2000, which is indicative of the representativeness of the field study data to the California passenger car and light-duty truck population.

Table IV-1:
Vehicle Model Year Comparison Between
EMFAC 2000 and the ARB Field Study

Vehicle Age (Years)	Percentage of Vehicles Represented				
	Lake Tahoe	The Bay Area	Los Angeles	Overall	EMFAC 2000 (Ver. 2.02)
1-5	34%	36%	30%	34%	31%
6-10	28%	31%	26%	29%	25%
11-15	18%	17%	15%	17%	23%
16-20	13%	8%	17%	12%	12%
21-25	3%	3%	5%	4%	4%
26-30	2%	2%	3%	2%	2%
> 30	2%	3%	4%	3%	3%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

C. Field Observations of Dispensed Gasoline

In evaluating the commingling impacts observed during the field study, it is important to first identify the types of fuels being dispensed. Non-oxygenated gasoline was considered fuel that had an MTBE content of less than or equal to 0.6 volume percent and an ethanol content less than 0.5 volume percent. MTBE-blended fuel had an MTBE content greater than 0.6 volume percent, and ethanol-blended fuel had an ethanol content greater than or equal to 0.5 volume percent. This is summarized in Table IV-2, along with the observed oxygenate concentrations in MTBE produced and ethanol-blended fuels.

Table IV-2:
Oxygenate Concentrations Observed in Field Study

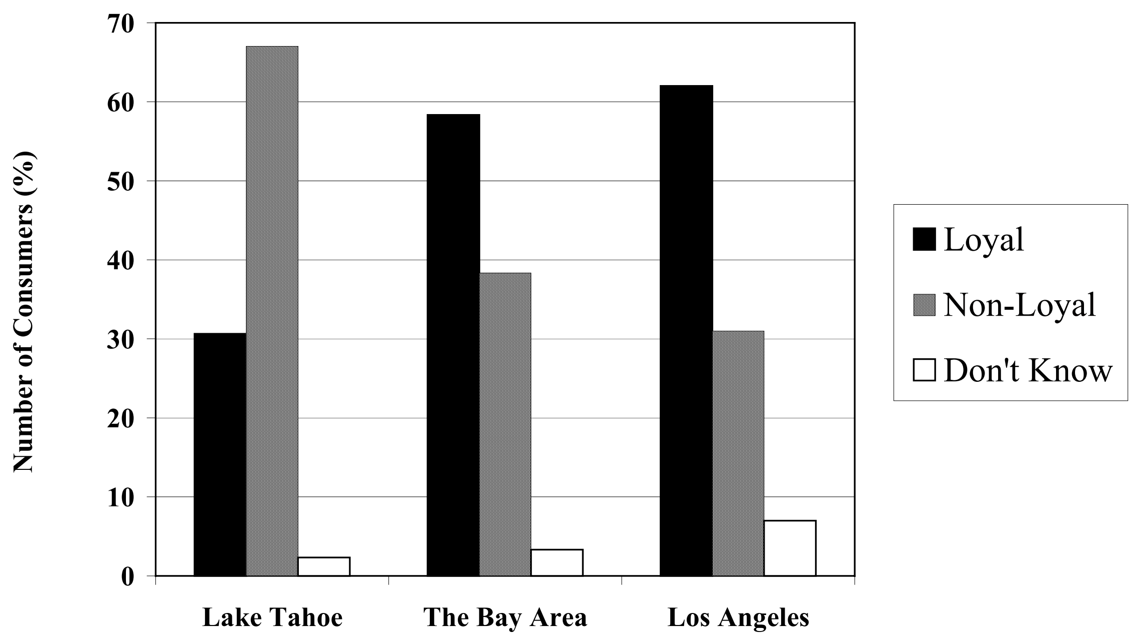
Fuel Type	Defining Oxygenate Concentration (Vol %)		Range of Oxygenate Observed (Vol %)	
	Ethanol	MTBE	Ethanol	MTBE
Non-Oxygenated	< 0.5	≤ 0.6	N/A	N/A
MTBE-Blended	< 0.5	>0.6	N/A	7.68 – 13.59
Ethanol-Blended	≥0.5	≤ 0.6	5.30 - 5.97	N/A

It is also important to note that typical California fuels being produced generally have an RVP of between 6.6 psi and 6.9 psi. The average dispensed fuel RVP measured in the field study was 6.76 psi. Fuels generally are not produced above 6.9 psi RVP to ensure that the fuel meets the summertime RVP cap of 7.0 psi currently in effect in California.

D. Characterization of Brand Loyalty

In conducting the field study, staff collected information on the brand loyalty of each consumer participating in the field study. In collecting these data, each consumer was asked if a different brand of gasoline was used for the last fueling of the vehicle. Each consumer response was recorded by staff on the field data sheet as either "yes", "no", or "don't know". For the purposes of staff's evaluation, "loyal" consumers were assumed to be those consumers who answered "no"; "non-loyal" consumers were assumed to be those consumers who answered "yes". These data are shown in Figure IV-1 for each of the three regions in the field study.

Figure IV-1. Gasoline Brand Loyalty* by Region



*Current and previous fuelings

As can be seen from Figure IV-1, in the Los Angeles and the Bay Area, over 50 percent of consumers participating in the field study identified themselves as loyal (used the same brand of gasoline as their previous fueling). In the Los Angeles area, this percentage was over 60 percent. Staff believes that the brand loyalty trend in these areas is indicative of consumers' normal, commuter type of behavior where they likely pass the same fueling stations each day. In these same areas, non-loyal consumers (those using a different brand of gasoline as their previous fueling) ranged between 30 and 40 percent, with less than 5 percent of consumers unsure of the previous brand of fuel used.

As compared to the Los Angeles and the Bay Area, the results in the Lake Tahoe area were significantly different. As can be seen in Figure IV-1, in the Lake Tahoe area the percentage of loyal consumers was slightly more than 30 percent, only about half the percentage as in Los Angeles and the Bay Area; conversely, the percentage of non-loyal consumers exceeded 65 percent, nearly twice that in these same two areas. In considering these results, this trend is expected since the Lake Tahoe region is a popular tourist destination, and there are fewer "major" brands of gasoline available in the region. Staff believes that the data are indicative of the need of non-local consumers to fuel in an unfamiliar area, thereby purchasing the most readily available fuel, regardless of brand. In reaching this conclusion, staff believes this pattern is likely atypical of a consumer's "normal" fuel purchasing patterns.

When the brand loyalty data in the Bay Area and Los Angeles were compared to the statewide data provided to the staff by gasoline marketers, the field study data were somewhat higher. Staff believes this is because the loyalty figure observed from the field study data may include some non-loyal consumers who happened to purchase the same brand of gasoline twice in a row as they were classified as consumers who "always" buy the same brand by default based on the wording of the field survey questionnaire.

Using data from the gasoline marketers, about 40 percent of California consumers always "use one gasoline brand," more than 50 percent "use two to three gasoline brands," and the remaining "use many gasoline brands." Rarely, do consumers make random brand switching. Most of the time, certain distinct patterns are followed. In the "use two to three brands" case, it is very likely that consumers use one brand for several consecutive fuelings, and occasionally switch to another brand. This hypothesis is supported by the field study data where brand loyal consumers represent a somewhat higher percentage than the "use one brand" case reported by the gasoline marketers. From a commingling stand point, the frequency with which consumers switch fuel types is important, not the number of brands being used. As any brand switching may not necessarily result in commingling when both brands are selling the same type of gasoline. Because of this, staff believes that the field study loyalty data are reasonable.

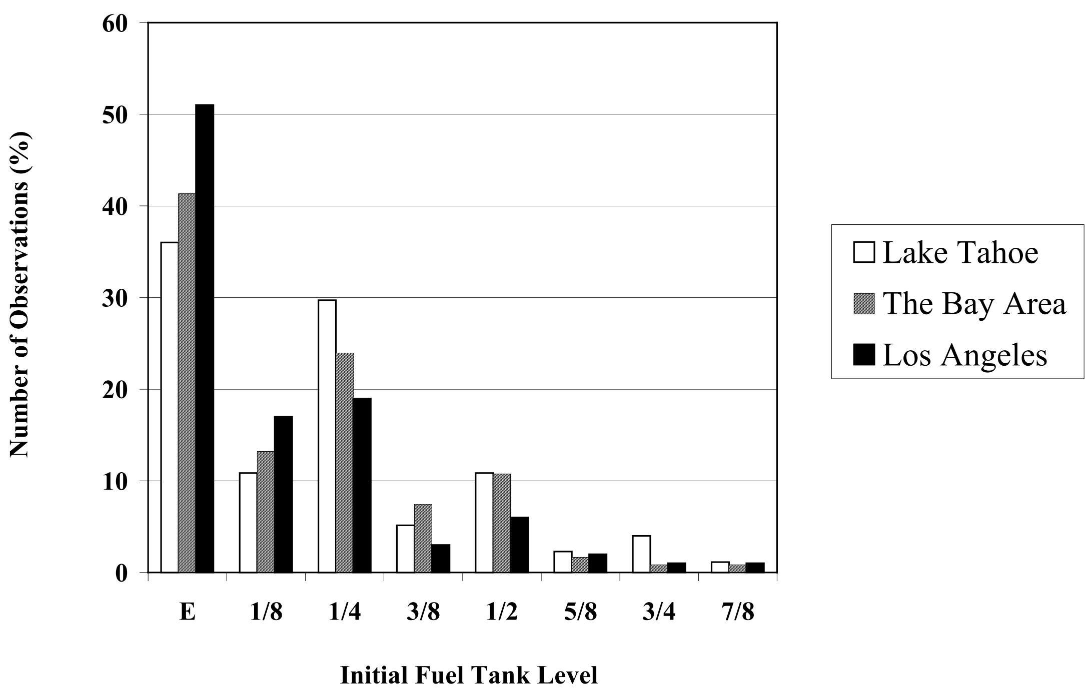
E. Initial Fuel Tank Levels

In conducting the field study, staff collected information on the initial fuel tank levels from each of the vehicles observed. The data are based on a visual observation of the fuel gauge display in the passenger compartment of the vehicle. These data are shown in Figure IV-2

As can be seen in Figure IV-2, almost 90 percent of the vehicles that were observed in Los Angeles region had fuel tank levels of a quarter tank or less when refueled, with about 50 percent registering near empty. In the Bay Area, almost 80 percent of the vehicles had a quarter tank or less, and 40 percent of the vehicles were nearly empty. However, since Lake Tahoe is generally a tourist destination, staff expected higher initial fuel tank levels due to visitors unfamiliarity with the region. The data support this hypothesis, with only about 35 percent of vehicles fueled at or near an empty tank. In general, though, initial fuel tank levels in each of the three regions were most often (nearly 80 percent) less than a quarter tank.

These data are consistent with a survey of over 1100 fuelings[3] by General Motors (GM). In the GM data, nearly 60 percent of the fuelings occurred with less than 0.2 of the fuel tank capacity remaining, and about 85 percent occurred with less than 0.3 of the fuel tank capacity remaining.

Figure IV-2. Distribution of Initial Fuel Tank Levels by Region

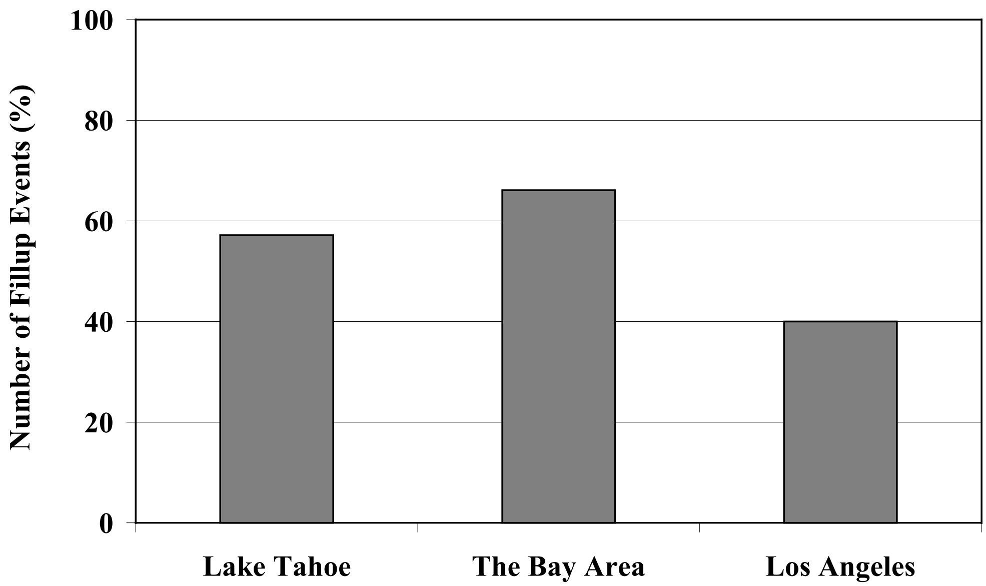


[3] "In-Use Volatility Impact of Commingling Ethanol and Non-Ethanol Fuels", Peter Caffrey and Paul Machiele, U.S. EPA, Society of Automotive Engineers (SAE) Paper 940765.

F. Characterization of Fueling Events

In conducting the field study, staff also collected information regarding the characterization of fuelings. For this information, staff collected information on consumer fuel purchasing patterns regarding the amount of fuel purchased. This information is shown below in Figure IV-3.

Figure IV-3. Fillup Events by Region



In the field study, a “fillup” was recorded as a fueling event where the activation of the gasoline dispenser’s automatic shut-off function was observed. As can be seen in Figure IV-3, the highest percentage of fillup events occurred in the Bay Area (over 65 percent), and the fewest fillup events were observed in the Los Angeles area (40 percent) while the Lake Tahoe area figure was in between. Staff believes this translates into about a 50 percent fillup rate within the State.

Similar to the initial vehicle fuel tank levels observed, the overall data for these three areas combined are consistent with the GM data reported by Caffrey and Machiele (SAE 940765). In that work, fillup (as represented by a final fuel tank level after fueling of 90 or 100 percent of capacity) events represented were nearly 50 percent of the 1,100 fuelings recorded.

G. Gasoline Grade Preference

In conducting the field study, staff recorded information on the grade of gasoline purchased for each fueling event observed. Staff then compared this to available data from the U.S. Department of Energy (U.S. DOE) regarding gasoline sales by grade in California[4], averaged over the same two month period that coincided with the implementation of the field study. These data are provided in Table IV-3, which shows the percent of consumers purchasing each of the three grades of gasoline available in California by region. As can be seen from Table IV-3, the overall vehicle fueling observations in the field study (by grade) are comparable to the U.S. DOE data of the statewide gasoline consumption.

Table IV-3:
Grade Selection Comparison Between
U.S. Dept. of Energy and the ARB Field Study

Gasoline Grade	California Consumer Grade Selection (Percent of Statewide Totals)[1]				
	U.S. DOE	The Bay Area	Los Angeles	Lake Tahoe	Overall
Premium	13	16	15	9	13
Mid-Grade	15	12	16	13	13
Regular	72	72	69	78	75
Total	100	100	100	100	100

[1] Totals may not add-up to 100 percent due to rounding.

[4] U.S. Department of Energy, Energy Information Administration, "Petroleum Marketing Monthly," August and September 2001 issues.

V. FIELD STUDY COMMINGLING RESULTS

This chapter discusses the RVP impacts observed in the field study from mixing different types of fuels (i.e., non-ethanol, ethanol, etc). The first part of the chapter discusses each of the various fuel mixing combinations observed. Because a different commingling impact can be expected with a specific fuel blending combination (ie, mixing MTBE fuel with MTBE fuel versus mixing ethanol blended fuel with non-oxygenated fuel), the associated changes in RVP due to each fuel mixing scenario are also discussed. Based on this, the commingling impacts for each region (based on the individual fuel mixing scenarios), as well as for the state as a whole, are then estimated.

A. Field Observations of Commingling Impacts

Based on staff's observations, there were five potential fuel-mixing combinations that occurred during the field study. These fuel-mixing combinations included:

- Mixing non-ethanol-blended gasolines.
- Mixing ethanol-blended gasolines.
- Dispensing ethanol-blended gasoline into non-ethanol-blended gasoline
- Dispensing non-ethanol-blended gasoline into already commingled gasoline
- Dispensing ethanol-blended gasoline into already commingled gasoline
- Dispensing non-ethanol-blended gasoline into ethanol-blended gasoline.

With the exception of the last combination listed above, the RVP characteristics of each of these fuel-mixing combinations are discussed below. The mixing of non-ethanol blends into ethanol blends is not further discussed because there were not sufficient data collected to perform an analysis for this fuel-mixing combination. However, staff has estimated a commingling impact from this fuel-mixing combination based on available literature, and it is presented in Table V-6 at the end of this chapter. The fuel-mixing combinations identified above are inclusive of all the documented fuelings regardless of fuel grade purchased and brand loyalty.

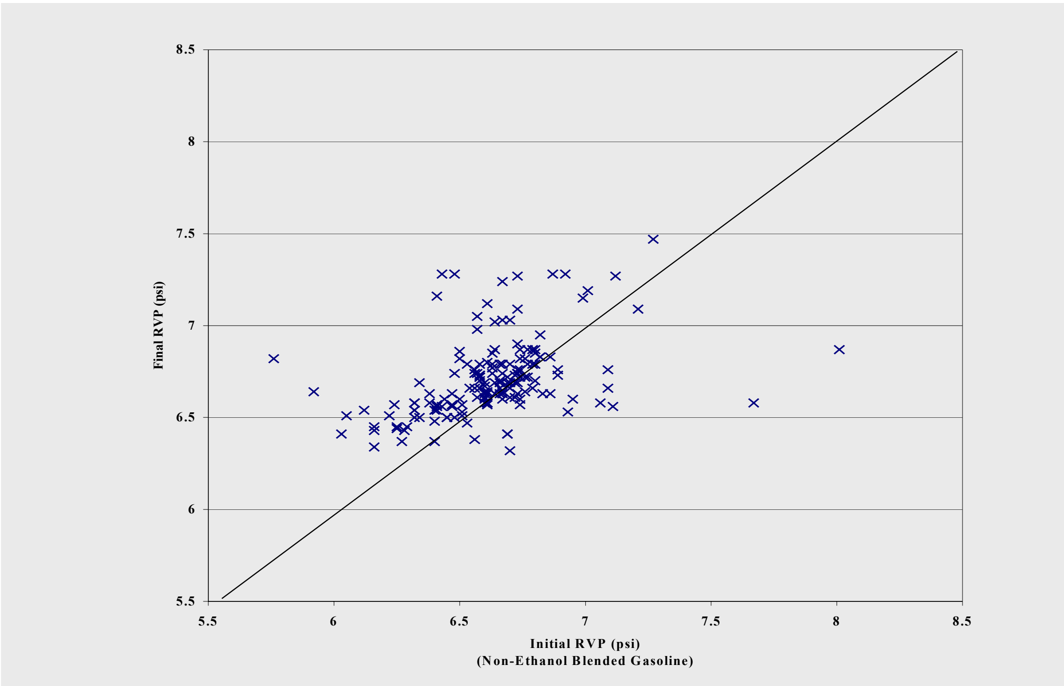
When evaluating the field data based on the above classifications, it is important to note that "non-ethanol blends" refer to either non-oxygenated or MTBE produced gasoline. "Commingled gasoline" refers to gasoline that contains at least 0.5 volume percent ethanol, but less than 5 volume percent ethanol, regardless of the MTBE content.

1. Mixing Non-Ethanol-Blended Gasolines

In general, the mixing of non-ethanol blended gasoline does not result in a commingling impact or unexpected increase in RVP of the resulting mixture. Because of this, both the federal RFG and the CaRFG3 regulations allow for the mixing of non-ethanol blends in the distribution system as long as any minimum oxygen content requirement is satisfied. During the period of time the field study was conducted, nearly 90 percent of gasolines supplied in California were non-ethanol blends. Because of this, most of the fuel samples obtained in the field study were non-ethanol blends.

In the field study, staff collected fuel samples from 165 fuelings involving non-ethanol blends. These data are shown in Figure V-1. The data are graphed according to the initial and final fuel tank RVP. In using this methodology, staff was able to graphically illustrate changes in the final fuel tank RVP as compared to the initial fuel tank RVP. The solid line in Figure V-1 represents no change in fuel tank RVP due to fueling.

Figure V-1. RVP Characteristics of Mixing Non-Ethanol Blended Gasolines

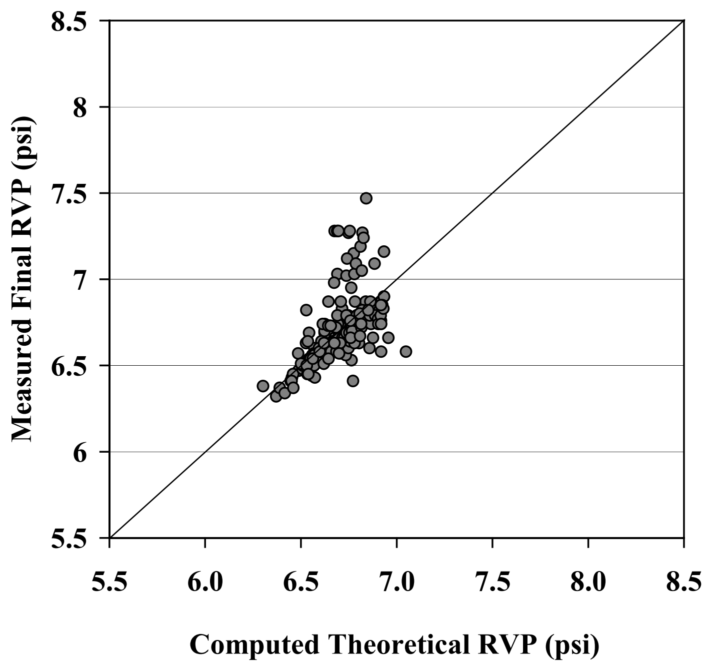


As can be seen in Figure V-1, on average small increases between the initial and final fuel tank RVP were observed in the field study data. The changes that were observed were likely the result of dispensing a higher RVP fuel into a "weathered" fuel in the vehicle fuel tank. Fuel weathering is a result of lighter, more volatile components evaporating from the fuel tank during the period between fuelings. This evaporative loss of volatile components results in a natural reduction in the fuel tank RVP with time. As a result, when higher RVP fuel is blended with a lower RVP weathered fuel in the vehicle fuel tank during fueling, the RVP of the existing fuel in the fuel tank increases linearly towards that of the dispensed fuel.

In light of this mixing of two fuels with different RVPs, staff was interested in evaluating how the final measured fuel tank RVP compared with what would be predicted due to the linear RVP response of mixing two dissimilar RVP fuels. To perform this evaluation, staff determined the initial tank volume prior to fueling as indicated by the fuel gauge, considering that the vehicle tank included a five percent tank 'heel' defined as the unusable volume of fuel at the very bottom of a vehicle fuel tank[5]. In addition, staff also assumed that five percent of the useable fuel remains even for a vehicle recorded as an empty tank in the field data. Using these assumptions and the volumetric amount of fuel dispensed, staff then calculated the theoretical final fuel tank RVP due solely to the linear contribution of each fuel's RVP in the final fuel. This value will be referred to as the "theoretical RVP". A more detailed explanation of staff's methodology is provided in Appendix F.

The results of staff's analysis are presented in Figure V-2. The data are graphed according to the measured final fuel tank RVP and the theoretical RVP. Staff believes that presenting the data in this manner is a better indicator of commingling impacts. This is because the theoretical RVP is independent of commingling impacts. Therefore, an increase in the measured final fuel tank RVP in relation to the theoretical RVP should represent the commingling impact. The solid line in Figure V-2 represents no change in fuel tank RVP due to commingling. As can be seen in Figure V-2, most of the data points are clustered along the solid line, indicating that, as expected, commingling does not occur when non-ethanol-blended gasolines are mixed.

Figure V-2. RVP Characteristics of Mixing Two Non-Ethanol-Blended Gasolines



[5] Support for consideration of a five percent tank heel is provided in the report, "A Vehicle Fuel Tank Flush Effectiveness Evaluation Program," Lee J. Grant, Southwest Research Institute, August 20, 2001. A copy is provided in Appendix E.

A descriptive statistical analysis of the complete set of fuel characteristics including mean, median, range, minimum, maximum, and sample count derived from these fuelings is presented in Appendix G.

Table V-1 summarizes the average measured RVP characteristics of mixing non-ethanol-blended gasoline in vehicle fuel tanks, as well as the average theoretical RVP calculated. As can be clearly seen, when non-ethanol fuels are mixed, the final measured RVP in the vehicle fuel tank is nearly identical to the theoretical RVP calculated, both of which are also nearly identical to that of the average fuel being dispensed into the vehicle fuel tank.

In Table V-1, the fact that the average dispensed fuel RVP (6.74 psi) is nearly identical to the theoretical RVP (6.71 psi) is important. Since the theoretical RVP of mixing two hydrocarbon fuels should be a linear function of the two fuels RVP and their relative volume proportions in the blend (i.e., initial and dispensed), a resultant RVP very close to one of the fuels RVP is indicative of a very high proportion of that fuel in the final mix. In the case of Table V-1, a significantly high percentage of dispensed fuel in the fuel tank. This is indicative of very low initial fuel tank levels, and is consistent with the data presented in Chapter IV which showed a large majority of the fuelings occurred at very low initial fuel tank levels, generally less than a quarter tank. As a result, the dispensed fuel RVP dominates the volume-weighted RVP, particularly for fillup fuelings.

Table V-1:
Average RVP Characteristics from the Mixing of Non-Ethanol-Blended Gasolines[1]

Fuel Sample	RVP (psi)
Initial Measured	6.63
Dispensed	6.74
Theoretical	6.71
Final Measured	6.72

[1]Based on 160 observed fuelings.

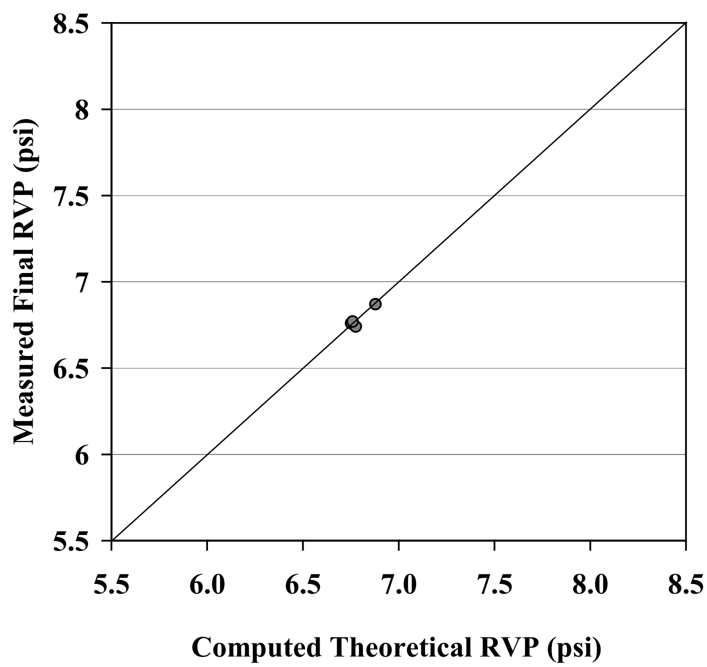
Finally, although staff observed 165 fuelings in this category, the average values presented in Table V-1 are based on 160 of those events. Data from five fuelings were not included in this analysis due to the extremely low RVP of the dispensed fuels. The minimum RVP specification incorporated into the Phase II federal RFG complex model is 6.4 psi (40 Code of Federal Regulations[CFR], section 80.45). The RVP of the gasoline dispensed in these five events was below this minimum RVP specification, and therefore, did not meet the minimum requirements for federal RFG. Since federal RFG areas will represent 80 percent of the California gasoline market later this year, staff does not believe it is appropriate to include those fuels in their statewide analysis as these fuels are unlikely to be widely distributed in California.

2. Mixing Ethanol-Blended Gasolines

Similar to non-ethanol-blended gasolines, the mixing of ethanol-blended gasolines does not result in a commingling impact or unexpected increase in RVP. This is because the two ethanol fuels have already experienced an increase in their RVPs due to the addition of ethanol during their production. Mixing them together will not result in any further increases in their RVP. As a result, when two ethanol fuels are mixed, staff expected that they should experience the same linear RVP response as mixing non-ethanol gasolines, and that the measured final RVP should be similar to the theoretical RVP.

In the field study, staff collected only four fuel samples involving the mixing of ethanol blended gasolines. These data are presented in Figure V-3. The data are graphed according to the measured final fuel tank RVP and the theoretical RVP. The solid line in Figure V-3 represents no change in fuel tank RVP due to commingling. As can be seen, most of the data points fall along the solid line, indicating that, as expected, commingling does not occur when ethanol-blended gasolines are mixed.

Figure V-3. RVP Characteristics of Mixing Two Ethanol-Blended Gasolines



A descriptive statistical analysis of the complete set of fuel characteristics including mean, median, range, minimum, maximum, and sample count derived from these fuelings is presented in Appendix H.

Table V-2 summarizes the average measured RVP characteristics of mixing ethanol-blended gasoline in vehicle fuel tanks, as well as the average theoretical RVP calculated. As can be clearly seen, when ethanol-blended fuels are mixed, the final measured RVP in the vehicle fuel tank is nearly identical to the theoretical RVP calculated.

Table V-2:
Average RVP Characteristics from the Mixing of Ethanol-Blended Gasolines[1]

Fuel Sample	RVP (psi)
Initial Measured	6.76
Dispensed	6.84
Theoretical	6.79
Final Measured	6.79

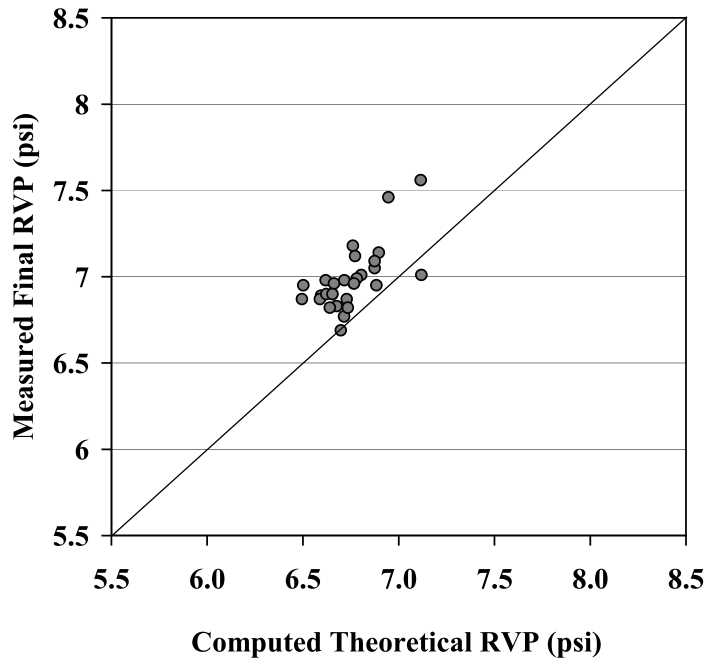
[1]Based on 4 observed fuelings.

3. Dispensing Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline

As expected, the dispensing of ethanol blended gasoline into non-ethanol blended gasoline resulted in an overall increase in the RVP of the fuel originally in the fuel tank. Staff believes that this increase in RVP occurs as a result of two phenomena. First, as seen previously in the mixing of non-ethanol fuels, adding higher RVP fuel to weathered fuel in a vehicle fuel tank raises the RVP of the weathered fuel. In addition, the commingling of ethanol with the original fuel in the tank also increases the RVP of that fuel. These two mechanisms combined result in the overall measured RVP increase in the fuel originally in the tank prior to fueling.

In the field study, staff collected fuel samples from 29 fuelings involving dispensing ethanol-blended gasoline into non-ethanol blends. These data are shown in Figure V-4. The data are graphed according to the measured final fuel tank RVP and the theoretical RVP. The solid line in Figure V-4 represents no change in fuel tank RVP due to commingling. As can be seen, most of the data points are above the solid line, indicating there is an increase in RVP between the theoretical and final measured fuel tank RVP.

Figure V-4. RVP Characteristics of Dispensing Ethanol-Blended into Non-Ethanol-Blended Gasoline



A descriptive statistical analysis of the complete set of fuel characteristics including mean, median, range, minimum, maximum, and sample count, derived from these fuelings is presented in Appendix I.

Table V-3 shows the average initial and final fuel tank RVP, the average dispensed fuel RVP, as well as the average theoretical RVP calculated. As can be seen, the data show that there is an RVP increase due to commingling of about 0.23 psi between the average theoretical and final fuel tank RVP.

Table V-3:
Average RVP Characteristics from Dispensing Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline[1]

Fuel Sample	RVP (psi)
Initial Measured	6.48
Dispensed	6.84
Theoretical	6.75
Final Measured	6.98

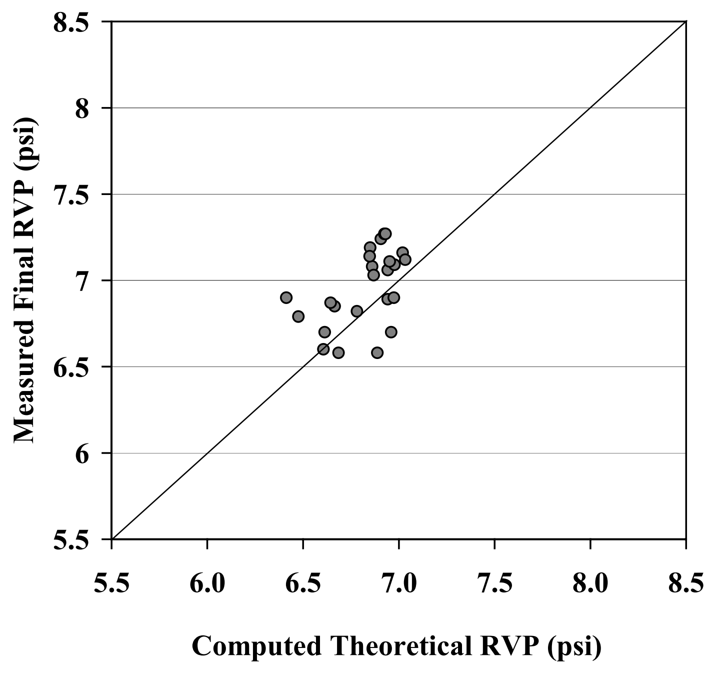
[1]Based on 29 observed fuelings.

4. Dispensing Non-Ethanol-Blended Gasoline into Already Commingled Gasoline

Staff's original expectation of dispensing non-ethanol-blended gasoline into already commingled gasoline was that an overall increase in the RVP of the fuel being dispensed into the tank would be observed. This is based on the anticipated commingling of the dispensed fuel by the ethanol present in the already commingled fuel in the vehicle fuel tank.

In the field study, staff collected fuel samples from 25 fuelings involving dispensing non-ethanol-blended gasoline into already commingled fuel. These data are shown in Figure V-5. The data are graphed according to the measured final fuel tank RVP and the theoretical RVP. The solid line in Figure V-5 represents no change in fuel tank RVP due to commingling. As can be seen, most of the data points are above the solid line, indicating there is an increase in RVP between the theoretical and final measured fuel tank RVP.

Figure V-5. RVP Characteristics of Dispensing Non-Ethanol Blended Gasoline into Already Commingled Gasoline



A descriptive statistical analysis of the complete set of fuel characteristics including mean, median, range, minimum, maximum, and sample count, derived from these fuelings is presented in Appendix J.

As can be seen in Figure V-5, similar to the previous fuel-blending scenario discussed, the results of this fuel-blending combination generally result in an increase in the measured final fuel tank RVP as compared to that predicted according to the theoretical RVP.

Table V-4 shows the average initial and final fuel tank RVP, the average dispensed fuel RVP, as well as the average theoretical RVP calculated. As can be seen, the data show that there is an RVP increase due to commingling of about 0.12 psi between the average theoretical and final fuel tank RVP.

Table V-4:
Average RVP Characteristics from Dispensing Non-Ethanol Blended Gasoline into Commingled Gasoline[1]

Fuel Sample	RVP (psi)
Initial Measured	6.93
Dispensed	6.77
Theoretical	6.85
Final Measured	6.97

[1]Based on 21 fuelings.

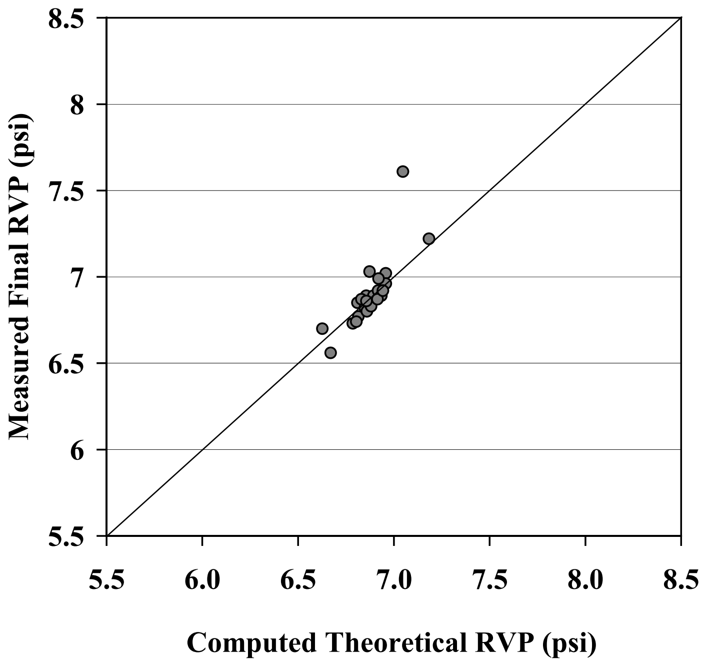
Although staff observed 24 fuelings in this category, the average values presented are based on 21 of those events. Data from three fuelings were not included in this analysis due to the extremely low RVP of the dispensed fuels. The minimum RVP specification incorporated into the Phase II federal RFG complex model is 6.4 psi (40,CFR, 80.45). The RVP of the gasoline dispensed in these four events was below this minimum RVP specification, and therefore, could not be used in federal RFG areas, which will represent 80 percent of the California market later this year.

5. Dispensing Ethanol-Blended Gasoline into Already Commingled Gasoline

Staff did not expect that the mixing of an ethanol-blended gasoline into an already commingled gasoline would result in a significant increase in RVP. This is because a commingled fuel has already experienced an RVP increase and staff believed that the mixing of an ethanol blended gasoline into an already commingled gasoline would result in little, if any, RVP increase. In addition, since as little as two volume percent ethanol will effect the full commingling impact, it was expected that additional ethanol would not cause any RVP increases.

In the field study, staff collected fuel samples from 25 fuelings where a mixing of an ethanol-blended gasoline into an already commingled gasoline was observed. These data are shown in Figure V-6. The data are graphed according to the measured final fuel tank RVP and the theoretical RVP. The solid line in Figure V-6 represents no change in fuel tank RVP due to commingling. As can be seen in Figure V-6, in general there were only minor differences in the final measured fuel tank RVP as compared to the theoretical RVP, indicating very small commingling impacts were observed.

Figure V-6. RVP Characteristics of Dispensing Ethanol-Blended Gasoline into Already Commingled Gasoline



A descriptive statistical analysis of the complete set of fuel characteristics including mean, median, range, minimum, maximum, and sample count, derived from these fuelings is presented in Appendix K.

Table V-5 shows the average initial and final fuel tank RVP, the average dispensed fuel RVP, as well as the average theoretical RVP calculated. As can be seen, the data show that there is an RVP increase of about 0.03 psi between the average theoretical and final fuel tank RVP.

Table V-5:
Average RVP Characteristics from Dispensing Ethanol-Blended Gasoline into Commingled Gasoline[1]

Fuel Sample	RVP (psi)
Initial Measured	6.90
Dispensed	6.86
Theoretical	6.88
Final Measured	6.91

[1]Based on 24 Fuelings

Although staff observed 25 fuelings in this category, the average values presented are based on 24 of those events. Data from one fueling event were not included in this analysis due a lack of confidence in the associated data. Data for this event indicated a 1977 Dodge Van with 7/8 initial fuel gage level, initial RVP of 7.56 psi, and an initial ethanol content of 2 percent, is then filled with 12.5 gallons of a dispensed fuel with an RVP of 6.75 psi and an ethanol content of 6 percent. The final fuel tank RVP was 8.2 psi. Due to the unconventional fuel characteristics in response to this vehicle's fueling, data associated with this event were excluded from the analysis for which the results are presented in Table V-5.

B. Overall Findings of Field Observations

Based on staff's above analysis, staff estimated the anticipated commingling impact on the statewide gasoline pool, as well as for the gasoline pools in each of the three areas. To do this, staff used the commingling impact expected for each of the previously discussed fuel blending scenarios, collectively shown in Table V-6.

Table V-6:
Commingling Impacts for Various Fuel Blending Scenarios

Fuel Mixing Scenario	Commingling Impact (∆RVP, psi)
Mixing non-ethanol-blended gasolines	-0.01
Mixing ethanol-blended gasolines	0.00
Dispensing ethanol blends into non-ethanol blends	0.23
Dispensing non-ethanol blends into ethanol blends	0.37[1]
Dispensing non-ethanol blends into already commingled gasoline	0.12
Dispensing ethanol blends into already commingled gasoline	0.03

[1] This fuel mixing scenario was not addressed in the previous discussion since sufficient data were not collected in the field study to quantify this value. However, staff estimated this impact using data contained in Figure 3 of "Addition of Nonethanol Gasoline to E10 – Effect on Volatility", as contained in Appendix L.

To estimate the overall anticipated statewide commingling impact, staff first used the consumer loyalty information collected in each area, as shown in Figure IV-1. In their analysis, staff assumed that brand loyal consumers were represented by "Mixing of non-ethanol blended gasolines" and "Mixing of ethanol-blended gasolines", which results in no commingling impacts.

Staff computed the anticipated statewide commingling impacts, summarized in Table V-8, as a weighted average of the following factors:

- The regional gasoline consumption[6] fraction as calculated in Table V-7 below. This fraction was used as a weighting factor for each region's commingling contribution.

Table V-7:
1998 Gasoline Consumption by Region[1]

Region	1998 Gasoline Consumption (1,000 gallons)	Regional Gasoline Consumption Fraction
Lake Tahoe	173,999	2%
The Bay Area	3,101,350	33%
Los Angeles	6,074,673	65%
Total	**9,350,023**	**100%**

[1] Source: California Energy Commission, Fuels Office, http://www.energy.ca.gov/fuels/gasoline_stations/index.html

[6] For staff's analysis, each area was defined as the air basin in which the field sampling occurred, and the fuel consumption was based on the 1998 fuel consumption for each county comprising the respective air basins.

- An average RVP increase of 0.188 psi from the last four fuel mixing scenarios from Table V-6, assuming that non-loyal consumers were equally represented by the last four scenarios (i.e., 25 percent of consumers saw an RVP increase of 0.23 psi, 25 percent of 0.32 psi, etc.). In addition, staff assumed that this factor is the same across regions.

- The percentage of non-loyal consumers from Figure IV-1. As can be seen in Figure IV-1, the percentages of loyal and non-loyal consumer observed do not add up to 100 percent since a small fraction of participants responded "don't know" when asked whether the current gasoline bought was the same as their last purchase. To account for the contribution from the "don't know" group in the commingling analysis, staff included this group into non-loyal consumers. Using this methodology, the corresponding non-loyal consumer figures in Lake Tahoe, the Bay Area, and Los Angeles areas are 69, 42, and 38 percent, respectively.

Staff estimated each region commingling contribution as a product of the above three factors, as shown in Table V-8. Although the Lake Tahoe region shows a much higher non-loyal consumer percentage, the gasoline consumption in the region is the least among the three regions surveyed. As a result, its contribution to the overall statewide commingling impacts is relatively small (only a 0.003 psi RVP increase). In contrast, the Los Angeles region yields the highest contribution, 0.046 psi, followed by the Bay Area, 0.026 psi. The estimated statewide commingling impact, as the sum of the three regions' RVP increase, is approximately 0.07 psi.

Table V-8:
Statewide Commingling Impacts
The 2001 ARB Field Study

Region	Regional Gasoline Consumption Fraction	Ave RVP Increase (psi)	Non-Loyal Consumer Fraction	Regional Commingling Contribution (psi)[1]
Lake Tahoe	0.02	0.188	0.69	0.003
The Bay Area	0.33	0.188	0.42	0.026
Los Angeles	0.65	0.188	0.38	0.046
Total	**1.00**	**Statewide Average**		**0.07**

1The sum of regional commingling contributions may be different from the 'Statewide Average' figure due to rounding.

While staff believes that their assessment has provided a reasonable estimation of the commingling impact of mixing non-ethanol fuel into already commingled fuel, it highlights the variability of commingling after the initial commingling event has occurred. This is because there are a significant number of variables that will influence the commingling impact, including the ethanol content of the commingled fuel, the number of subsequent fuelings, and the amount of fuel present prior to fueling. Staff believes that a more accurate estimation of the commingling impacts of mixing these two fuels can be achieved through the use of statistical modeling.

VI. SIMULATION MODELING OF COMMINGLING IMPACTS

In addition to documenting actual impacts of commingling on individual vehicle fuel tanks as observed in the field study, a simulation model was used to estimate potential statewide commingling impacts.

A. Introduction

Using statistical and mathematical approaches, a computer simulation model (model) can simulate complex consumer fuel purchasing decisions under a variety of different sets of conditions or scenarios. In the case of commingling, the model would use input data from assumed conditions that may be prevalent in the future and from field survey data of consumer fueling habits.

This is useful for several reasons. First and foremost, it allows a commingling impact analysis to proceed even though some key market factors that may affect the results are unobserved. In the case of CaRFG3, these factors include ethanol market share, consumers purchase propensity toward ethanol-blended fuel, and the properties of future gasoline blends. They are unknown since the use of ethanol as an oxygenate on a level comparable to MTBE has not yet occurred. In general, to arrive at meaningful results, reasonable assumptions concerning these factors are necessary.

Consumer fueling habits also play an integral role in commingling analysis. The type and volume of dispensed fuel as well as remaining fuel in a vehicle fuel tank prior to fueling influence the RVP of a mixed fuel, and, hence, the commingling impact. As an example, if consumers always purchased fuel when registering nearly an empty tank, the volume of remaining fuel would be nearly negligible, greatly minimizing potential commingling impacts, regardless of the type and volume of fuel being dispensed in each fueling event.

Laboratory analysis of a fuel tank RVP prior to fueling helps shed some light on a consumer's fueling history, e.g., if they had dispensed ethanol-blended fuel in the past. However, the laboratory testing can not establish sequential fuelings that ultimately led to a fuel's measured RVP. In the field, staff recorded only two fuelings—the current and previous. Because of the role consumer fueling habits play in commingling, and the difficulties in using laboratory analysis to determine the specifics of previous fuelings, a simulation model is indispensable. The model is capable of simulating a long sequence of fuelings from a large number of consumers who on average behave similarly to the consumers observed in field study.

All things considered, commingling analysis is complex. So long as the sampled consumers are representative of the California consumer population, the simulation results can be generalized to approximate statewide commingling impacts.

B. Simulation Model

Staff used a simulation model that was developed by David M. Rocke, Ph.D., University of California, Davis (UCD), pursuant to an ARB contract, and made available to the public in 1999. A copy of the FORTRAN source code is attached (Appendix M), including a user's manual.

Using a statistical and mathematical approach, the model makes use of random sample data, expands the scope of the analysis that may not have been observed in the actual data by randomly drawing new observations based on the observed parameters of important variables (e.g., mean and standard deviation of initial fuel tank levels), and, at the end, summarizes the results. In the process, it also takes into account variation and uncertainty from which a valid inference can be drawn.

In evaluating commingling impacts, staff began with observations of consumer fueling patterns, as well as RVP changes in vehicle fuel tanks, from a random sample of the California motorist population. Staff derived key parameters, means and standard deviations, from the sample that is assumed governed by certain probability distributions where variation and uncertainty are considered. The model takes this information, and simulates consumer fuel buying habits by allowing each individual to be randomly different from the others; yet, on average, they should mimic the observed random sample. This randomness is vital as it provides a mean for staff to generalize the results for the entire population to reach a valid conclusion.

C. Methodology of Simulation Analysis

The field study showed that consumers behave differently across geographic regions in the state. For example, consumers in Los Angeles showed higher brand loyalty, refueled when less fuel remained in the vehicle tank, but were less likely to fillup than consumers in the Bay Area or Lake Tahoe (Figure IV-3). Based on this information, consumers from each region were analyzed separately to determine commingling impacts.

1. Loyal Consumers

A key assumption in staff's modeling work was that fueling by those consumers that used the same brand of gasoline as their previous fuel purchase ("loyal" consumers) resulted in no or negligible commingling occurring in their vehicle tanks.

The basis for this assumption is that, a fuel station that sells a certain brand of gasoline is unlikely to sell two types of fuel simultaneously (i.e., non-ethanol and ethanol-blended gasolines). As a result, loyal consumers get the same fuel type for every fueling, so the mixing of non-ethanol and ethanol-blended gasolines, on which the commingling analysis is based, will not occur. Ideally, fuel-type loyalty data should be used instead of brand loyalty to assess the commingling impacts. However, in the absence of fuel-type loyalty data, brand loyalty data are the best surrogate data. More discussion on brand loyalty data is provided in the next section.

2. Non-Loyal Consumers

Staff then used the UCD model to simulate a wide range of scenarios of commingling impacts for "non-loyal" consumers in each region. To develop a statewide average of commingling impacts, the contribution from non-loyal consumers toward commingling in each region was weighted by the corresponding proportion of non-loyal consumers and gasoline consumption, as described in Chapter IV.

D. Input Data & Assumptions

As previously described, the actual impacts of commingling on emissions depend on many variables that are input to the model. The input data are bifurcated according to future ethanol market conditions and current consumer behavior patterns that are expected to hold in the future.

1. Future Ethanol Market Conditions

Uncertainty involved in dealing with these data necessitates staff to assume various scenarios that are expected to cover a wide range of potential commingling impacts and to bracket the likely range of commingling impacts. In selecting values to input into these scenarios, staff used the best data available, including recent reports, and stakeholder consultation.

Ethanol Market Share: Under a waiver scenario, staff assumed that the future California ethanol market share would vary from 25 percent to 65 percent of the gasoline market. This is consistent with that documented in a report prepared for the U.S. EPA by MathPro Inc., titled "Analysis Of The Production Of CaRFG3 With And Without An Oxygen Waiver," (2001). Staff further assumed that this assumption holds across gasoline grades. That is, ethanol market share is the same for all grades. By assuming a constant ethanol market share across grades, staff has attempted to account for the commingling impacts associated with potential grade switching when information on grade loyalty is currently unavailable.

Ethanol Blending Concentrations: After consulting with gasoline producers, staff assumed that gasoline produced with either 6 volume percent or 7.7 volume percent of ethanol are the likely future California fuel blends. As such, staff utilizes these fuels in their analysis. Like ethanol market share, these blends also apply to all grades due to fuel distribution system constraints (i.e., fuel quality specifications set by a common carrier pipeline company). Consequently, grade switching within the same brand would not lead to commingling. This assumption seems reasonable, in part, because most grade switching is expected to occur within the same brand, and both regular and premium grade of gasolines are expected to contain the same amount of ethanol for a given gasoline brand. Moreover, consumer survey data show grade market share remains constant over time, except during short periods of gasoline price spikes.

Based on average RVP of the dispensed fuels from the field study, staff assumed 6.71 psi base RVP for non-oxygenated fuel and 5.74 psi for ethanol fuel (i.e., 6.84 psi RVP from the average 5.6 volume percent ethanol-blended gasolines observed in the field minus a 1.1 psi expected RVP increase from ethanol blending).

Fuel Type Switching Patterns: Because the pattern in which ethanol and non-ethanol gasolines are dispensed into a vehicle has a significant impact on commingling, the simulation model must generate the non-loyal consumers fuel type switching patterns to produce an estimate of the commingling impacts. First, the model randomly assigns each consumer with a fixed "ethanol purchase propensity value". Appendix N describes this concept in more detail. Using this value, the model then randomly generates a sequence of fuel switching patterns.

For example, consider two non-loyal consumers with a 50 percent ethanol purchase propensity. In this case, the two consumers are equally likely to switch between non-ethanol-blended and ethanol-blended gasolines for each fueling event. For ten fueling events, the first consumer would cause maximum commingling impacts if they alternately switch fuel type. If "N" and "E" denote fueling non-ethanol and ethanol-blended gasolines, respectively, NENENENENE or ENENENENEN represents the above sequence of ten fuelings. All else being equal (e.g., remaining fuel in a vehicle fuel tank prior to fueling and amount of fuel dispensed), contrast this with the minimal commingling impacts from the second consumer who switches fuel with the following sequence: NNNNNEEEEE or EEEEENNNNN. In the latter case, the first five fuelings are of one type followed by the next five of another type, so fueling number six and beyond are where the commingling impacts should be considered. However, if at the7th fueling a consumer rolled in with an empty tank, the commingling impacts would theoretically be limited to the 6th fueling only.

2. Consumer Fueling Habits

Table VI-1 below summarizes non-loyal consumer fueling habits by region. These fueling habits are more fully discussed below.

Brand Loyalty: The regional non-loyal consumer fractions from Figure IV-1, including the 'don't know' group, are again shown in Table VI-1. These figures and the regional gasoline consumption (Table V-7) were used as weighting factors to estimate statewide commingling impacts.

Table VI-1 Non-Loyal Consumers* Fueling Information By Region
The 2001 ARB Field Study

Variable	Lake Tahoe	SF Bay Area	Los Angeles
Non-Loyal Consumer (%)	69	42	38
Ave. Initial Fuel Tank Levels (as a fraction of usable tank capacity)	0.23	0.2	0.18
Fillup (%)	52	58	24
Ave. Fuel Amount Purchased for Non-Fillup (as a fraction of usable tank capacity)	0.35	0.32	0.37

*Including "don't know" group

<u>Initial Fuel Tank Level:</u> According to the field study, the majority of consumers (about 80 percent) fuel when there is ¼ tank of gasoline or less remaining in their tanks, with more than 40 percent registering nearly an empty tank. In evaluating the data, the mean initial fuel tank level for non-loyal consumers is comparable to the overall sample's mean. On average, consumers in Los Angeles have lower initial fuel tank levels than consumers in the Bay Area or Lake Tahoe, as shown in Table VI-1.

In practice, as described in the previous chapter, although fuel gauge may register empty, staff believes that some fuel still remains in the tank. Staff assumed about five percent tank capacity of usable fuel for initial fuel tanks recorded as empty ("E") in the field study. The mean tank levels presented in Table VI-1 were computed based on this assumption.

In addition, staff assumed a five-percent tank "heel," regardless of initial fuel tank levels. This assumption is supported by data from the Southwest Research Institute (Appendix E). As a result, the simulation model also assumes a five-percent or one-gallon tank heel, based on an average 20-gallon tank capacity. This 20-gallon tank capacity is derived from weighted average tank capacity of passenger car, estimated to be16-gallon, and light-duty trucks estimated to be 24-gallon where both vehicle classes are about equally represented in the sample.

<u>Amount Of Fuel Purchased:</u> As can be seen in Table VI-1, the data collected on non-loyal consumers follow similar fillup trends as the overall consumers observed in Figure IV-3. For example, non-loyal consumers in Los Angeles are the least likely to fillup among non-loyal consumers in the three regions. Also, the data for the average amount of fuel purchased for non-fillup events are comparable among the three regions.

3. Summary of Input Data

From the mean and standard deviation of each variable in Table VI-2, the corresponding input parameters (i.e., beta distribution) were derived for the commingling simulation analysis. Table VI-2 summarizes the input data and assumptions for the model. The upper portion of the table (above the dashed line) lists the input assumptions for the future ethanol market conditions while the lower portion identifies the field survey information. Unlike the future ethanol market conditions, the field survey information is assumed to remain constant for each different scenario analyzed (this is further explained in Chapter VII.). For example, premium consumers would fillup with the same frequency, regardless of whether ethanol market share was 25 percent or 50 percent.

Table VI-2 Input Data & Assumptions

For Simulation Model

Variables		Lake Tahoe	SF Bay Area	Los Angeles
Ethanol Content (vol%)		6 or 7.7	6 or 7.7	6 or 7.7
Base RVP (psi)	- Non-oxygenated	6.71	6.71	6.71
	- Oxygenated	5.74	5.74	5.74
Ethanol Market Share (%)		25 - 65	25 - 65	25 - 65
Distribution of EtOH Purchase Propensity $(\alpha+\beta)^*$		1, 2, or 5	1, 2, or 5	1, 2, or 5
Initial Fuel Tank Level (mean, fraction of tank cap.)		0.23	0.2	0.18
Distribution of Initial Fuel tank Level $(\alpha+\beta)$		3.3	4.5	2.6
Fillup Frequency (mean)		0.52	0.58	0.24
Distribution of Fillup Frequency $(\alpha+\beta)$		6.7	3.6	4.7
Fuel Purchased for Non-Fillup (mean, fraction of tank cap.)		0.42	0.36	0.42
Dist. of Fraction Amount Purchased for Non-Fillup $(\alpha+\beta)$		2.8	4.6	2.5

*The 2001 ARB field study did not specifically elicit cunsumers purchase propensity toward ethanol fuel.

The figures are for different assumptions (1 = less conservative, 2 = base case, and 5 = more conservative scenarios).

VII. SIMULATION RESULTS

This chapter describes the results of staff's use of the UCD simulation model to access the potential impacts of CaRFG3 commingling.

A. Statewide Potential Commingling Impacts

Using the UCD simulation model and assumed future ethanol market conditions (as discussed in Chapter VI), as well as consumer fueling behavior from the field study (as described in Chapter IV) as input, staff simulated a total of 162 fueling scenarios. These included all possible combinations of:

- 3 regions;
- 3 ethanol purchase propensity distributions;
- 9 ethanol market shares from 25 percent to 65 percent in five percent increments, and;
- 2 ethanol blends, 6 volume percent and 7.7 volume percent.

Each scenario represents 5,000 consumers with 500 fuelings per consumer, resulting in the modeling of over 400 million fuelings. The model then computes the average commingling effect for each scenario.

The first set of scenarios (i.e., ethanol purchase propensity based on a beta distribution, with $\alpha + \beta$ equal to 2) is collectively called the base case scenario. Table VII-1 summarizes the results of the base case scenario. The top half (above solid line) of Table VII-1 shows the commingling impacts of using a 6 volume percent ethanol blend while the bottom half shows the impacts of using a 7.7 volume percent blend. The two blends are assumed to have the same base RVP. RVP increases due to commingling are estimated for each region, as shown in Appendix O. These increases are weighted by the corresponding regional non-loyal consumer proportions and gasoline consumptions as described in Chapter VI, and the results are presented in Table VII-1. The last column in Table VII-1 is the total statewide commingling impact as the sum of the three regions weighted-average RVP increases for each ethanol market penetration. For example, if ethanol market share is 25 percent of total gasoline pool, the regional commingling contribution are estimated to be 0.002 psi, 0.020 psi, and 0.033 psi RVP in Lake Tahoe, the Bay Area, and Los Angeles, respectively, for 6 volume percent ethanol blends.

As expected, the anticipated commingling effect increases with ethanol market penetration, and peaks at around 45 percent to 50 percent market share. For the base case scenario, the model estimated average statewide commingling impacts of 0.055-0.069 psi RVP for 6 volume percent ethanol blends and 0.062-0.077si RVP for 7.7 volume percent ethanol blends.

Table VII-1
Estimated Statewide Commingling Impacts For Various Ethanol Blends And Market Shares
Using The 2001 ARB Field Study Input Parameters
Base Case Scenario (Beta Distribution, $\alpha+\beta=2$)
(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	Estimated RVP Increase Due To Commingling By Region (psi)			
				Lake Tahoe*	Bay Area*	Los Angeles*	Statewide
25	6	6.71	5.74	0.002	0.020	0.033	0.055
30	6	6.71	5.74	0.002	0.022	0.037	0.062
35	6	6.71	5.74	0.002	0.022	0.040	0.064
40	6	6.71	5.74	0.002	0.022	0.043	0.067
45	6	6.71	5.74	0.003	0.024	0.041	0.068
50	6	6.71	5.74	0.003	0.024	0.042	0.069
55	6	6.71	5.74	0.002	0.024	0.043	0.069
60	6	6.71	5.74	0.002	0.024	0.039	0.066
65	6	6.71	5.74	0.002	0.022	0.037	0.061
25	7.7	6.71	5.74	0.002	0.022	0.037	0.062
30	7.7	6.71	5.74	0.002	0.025	0.042	0.069
35	7.7	6.71	5.74	0.003	0.025	0.044	0.072
40	7.7	6.71	5.74	0.003	0.025	0.048	0.075
45	7.7	6.71	5.74	0.003	0.027	0.046	0.076
50	7.7	6.71	5.74	0.003	0.027	0.047	0.077
55	7.7	6.71	5.74	0.003	0.026	0.048	0.077
60	7.7	6.71	5.74	0.003	0.026	0.044	0.073
65	7.7	6.71	5.74	0.002	0.025	0.041	0.068

*These figures are calculated from the average RVP increases in each region weighted by the corresponding non-loyal consumer proportions and gasoline consumptions.

B. Sensitivity Analysis

Using the UCD model, staff also performed sensitivity analysis of potential commingling impacts. The sensitivity analysis is related to staff's input assumptions, regarding different ethanol purchase propensities.

The results of this sensitivity analysis are shown in Tables VII-2 and VII-3. Table VII-2 presents a more conservative ($\alpha + \beta=5$) estimate of commingling impacts relative to the base case while Table VII-3 is less conservative ($\alpha + \beta=2$) compared to the base case.

Using the same methodology as in the base case, the statewide commingling impacts were estimated. Again as can be seen in the tables, the largest impacts occur when the ethanol market share is around 45 percent to 50 percent.

Table VII-2
Estimated Statewide Commingling Impacts For Various Ethanol Blends And Market Shares
Using The 2001 ARB Field Study Input Parameters
More Conservative Scenario (Beta Distribution, $\alpha+\beta=5$)
(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	Estimated RVP Increase Due To Commingling By Region (psi)			
				Lake Tahoe*	Bay Area*	Los Angeles*	Statewide
25	6	6.71	5.74	0.003	0.026	0.043	0.072
30	6	6.71	5.74	0.003	0.028	0.046	0.076
35	6	6.71	5.74	0.003	0.029	0.050	0.082
40	6	6.71	5.74	0.003	0.031	0.052	0.086
45	6	6.71	5.74	0.003	0.030	0.054	0.087
50	6	6.71	5.74	0.003	0.030	0.053	0.086
55	6	6.71	5.74	0.003	0.030	0.052	0.084
60	6	6.71	5.74	0.003	0.028	0.050	0.081
65	6	6.71	5.74	0.003	0.026	0.046	0.075
25	7.7	6.71	5.74	0.003	0.029	0.048	0.081
30	7.7	6.71	5.74	0.003	0.031	0.052	0.086
35	7.7	6.71	5.74	0.003	0.032	0.056	0.091
40	7.7	6.71	5.74	0.003	0.034	0.058	0.096
45	7.7	6.71	5.74	0.003	0.034	0.060	0.097
50	7.7	6.71	5.74	0.003	0.033	0.059	0.096
55	7.7	6.71	5.74	0.003	0.033	0.057	0.094
60	7.7	6.71	5.74	0.003	0.031	0.055	0.090
65	7.7	6.71	5.74	0.003	0.029	0.051	0.083

*These figures are calculated from the average RVP increases in each region weighted by the corresponding non-loyal consumer proportions and gasoline consumptions.

Table VII-3
Estimated Statewide Commingling Impacts For Various Ethanol Blends And Market Shares
Using The 2001 ARB Field Study Input Parameters
Less Conservative Scenario (Beta Distribution, $\alpha+\beta=1$)
(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	Estimated RVP Increase Due To Commingling By Region (psi)			
				Lake Tahoe*	Bay Area*	Los Angeles*	Statewide
25	6	6.71	5.74	0.001	0.014	0.023	0.039
30	6	6.71	5.74	0.002	0.017	0.026	0.045
35	6	6.71	5.74	0.002	0.017	0.028	0.047
40	6	6.71	5.74	0.002	0.018	0.032	0.051
45	6	6.71	5.74	0.002	0.017	0.031	0.050
50	6	6.71	5.74	0.002	0.019	0.031	0.052
55	6	6.71	5.74	0.002	0.018	0.031	0.051
60	6	6.71	5.74	0.002	0.017	0.028	0.046
65	6	6.71	5.74	0.002	0.017	0.027	0.046
25	7.7	6.71	5.74	0.002	0.016	0.026	0.043
30	7.7	6.71	5.74	0.002	0.019	0.029	0.050
35	7.7	6.71	5.74	0.002	0.019	0.032	0.053
40	7.7	6.71	5.74	0.002	0.020	0.035	0.057
45	7.7	6.71	5.74	0.002	0.019	0.035	0.056
50	7.7	6.71	5.74	0.002	0.021	0.034	0.058
55	7.7	6.71	5.74	0.002	0.020	0.034	0.056
60	7.7	6.71	5.74	0.002	0.019	0.031	0.052
65	7.7	6.71	5.74	0.002	0.019	0.031	0.051

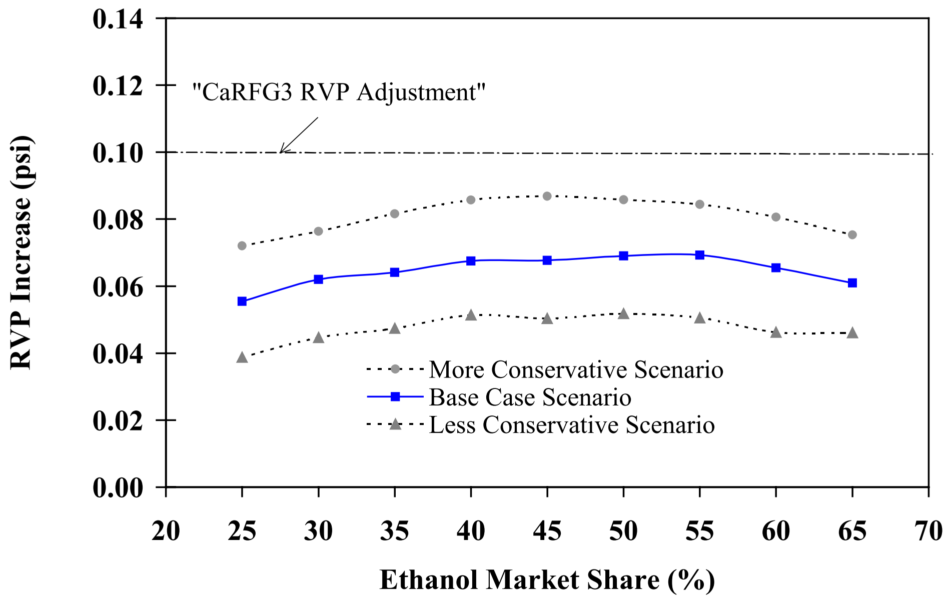
*These figures are calculated from the average RVP increases in each region weighted by the corresponding non-loyal consumer proportions and gasoline consumptions.

C. Overall Findings Of Simulation Modeling

Figure VII-1 combines the statewide commingling impacts of 6 volume percent ethanol blend for three different scenarios. The solid line curve represents the results of the base case scenario as a function of ethanol market share while the two dashed lines represent the results of the sensitivity analysis. As previously discussed, the 6 volume percent ethanol blends are the most likely ethanol fuels to be supplied to California. As can be seen in Figure VII-1 the statewide commingling impacts are estimated to be less than 0.1 psi RVP, which is below the 0.1 CaRFG3 RVP offset in the Predictive Model.

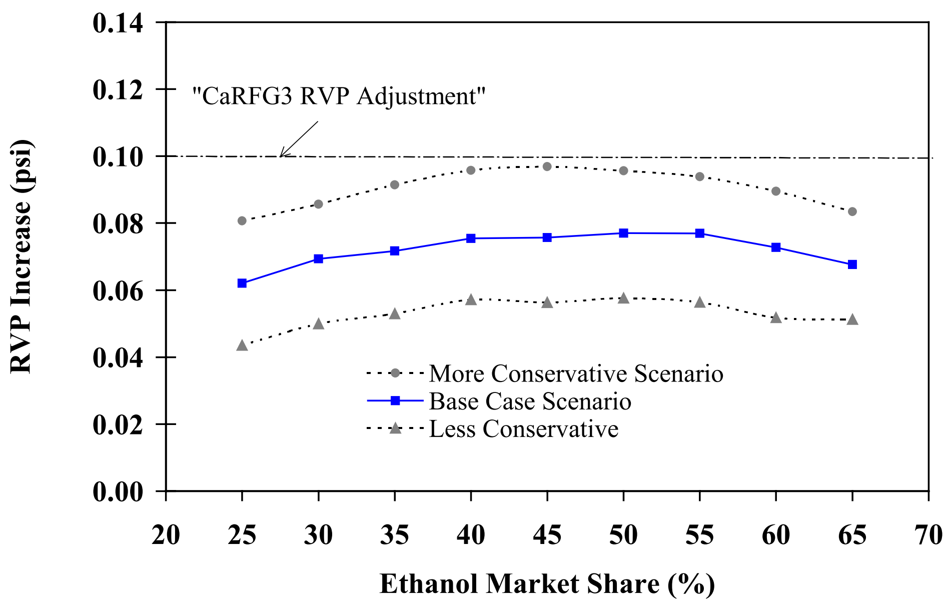
Similarly, Figure VII-2 represents the statewide commingling impacts of 7.7 volume percent ethanol blends. These blends produce somewhat higher commingling impacts than the 6 volume percent blends. However, all scenarios show that the impacts are less than 0.1 psi RVP.

Figure VII-1.*
Statewide Commingling Impacts Of 6 Vol% Ethanol Blend For Various Market Shares Using The 2001 ARB Field Study Input Parameters



*Each point represents a weighted average of regional RVP increase from 5000 consumers with 500 fuelings each.

Figure VII-2.*
Statewide Commingling Impacts Of 7.7 Vol% Ethanol Blend For Various Market Shares Using The 2001 ARB Field Study Input Parameters



*Each point represents a weighted average of regional RVP increase from 5000 consumers with 500 fuelings each.

D. Comparison of Field Observations to Simulation Results of Statewide Potential of Commingling Impacts

A unique feature of staff's commingling analysis is the ability to verify the commingling impacts that were observed in the field, which could not encompass a wide range of scenarios to the simulation results that would bridge these gaps. Conversely, using the simulation model staff was able to analyze possible commingling scenarios, which were unobserved in the field, and then use field observed commingling impacts to gauge the reasonableness of such analysis.

Based on this comparison, both the field observations and simulation modeling results are in good agreement to conclude that the statewide potential commingling impact of CaRFG3 is less than 0.1 psi RVP.

E. Other Factors that May Reduce the Commingling Impacts

It is likely that in certain areas, due to constraints in the fuel distribution systems, gasoline retailers would sell only one type of gasoline—either ethanol or non-ethanol blended gasoline—under different brand names. Although consumers described themselves as non-loyal with regard to gasoline brand, there should be limited commingling impacts in these "captive" areas.

VIII. ARB EVALUATION OF THE U.S. EPA COMMINGLING ANALYSIS

This chapter discusses staff's evaluation of the U.S. EPA's commingling analysis performed as part of their denial of California's request for a waiver of the federal oxygen mandate, including a comparison of the results of the U.S. EPA's analysis to that of the ARB.

C. U.S. EPA Findings on Commingling Impacts

Staff reviewed the U.S. EPA technical support document of potential commingling impacts in California, with the focus on the South Coast air basin, in response to Governor Davis' request for a waiver from the U.S. EPA from the federal oxygen requirement for federal reformulated gasoline areas. A copy of the U.S. EPA commingling analysis is provided in Appendix Q.

In its denial, the U.S. EPA stated that it believed there was great uncertainty regarding potential increases in VOC evaporative emissions from commingling in vehicle fuel tanks. U.S. EPA rejected ARB's conclusion that a 0.1 psi increase was most likely, and stated that the potential commingling impacts could range from greater than 0.1 up to 0.3 psi RVP. Using the upper end of this range, U.S. EPA concluded that the CaRFG3 regulations might not be sufficiently protective to prevent an overall increase in VOC emissions due to a large commingling effect.

D. Comparison of U.S. EPA and ARB Commingling Evaluations

Upon comparing the ARB and the U.S. EPA commingling analysis, staff observed several key differences in both methodology and use of data. These differences result in contrasting conclusions between the two analyses.

A distinct difference between the two analyses is in the way brand-loyal consumers, those who always purchase one brand of gasoline, are handled. Staff assumed no or negligible commingling effects from this group of consumers. In contrast, the U.S. EPA assumed the group would contribute to commingling.

For input data that are a function of future market provisions, staff relied on the most up-to-date and reliable sources. Except for ethanol purchase propensity, both analyses shared similar information. For example, staff adopted ethanol market penetration from a study under the U.S. EPA contract.

Both the ARB and the U.S. EPA had access to consumer fueling habits information that, while obtained from different sources, was quite similar. However, the handling of these data was very different between the ARB and the U.S. EPA. ARB staff took precautionary steps to verify that these data were representative to population, and compared them to reliable sources for accuracy. However, the U.S. EPA, apparently based on its own judgment of what might possibly occur, modified the data.

These modifications produced lower brand loyalty, lower percent of fillup, and higher initial fuel tank levels than used by the ARB staff. Each of these modifications leads to a higher commingling effect. ARB staff believes that the data collected in their field study conclusively demonstrates that the use of modified data by U.S. EPA does not represent fueling habits in California, and produced an over estimation of the commingling analysis for the state. As a result, the U.S. EPA's analysis is fundamentally flawed, and the conclusions are questionable[7].

Because of these factors, the U.S. EPA's analysis has resulted in a 0.1 to 0.3 psi range of RVP increases from commingling in the South Coast air basin, with 0.2 psi RVP chosen as the likely commingling impact (see Appendix Q). Given the field observations now available and an improved simulation model, staff believes that the U.S. EPA has grossly overestimated the potential commingling impacts by, at least, a factor of two.

[7] A similar conclusion was reached in an analysis produced by Systems Applications International ("Analysis of Commingling Due to Ethanol Blends"). In that analysis, the validity of the U.S. EPA analysis was questioned. This analysis, using the same model, but inputting the actual U.S. EPA data instead (i.e., unmodified), concluded that using the modified data would result in commingling impacts approximately twice as high as what it would have been using the actual data. A copy of this analysis is provided in Appendix P.

Appendix A:

Working Group

Air Resources Board
CaRFG3 Commingling Study Working Group

NAME	COMPANY
Bruce Heine	Williams
Cal Hodge	A 2nd Opinion, Inc.
Chuck A. Le Tavec	BP
Dennis Lamb	DWL Services
Duong Trinh	ARB
Ellen Shapiro	Auto Alliance
Erik White	ARB
Fred Schmidt	ARB
Gary Whitten	ICF Consulting
Gina Grey	WSPA
Jim Uihlein	BP
John Freel	Chevron
Loren Beard	Daimler Chrysler
Micheal Okafor	ARB
Mike Ingham	Chevron
Neil Koehler	Kinenergy
Nelson Chan	ARB
Raak Veblen	ARB
Ramesh Ganeriwal	CEC
Steve Smith	Tosco Corp.
Thomas Eveland	Atty
Tom Koehler	Celilo Group

Appendix B:

Working Group Comments on Preliminary Draft Assessment

Major Comments from the Working Group and Peer Reviewer

On the ARB's Commingling Study

Date	Organization	Comment	Staff Comment / Action
4/9/2002	A 2nd Opinion, Inc. (Cal Hodge)	- Nothing substantial	- None
4/24/2002	Valero (Simone Yuan-Newman)	- Fuel weathering effect on commingling - The adequacy of 5% tank 'heel' assumption	- Field data are inconclusive - Low initial tank level so weathering may not play a major role - A CRC study by SwRI (Aug. 2002) conforms that on average tank heel is about 5.2%
4/24/2002	Chevron (Lew Gibbs)	- Vehicle age distribution in 3 regions - Plot final RVP vs. dispensed RVP - Fuel weathering effect on commingling, especially in the Lake Tahoe area - Plot initial fuel tank level by region - The adequacy of 5% tank 'heel' assumption	- They are similar - Will be added in the final report - Same as above - Will be added in the final report - Same as above
5/7/2002	ExxonMobil (Craig P. Knoeller)	- CARB has overestimated the statewide commingling impacts by assuming that ethanol market penetration would be uniform throughout the state	- Will make adjustment to the analysis when information on fuel distribution constraints, under a waiver scenario, become more available
4/25/2002	UC, Berkeley (Rob Harley)	Fist Part: Field Study - Avoid using 'statewide' term in commingling analysis, but focus more on urban areas (SF, LA) - Plot initial fuel tank level by region - Use 'quantitative' analysis of commingling	 - Will add more discussion to clarify the meaning of 'statewide' commingling impact, and add urban area analysis (LA) to address the U.S. EPA denial - Same as above - Will include it as an addition or

Appendix C:

Fuel Sampling Protocol

CaRFG3 Commingling Study – Fuel Sampling Protocol

I. Introduction

In adopting the regulations for California Phase 3 reformulated gasoline (CaRFG3) by way of Resolution 99-39, the Board directed staff to further evaluate the expected real-world emissions impact of commingling CaRFG3 containing ethanol with CaRFG3 not containing ethanol in motor vehicle fuel tanks. Because as little as two volume percent ethanol in gasoline will raise its Reid vapor pressure (RVP) by about one pound per square inch (psi), commingling may result in increased evaporative motor vehicle emissions. The extent of commingling and its impact on evaporative emissions depends on several factors, including whether the federal reformulated gasoline year-round minimum oxygen requirement will continue to apply in California, refiner choices regarding the mix of oxygenated and non-oxygenated gasoline in a given area, and customer choices regarding brand and grade loyalty.

II. Field Study Overview

One aspect to be incorporated into the evaluation is a field study of the actual impacts of commingling fuels in vehicle fuel tanks. It is anticipated that this field study will be conducted at retail gasoline facilities in the Los Angeles, San Francisco, and Lake Tahoe areas of California. Sampling will be performed by teams consisting of three members each, with three teams deployed at three different stations on any given day. Teams will spend a minimum of one day at each station identified for participation in the study, two or three days in each geographical area. Although the actual time needed to draw a sample will be approximately 3 minutes, it is estimated that each team will be able to sample only about three vehicles per hour. Each team will likely collect about 35 fuel samples per day, resulting in between about 200 and 300 fuel samples generated per region. Vehicle fuel tank samples will be obtained from all customers willing to participate in the field study. The obtained fuel samples (including representative underground tank samples) will be analyzed for the fuel properties needed to evaluate the actual impact of commingling on vehicle evaporative emissions.

Fieldwork for this study will be conducted in two phases. The first phase, to be conducted in late June, was is to evaluate the efficacy of the draft fuel sampling protocol. Samples were will be taken from each of the service station's underground tanks upon arrival and departure at each test site. Vehicle fuel tank samples were will be obtained prior to refueling from all customers willing to participate. While the sampling and refueling operations were are taking place, the customers were will be interviewed to obtain information necessary for further evaluation. This information was will be recorded on field data sheets (sample attached) and will included a control number, sample identification numbers, date, time, year/make/model of vehicle, initial fuel gauge level, and amount (in gallons) and grade of product dispensed, and whether the customer had purchased a different brand of fuel within the last two refuelings. A second fuel sample was will be obtained from their vehicle tank after refueling. Experience gained in this first phase has been used to will determine if and how the draft sampling protocol could can be improved and finalized.

The second phase of fieldwork, to be conducted from early August July through late September August, will be the implementation of this the finalized sampling protocol. Samples will be taken from each of the service station's underground tanks upon arrival and departure at each test site. Vehicle fuel tank samples will be obtained prior to refueling from all customers willing to participate. While the sampling and refueling operations are taking place, the customer will be interviewed to obtain information necessary for further evaluation and to identify vehicles expected to have commingled fuel in their tank after refueling. This information will be recorded on field data sheets and will include a control number, sample identification numbers, date, time, year/make/model of vehicle, initial fuel gauge level, and amount (in gallons and dollars) and grade of product dispensed, and whether the customer had purchased a different brand of fuel within the last refueling. If an initial sample is successfully obtained from the vehicle fuel tank, a second fuel sample will be obtained from those vehicles expected to have commingled fuel in their tank after refueling. If an initial sample is not obtained from the vehicle fuel tank, a second fuel sample will not be taken. There will be two or three four different fuel samples that must be correctly identified and properly associated with each vehicle successfully tested.

Upon completion of the second phase of fieldwork, staff will evaluate the need to supplement the data with an additional focused study to better capture and characterize ethanol blends.

Samples from the vehicle tanks and the station's underground tanks will be obtained using American Society of Testing and Materials (ASTM) D 5842-95, "Standard Practice for Sampling and Handling of Fuels for Volatility Measurement". Vehicle tanks are not mentioned in the ASTM sampling method. However, we will be essentially following the tank tap portion of the sampling method using apparatus that the Air Resources Board (ARB) has successfully used for some time to obtain diesel samples from vehicle tanks to check for presence of red dye (see Section III.F for photos of apparatus). Special care will be taken to ensure that minimal evaporation takes place during the sampling process so that accurate RVP results will be obtained.

To minimize the amount of handling and the duration of sample storage prior to RVP analysis, samples will be analyzed for RVP in ARB's mobile laboratory that will be located in the general vicinity of the stations participating in the field study. This should enable the completion of most samples RVP analyses within 24 hours. All samples will be analyzed for RVP using ARB's "Test Method for the Determination of the Reid Vapor Pressure Equivalent Using an Automated Vapor Pressure Test Instrument" (see California Code of Regulation Title 13 §2297). All samples will subsequently be transported to ARB laboratory facilities in El Monte to be analyzed for the volumetric amount and type of oxygenate, as well as total oxygen content, by ASTM D 4815-94, "Standard Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C1 to C4 Alcohols in Gasoline by Gas Chromatography".

III. Sampling Protocol

A. Required Equipment

- 4-oz. clear glass sample bottles with lined plastic lids
- 1-liter aluminum sample bottles with foil lined plastic lids
- Polypropylene ¼ inch O.D. tubing
- ¼ inch x 25 ft. copper cooling coil
- 2 gal. round insulated water dispenser for cooling coil
- Ice & water
- Hand-operated vacuum pump
- Sample labels/Field data sheets
- Nozzle extension
- Sectioned boxes for 4-oz. bottle storage
- Ice chests for sample bottle conditioning and sample storage
- Cleanup and equipment maintenance supplies
- 16-20 oz. glass wash bottle
- Product rinse container (portable gas can)

B. Sampling Procedures

1) Vehicle Tank Sampling

A modified version of ASTM D 5842-95 will be used to obtain the vehicle fuel tank samples. While this method does not specifically address sampling from a vehicle fuel tank, the tank tap sampling procedure is being adapted to accommodate our specific needs. The sampling equipment is the same equipment that has been successfully used in ARB's ongoing program to sample vehicle fuel tanks to test for red dyed diesel fuel, with the addition of a copper cooling coil to condition the sample. Approximately 16 oz. of fuel will be removed from the vehicle tank for each 4-oz. sample obtained.

Prior to drawing each individual sample, the capped 4-oz. glass sample bottle will be chilled in an ice bath and preconditioned with the fuel to be sampled. To obtain the sample, a polypropylene sample line connected to the inlet of the cooling coil will be inserted into the vehicle's fuel fill pipe until it reaches product. The sampling apparatus will be flushed with product prior to obtaining the sample. A 16-20 oz. glass wash bottle will be connected to the hand-operated vacuum pump with the outlet end of the cooling coil inserted through the pump compression fitting into the bottom of the bottle. To adequately flush the sample line and cooling coil, approximately 10 oz. of fuel will be drawn through the apparatus into the wash bottle. The wash bottle will then be replaced with a clean, chilled, 4-oz. glass sample bottle and an additional 1 oz. of fuel will then be pumped into the sample bottle for preconditioning. The preconditioning fuel will then be discarded from the 4-oz. glass sample bottle and then poured into the wash container prior to obtaining the actual sample. All This wash material will be collected and disposed of according to the procedures described in Section E of this protocol. The sample will then be obtained by pumping additional fuel through the preconditioned apparatus. When the bottle is 70 to 85% full, it will be disconnected from the pump, capped, labeled, and stored in a cool location out of direct sunlight. All sample labels will include both the sample identification number and the unique control number associated with each participating sample vehicle. Care will be taken to minimize the amount of time the sample bottle is uncapped to avoid the potential for sample contamination from water condensation inside the bottle.

Samples containing visible water or other unusual contamination will not be considered valid for the purposes of this study and shall be disposed. Since the pump works on a vacuum principle, a negative pressure will be produced within the bottle. As a result, no product will touch the pump itself but instead will be drawn from the vehicle fuel tank through the sample line, through the cooling coil, and bottom-fill the 4-oz. glass sample bottle. If any product is accidentally drawn into the pump by overfilling or tipping the bottle, the pump will be disassembled, wiped down with a clean, dry shop towel, and air-dried prior to its next use.

2) <u>Service Station Nozzle Sampling</u>

ASTM D 5842-95 will be used to obtain samples from the service station's underground tanks for all grades dispensed at the station. Although this method allows the use of 4-oz. sample bottles, 1-liter sample bottles will be used due to their ease of use when obtaining a dispenser sample. The 1-liter sample bottles will be chilled in ice water prior to and while obtaining a sample. The bottle will be rinsed with product and drained before being bottom-filled with a nozzle extension attached to the service station dispenser nozzle. After the bottle is filled between 70 to 85% full, the bottle will be capped, labeled, and stored in a cool location out of direct sunlight. Care will be taken to minimize the amount of time the sample bottle is uncapped to avoid the potential for sample contamination from water condensation inside the bottle.

C. <u>Sample Handling Procedures</u>

It is essential that proper sample identification and field data sheet referencing is completed for each vehicle sample set. Preformatted Preprinted self-adhesive sample identification labels will be completed and attached to each sample bottle with each sample identification number also being recorded on the and corresponding field data sheet. Label ink and adhesive will be resistant to water and gasoline to assure identification integrity. Vapor pressures are extremely sensitive to evaporation loses and to slight changes in composition. Necessary precautions will be observed when handling samples to ensure the samples are representative of the product and satisfactory for RVP analysis.

D. Analytical Methods

Fuel samples obtained will be analyzed by the following methods:

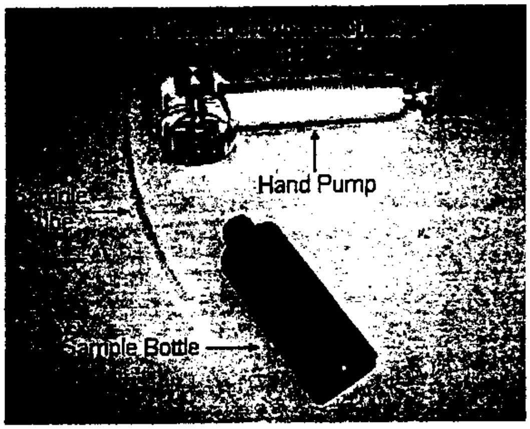
Fuel Quality	Analysis Method
RVP (psi)	CCR Title 13 §2297*
Oxygen Content (wt.%)	ASTM D 4815-94
MTBE (vol.%)	ASTM D 4815-94
Ethanol (vol.%)	ASTM D 4815-94

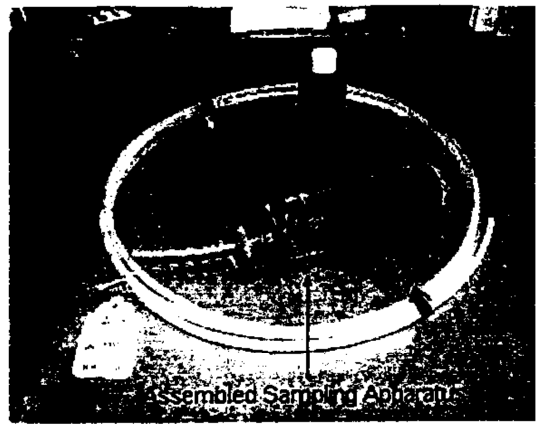
*Paragraph (d)(1.0) which specifies a Title 13 sampling method will be replaced with ASTM D 5842 sampling method which allows for the use of either 32-oz or 4-oz bottles.

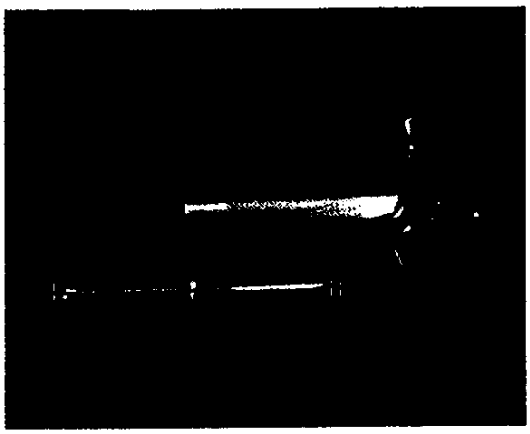
E. Disposal of Fuel Samples & Wash Materials

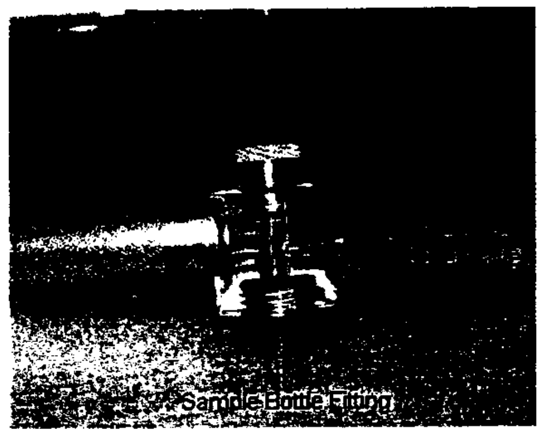
All waste gasoline generated from the sampling and analytical procedures will be collected in approved gasoline storage containers and disposed of at authorized gasoline recycling facilities.

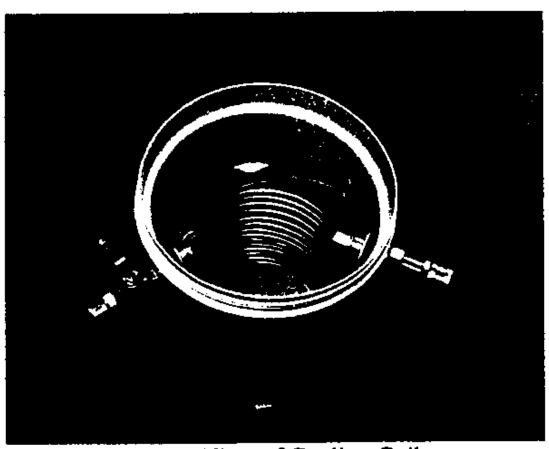
F. Tank Sampling Apparatus



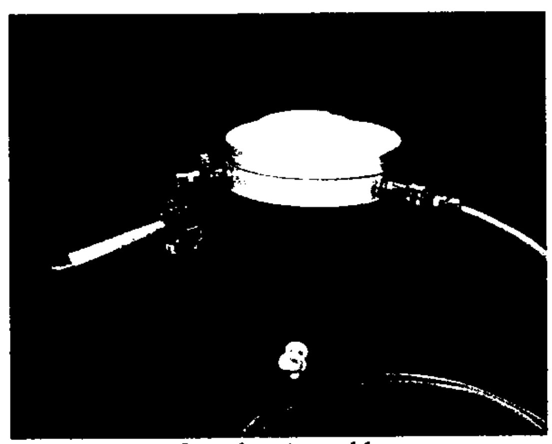








Interior View of Cooling Coil



Complete Assembly

FIELD DATA SHEET

CaRFG3 Commingling Study - Fuel Sampling Program

Date: ____________ Time: ________ Control No: ___________

Vehicle Information

Year: ______________________________ Make: ____________________________

Model: ______________________________ Fuel Gauge: E -------\-------|-------/------- F

1st Sample Obtained? Yes ___No ___ Sample No: ________________________

Refueling Information

Brand: ____________ Grade: ________ Amount: $________ & ________gal.

Was a different brand of gasoline used for the last refueling? Yes ___ No ___ ? ___

2nd Sample Obtained? Yes ___No ___ Sample No: ________________________

Sampling Team Member: ____

(Certification from a team member that is not the custodian that the test was performed)

Customer's Name: ____

Customer's Signature: ____

(Required for accounting purposes. Signature acknowledges receipt of $5 payment for services.)

Script

Action	Elapsed Time
Customer enters station, is greeted by team member, and offered incentive for voluntary participation in study.	00:00.30
Team proceeds to obtain initial sample and vehicle information.	00:03.30
Customer refuels vehicle.	00:06.30
Team proceeds to obtain second sample, completes field data sheet.	00:09.30
Customer's signature is obtained in exchange for payment of incentive.	00:10.00

Appendix D:

Field Study Data Set

CaRFG3 Commingling Study Fuel Sampling Data

control no.	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
	year	make	model	gage	1st	rvp^1	O_2^1	eth^1	$mtbe^1$	tam^1	site	grd	cost	gal	fill	dif	2nd	rvp^2	O_2^2	eth^2	$mtbe^2$	tam^2	rvp^{am}	O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}	rvp^{pm}	O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
LT1-01	2000	Saturn	SL2	E	1	6.87	2.06	0.00	11.31	0.00	no.1	R	16.80	10.53	1	1	1	6.96	2.21	5.06	1.79	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-02	1988	Subaru	DL	5/8	0						no.1	R	10.00	6.50	0	1	0						6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-03	1990	Toyota	PU	E	1	6.48	0.45	0.04	2.22	0.00	no.1	R	23.42	15.22	1	1	1	6.87	2.01	5.16	0.52	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-04	2001	Chev	Lumina	3/4	0						no.1	R			1	1	0						6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-05	1997	Honda	Civic CX	E	0						no.1	R	14.31	9.30	1	1	0						6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-06	1986	Toyota	4Runner	1/4	1	7.18	0.56	0.89	1.09	0.00	no.1	R	5.00	3.25	0	1	1	7.61	1.25	2.98	0.79	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-07	1995	Ford	Explorer	1/8	1	7.09	1.65	4.30	0.29	0.00	no.1	R	26.26	17.07	1	0	1	6.85	2.11	5.56	0.25	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-08	1977	Dodge	Sprtsmn Vn	7/8	1	7.56	0.76	1.91	0.26	0.00	no.1	R	19.31	12.55	1	0	1	8.21	0.95	2.42	0.27	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-09	1997	Jeep	Cherokee	E	1	6.61	0.08	0.00	0.29	0.00	no.1	R	10.00	6.50	0	1	1	6.98	1.85	4.86	0.24	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-10	1997	Chev	Silverado PU	5/8	1	6.35	1.93	0.00	10.54	0.00	no.1	R	18.60	12.09	1	1	1	6.87	2.15	3.07	5.54	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-11	1973	Chev	1T PU	1/8	1	6.25	1.67	4.39	0.24	0.00	no.1	R	21.20	13.78	1	1	1	6.56	1.88	4.94	0.25	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-12	1996	Chev	1500 PU	E	1	6.72	1.95	5.08	0.35	0.00	no.1	R	33.70	21.90	1	0	1	6.76	2.26	5.97	0.25	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-13	1999	Dodge	Caravan	1/8	1	6.28	1.99	0.00	10.92	0.00	no.1	R	20.00	13.00	1	1	1	6.83	2.19	4.34	3.14	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-14	1999	Toyota	Tacoma PU	E	1	6.87	1.48	3.85	0.25	0.00	no.1	R	10.00	6.50	0	1	1	6.73	2.23	5.90	0.25	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-15	1999	Mitsubishi	Mirage	1/2	1	6.63	1.68	0.38	7.82	0.70	no.1	P	7.77	4.47	1	1	1	6.90	1.82	2.29	4.93	0.46	6.70	2.09	5.50	0.25	0.00	6.66	2.08	5.48	0.25	0.00
LT1-16	1993	VW	Eurovan	1/4	1	6.28	1.02	0.00	5.57	0.00	no.1	R	22.77	14.80	1	1	1	6.98	1.89	4.18	1.84	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-17	1990	Lincoln	Towncar	1/4	1	6.83	1.97	5.30	0.00	0.00	no.1	R	17.06	11.08	1	1	1	6.74	2.17	5.74	0.23	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-18	1977	Jeep	CJS	E	0						no.1	R	26.08	16.95	1	1	0						6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-19	2001	Toyota	4Runner	E	1	6.24	1.74	0.00	9.53	0.00	no.1	R	26.01	16.90	1	1	0						6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-20	2000	Jeep	Cherokee	1/8	1	6.11	0.07	0.03	0.34	0.00	no.1	R	10.00	6.50	0	1	1	6.95	1.76	4.60	0.27	0.00	6.72	2.26	5.98	0.23	0.00	6.79	2.28	6.02	0.23	0.00
LT1-21	2000	Ford	Expedition	1/4	0						no.2	R	32.65	18.15	1	0	0						6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-22	1989	Jeep	Cherokee	E	1	6.93	0.05	0.00	0.29	0.00	no.2	R	4.77	2.65	0	1	1	6.53	0.06	0.00	0.31	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-23	1988	Ford	F250 PU	E	1	6.16	0.62	0.00	3.37	0.00	no.2	M	13.00	5.70	0	0	1	6.45	0.27	0.00	1.47	0.00	6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-24	1991	Mercedes	500SL	E	1	6.56	1.87	0.00	10.24	0.00	no.2	P	37.15	18.40	1	0	1	6.38	0.28	0.00	1.53	0.00	6.28	0.05	0.00	0.25	0.00	6.27	0.04	0.00	0.24	0.00
LT1-25	2000	GMC	Jimmy	1/4	1	6.74	0.14	0.00	0.57	0.00	no.2	R	6.01	3.34	0	?	1	6.76	0.09	0.00	0.48	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-26	1989	Chev	Blazer	1/4	1	6.4	0.05	0.00	0.28	0.00	no.2	M	20.03	10.38	0	0	1	6.48	0.05	0.00	0.29	0.00	6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-27	1993	Jeep	Cherokee	E	1	6.61	2.00	0.53	9.24	0.70	no.2	R	10.00	5.56	0	1	1	6.70	0.57	0.10	2.79	0.14	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-28	2002	Mercedes	C320 Sptwgn	1/4	0						no.2	M	22.07	11.44	1	1	0						6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-29	2000	Chrysler	Concorde	1/4	0						no.2	R	20.25	11.26	1	0	0						6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-30	1997	Ford	Contour	E	1	6.89	0.24	0.04	1.04	0.24	no.2	R	6.17	3.43	0	0	1	6.73	0.12	0.00	0.64	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-31	2001	Lexus	ES300	1/8	0						no.2	M	27.38	14.19	1	0	0						6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-32	1967	GMC	PU	1/8	1	6.43	0.33	0.00	1.82	0.00	no.2	R	17.65	9.81	0	0	1	6.56	0.14	0.00	0.79	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-33	1999	Ford	Ranger PU	E	0						no.2	R	25.38	14.11	1	1	0						6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-34	2000	VW	Passat	1/4	0						no.2	M	21.79	10.79	1	1	0						6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-35	1987	Saab		E	1	6.25	0.22	0.00	1.19	0.00	no.2	R	10.00	5.56	0	1	1	6.45	0.12	0.00	0.67	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-36	1985	Audi	4000S	E	1	6.41	1.27	0.00	5.62	1.51	no.2	R	10.00	5.56	0	1	1	6.56	0.37	0.00	1.69	0.35	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-37	1996	Dodge	Caravan	5/8	1	6.72	0.25	0.00	1.39	0.00	no.2	R	12.98	7.22	1	0	1	6.69	0.19	0.00	1.02	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00

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control no.	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
	year	make	model	gage	1st	rvp^1	O_2^1	eth^1	$mtbe^1$	tam^1	site	grd	cost	gal	fill	dif	2nd	rvp^2	O_2^2	eth^2	$mtbe^2$	tam^2	rvp^{am}	O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}	rvp^{pm}	O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
LT1-38	1998	GMC	Sonoma	E	1	6.86	0.09	0.00	0.29	0.00	no.2	M	29.00	15.03	1	1	1	6.63	0.05	0.00	0.30	0.00	6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-39	1998	Subaru	Outback	E	1	6.44	0.09	0.00	0.33	0.00	no.2	M	24.98	12.95	1	1	1	6.60	0.05	0.00	0.29	0.00	6.63	0.05	0.00	0.28	0.00	6.54	0.05	0.00	0.27	0.00
LT1-40	1993	Isuzu	Trooper	E	1	6.5	0.07	0.00	0.39	0.00	no.2	R	19.92	11.08	0	0	1	6.60	0.06	0.00	0.32	0.00	6.60	0.06	0.00	0.33	0.00	6.63	0.06	0.00	0.32	0.00
LT1-41	2001	Ford	150 PU	E	1	6.8	0.91	2.33	0.24	0.00	no.3	R	15.00	9.56	0	1	1	6.99	1.75	4.60	0.21	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-42	2001	Volvo	S80	1/4	0						no.3	R	18.49	11.78	1	1	0						6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-43	1971	Chev	Blazer	3/4	1	6.93	1.79	4.71	0.22	0.00	no.3	R	8.35	5.32	1	1	1	6.89	1.78	4.80	0.00	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-44	1992	Mercury	Sable	5/8	1	6.44	1.89	0.00	10.36	0.00	no.3	R	10.00	6.37	1	1	1	6.90	1.88	2.14	5.93	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-45	1999	Cadillac	DeVille	3/4	1	6.53	2.01	2.49	5.93	0.00	no.3	P	13.00	7.35	0	1	1	6.70	2.03	3.42	4.15	0.00	6.80	2.09	5.46	0.36	0.00	6.79	2.09	5.48	0.33	0.00
LT1-46	1999	Hyundai	Elantra	1/4	0						no.3	R	10.00	6.37	0	1	0						6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-47	2001	Chrysler	T&C Van	1/2	1	6.4	1.54	0.00	8.44	0.00	no.3	R	18.00	11.47	1	1	1	6.96	1.79	3.20	3.30	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-48	1993	Mercury	Grd Marquis	1/4	1	6.31	1.84	0.00	10.07	0.00	no.3	R	20.48	13.05	1	1	1	6.96	1.87	3.04	4.08	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-49	1987	Hyundai	Excel	1/4	1	6.79	2.07	5.46	0.24	0.00	no.3	R	10.00	5.99	0	0	1	6.87	2.06	5.42	0.28	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-50	1979	Toyota	PU	E	1	6.82	1.91	3.11	3.90	0.29	no.3	R	10.00	6.37	0	1	1	6.87	1.99	4.87	0.97	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-51	2001	Dodge	Caravan	3/8	1	6.22	1.90	0.05	9.98	0.38	no.3	R	21.01	13.39	1	1	1	6.90	1.94	3.83	2.85	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-52	1995	Toyota	Corolla	3/8	0						no.3	R	12.24	7.80	1	0	0						6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-53	1998	Chev	1500 PU	1/4	0						no.3	R	35.00	22.31	1	1	0						6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-54	2001	Ford	Taurus	1/4	0						no.3	R	16.50	10.52	1	1	0						6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-55	1985	Toyota	PU	1/8	1	7.54	0.61	1.42	0.29	0.00	no.3	R	10.00	6.37	0	0	1	7.22	1.25	3.26	0.24	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-56	1984	Nissan	Maxima	1/8	1	7.31	0.39	0.91	0.27	0.00	no.3	M	20.41	12.20	1	0	1	6.99	1.66	4.35	0.27	0.00	6.79	2.09	5.46	0.35	0.00	6.92	2.06	5.40	0.27	0.00
LT1-57	1993	Toyota	PU	1/8	1	6.76	0.39	0.20	1.73	0.00	no.3	R	10.00	6.37	0	1	1	7.09	1.55	3.85	0.66	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-58	1993	Lincoln	Towncar	3/8	1	6.72	1.96	4.68	1.23	0.00	no.3	R	17.03	10.86	1	0	1	6.86	1.97	5.00	0.65	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-59	1991	Mercury	Topaz	E	1	6.93	1.34	3.44	0.26	0.00	no.3	R	5.00	3.19	0	1	1	6.92	1.69	4.44	0.21	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT1-60	1993	Ford	Ranger PU	E	1	6.25	0.07	0.00	0.30	0.00	no.3	R	27.80	17.72	1	1	1	6.95	1.66	4.36	0.21	0.00	6.98	2.03	5.36	0.22	0.00	6.92	2.00	5.38	0.00	0.00
LT2-01	1998	Dodge	Durango	7/8	1	7.01	2.08	2.49	6.12	0.22	no.4	M	10.00	6.10	1	1	1	7.06	1.59	1.87	4.77	0.17	6.43	0.06	0.00	0.34	0.00	6.44	0.06	0.00	0.30	0.00
LT2-02	1992	Honda	Accord	1/4	0						no.4	R	8.00	5.20	0	1	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-03	1983	Dodge	Ram PU	E	1	6.51	1.06	0.00	5.80	0.00	no.4	R	6.01	3.91	0	0	1	6.57	0.56	0.00	3.09	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-04	1991	Nissan	Pathfinder	1/8	1	6.67	0.12	0.00	0.52	0.00	no.4	R	25.32	16.45	1	1	1	6.60	0.08	0.00	0.41	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-05	1995	Chevy	Astro	1/4	1	6.45	2.00	0.00	10.59	0.00	no.4	R	7.00	4.55	0	1	1	6.50	1.29	0.00	6.90	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-06	1998	Ford	Escort	1/4	0						no.4	R	10.00	6.50	0	1	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-07	1999	Chevy	Astro	1/4	1	6.47	2.04	0.00	10.29	1.00	no.4	R	22.23	14.45	1	1	1	6.56	0.82	0.00	4.14	0.41	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-08	1993	Chevy	1500 PU	1/8	1	8.01	0.07	0.00	0.36	0.00	no.4	R	31.33	20.34	1	0	1	6.87	0.07	0.00	0.37	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-09	1991	Dodge	Shadow	1/4	1	6.74	2.19	0.00	9.20	0.00	no.4	R	11.45	7.44	1	1	1	6.87	0.90	0.00	3.95	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-10	1978	Toyota	PU	1/2	1	6.64	2.01	0.00	11.04	0.00	no.4	R	12.50	8.12	1	1	1	6.69	1.05	0.00	5.77	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-11	2001	Toyota	Avalon	1/4	0						no.4	R	19.25	12.51	1	1	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-12	1994	Ford	Ranger	1/4	1	6.61	0.06	0.00	0.31	0.00	no.4	R	10.00	6.50	0	1	1	6.64	0.07	0.00	0.36	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-13	2000	Dodge	Intrepid	1/2	0						no.4	R	13.49	8.77	1	1	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-14	1997	Toyota	Tacoma	E	1	6.87	2.04	0.00	1.82	0.00	no.4	R	10.00	6.50	0	1	1	7.28	0.60	0.00	0.81	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00

CaRFG3 Commingling Study Fuel Sampling Data

control no.	vehicle information				got 1^{st}	rvp^1	wt%	volume %			refueling information						got 2^{nd}	rvp^2	wt%	volume %			rvp^{am}	wt%	volume %			rvp^{pm}	wt%	volume %		
	year	make	model	gage			O_2^1	eth^1	$mtbe^1$	tam^1	site	grd	cost	gal	fill	dif			O_2^2	eth^2	$mtbe^2$	tam^2		O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}		O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
LT2-15	1973	Chevy	1500 PU	1/4	1	6.48	0.07	0.00	0.40	0.00	no.4	R	15.51	10.08	1	0	1	6.50	0.07	0.00	0.38	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-16	1996	GMC	1500 PU	3/8	1	6.41	1.67	0.00	9.13	0.00	no.4	R	10.00	6.50	0	1	1	6.57	0.54	0.00	2.97	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-17	1985	Toyota	PU	E	1	6.92	1.93	0.00	0.24	0.00	no.4	R	10.00	6.50	0	1	1	7.28	0.79	0.00	0.33	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-18	1993	Oldsmobile	Royale	1/2	0						no.4	R	15.65	10.17	1	1	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-19	1991	Ford	Explorer	E	1	6.12	0.05	0.00	0.30	0.00	no.4	R	25.07	16.29	0	0	1	6.54	0.07	0.00	0.38	0.00	6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-20	1995	Saturn	SL2	1/2	0						no.4	R	8.15	5.30	1	0	0						6.58	0.07	0.00	0.40	0.00	6.63	0.08	0.00	0.42	0.00
LT2-21	2001	Mazda	Millenia	1/4	1	6.28	0.19	0.00	1.04	0.00	no.5	R	18.52	12.03	1	1	1	6.82	1.82	4.72	0.36	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-22	1996	Jeep	Cherokee	1/4	1	6.54	2.26	0.00	12.38	0.00	no.5	R	23.40	15.20	1	1	1	6.77	2.12	3.88	3.72	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-23	2001	Chevy	Tracker	E	0						no.5	R	18.29	11.88	1	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-24	1999	Nissan	Pathfinder	1/4	0						no.5	R	22.66	14.72	1	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-25	1985	Ford	Bronco II	1/4	0						no.5	R	5.00	3.25	0	0	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-26	1991	Chevy	2500 PU	E	1	6.25	2.03	0.00	11.15	0.00	no.5	R	33.00	21.44	1	1	1	6.82	2.10	4.74	1.86	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-27	1990	Chevy	1500 PU	1/4	1	7.01	1.87	3.12	3.90	0.00	no.5	R	24.00	15.59	1	1	1	6.82	2.03	4.71	1.54	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-28	1993	Jeep	Wrangler	1/4	1	6.83	0.43	0.93	0.44	0.00	no.5	R	15.00	9.75	0	1	1	6.74	1.66	4.32	0.30	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-29	1994	Chevy	1500 PU	1/4	1	6.89	0.90	2.11	0.64	0.00	no.5	R	4.99	3.43	0	1	1	6.89	1.37	3.45	0.49	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-30	1995	Subaru	Legacy	E	0						no.5	R	5.65	3.67	0	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-31	1995	Chevy	Astro	1/2	1	6.41	1.10	0.00	6.06	0.00	no.5	R	24.56	15.96	1	1	1	6.87	1.69	3.24	2.67	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-32	1984	Ford	F150	E	0						no.5	R	25.00	16.25	0	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-33	1995	Dodge	Neon	E	0						no.5	R	5.00	3.25	0	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-34	1989	Dodge	Ram PU	E	0						no.5	R	10.00	6.50	0	1	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-35	1988	Buick	LeSabre	E	0						no.5	R	10.00	6.50	0	0	0						6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-36	1985	Chevy	Blazer	E	1	7.01	1.10	2.83	0.25	0.00	no.5	P	9.00	5.18	0	1	1	6.77	1.85	4.87	0.24	0.00	6.70	2.09	6.02	0.23	0.00	6.73	2.30	6.09	0.23	0.00
LT2-37	1996	Ford	Explorer	E	1	5.87	1.92	0.00	10.21	0.34	no.5	R	28.39	18.45	1	1	1	6.69	2.07	4.66	1.85	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-38	1998	Pontiac	Transport	1/4	1	6.7	0.10	0.00	0.37	0.00	no.5	R	17.70	11.50	1	1	1	7.18	1.24	3.19	0.30	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-39	1992	Ford	Ranger	1/2	1	6.43	1.53	0.00	8.40	0.00	no.5	M	18.32	11.18	1	1	1	6.89	2.07	4.06	3.08	0.00	6.87	2.07	5.93	0.00	0.00	6.79	2.24	6.04	0.00	0.00
LT2-40	1973	VW	Beetle	E	1	7.02	1.45	3.77	0.28	0.00	no.5	R	10.00	6.50	0	1	1	6.87	1.95	5.11	0.26	0.00	6.72	2.26	5.50	0.25	0.00	6.80	2.08	5.49	0.26	0.00
LT2-41	2001	Ford	F150	1/8	0						no.6	R	22.70	14.75	1	1	0						6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-42	1984	Audi	4000S	E	1	5.8	0.04	0.00	0.21	0.00	no.6	R	23.58	15.32	1	1	1	7.01	1.69	4.55	0.03	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-43	1984	Ford	Econoline	3/4	1	7.18	0.08	0.00	0.29	0.00	no.6	R	13.00	8.45	1	1	1	7.56	0.90	2.28	0.27	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-44	1996	Isuzu	Rodeo	1/4	1	6.89	1.19	0.45	5.47	0.00	no.6	R	5.47	3.55	0	1	1	7.14	1.43	1.96	3.83	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-45	1996	Dodge	Stratus	E	0						no.6	R	17.84	11.59	1	1	0						6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-46	1985	Ford	F250	1/2	1	6.69	2.05	5.22	0.63	0.00	no.6	R	10.00	6.10	0	1	1	6.77	2.03	5.22	0.47	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-47	1992	Dodge	Ram PU	1/4	1	7.41	0.26	0.47	0.50	0.00	no.6	R	15.46	10.05	0	1	1	7.01	1.88	4.96	0.22	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-48	1986	Jeep	Cherokee	3/8	1	6.87	1.96	4.63	1.32	0.00	no.6	R	15.70	10.20	1	0	1	6.89	1.98	4.96	0.73	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-49	1991	Mercedes	300SL	1/2	1	7.02	1.35	0.79	5.79	0.00	no.6	M	20.44	12.47	1	1	1	7.02	1.81	3.57	2.64	0.00	6.89	1.98	5.34	0.00	0.00	6.89	1.99	5.35	0.00	0.00
LT2-50	1991	Toyota	Land Cruiser	1/8	1	6.14	1.86	0.00	10.21	0.00	no.6	R	24.46	15.90	1	1	1	6.99	2.00	4.82	1.17	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-51	2001	Ford	Mustang	1/4	1	6.43	1.21	0.00	6.63	0.00	no.6	R	12.58	8.17	1	1	1	7.12	1.66	2.78	3.43	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00

CaRFG3 Commingling Study Fuel Sampling Data

control	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
no.	year	make	model	gage	1^{st}	rvp^1	O_2^1	eth^1	$mtbe^1$	tam^1	site	grd	cost	gal	fill	dif	2^{nd}	rvp^2	O_2^2	eth^2	$mtbe^2$	tam^2	rvp^{am}	O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}	rvp^{pm}	O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
LT2-52	1984	Jeep	Wrangler	1/8	0						no.6	R	10.00	6.50	0	0	0						6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-53	1985	Chevy	El Camino	E	1	6.96	0.79	0.53	2.68	0.62	no.6	R	20.00	13.00	0	1	1	6.92	1.99	5.22	0.29	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-54	1986	Ford	F250	1/2	1	7.02	1.60	1.89	4.93	0.00	no.6	M	8.05		1	1	1	6.96	1.78	3.01	3.65	0.00	6.89	1.98	5.34	0.00	0.00	6.89	1.99	5.35	0.00	0.00
LT2-55	1986	Ford	F250	1/4	1	6.83	1.45	0.51	6.91	0.00	no.6	M	25.00	15.26	1	1	1	7.03	1.83	3.31	3.28	0.00	6.89	1.98	5.34	0.00	0.00	6.89	1.99	5.35	0.00	0.00
LT2-56	1994	Ford	Aerostar	E	1	6.57	2.06	4.89	1.32	0.00	no.6	M	16.78	10.24	1	0	1	6.80	2.04	5.27	0.46	0.00	6.89	1.98	5.34	0.00	0.00	6.89	1.99	5.35	0.00	0.00
LT2-57	1997	Jeep	Cherokee	E	1	6.54	0.60	0.00	3.31	0.00	no.6	R	25.61	16.64	1	1	1	7.05	1.63	3.81	1.17	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-58	1984	Mercury	Topaz	E	1	6.61	1.86	4.91	0.23	0.00	no.6	R	18.00	11.69	1	0	1	6.83	1.95	5.25	0.00	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-59	1988	Mitsubishi	Montero	1/2	1	6.98	0.33	0.00	1.66	0.00	no.6	R	11.66	7.58	1	1	1	7.46	0.99	2.16	1.05	0.00	6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT2-60	1996	Chevy	Lumina	1/2	0						no.6	R	10.00	6.50	0	1	0						6.95	2.00	5.38	0.00	0.00	6.87	1.97	5.30	0.00	0.00
LT3-01	1992	Cadillac	DeVille	3/8	0						no.7	R	17.89	9.95	0	0	0						6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-02	1996	Mercedes	C280	3/8	1	7.05	0.55	0.88	1.25	0.00	no.7	P	22.48	11.25	1	1	1	6.60	0.14	0.14	0.45	0.00	6.27	0.05	0.00	0.26	0.00	6.34	0.05	0.00	0.26	0.00
LT3-03	2001	Dodge	Neon	1/8	1	5.92	1.76	0.00	8.90	0.82	no.7	R	17.94	9.97	1	1	1	6.64	0.39	0.00	2.05	0.11	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-04	2000	Oldsmobile	Intrigue	3/8	1	6.34	1.87	0.00	9.27	1.12	no.7	R	15.38	8.55	1	0	1	6.50	1.12	0.00	5.52	0.68	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-05	1989	Izusu	4x4 PU	E	1	6.7	1.79	0.00	9.20	0.69	no.7	R	33.34	18.53	1	0	1	6.61	0.23	0.00	1.27	0.00	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-06	1996	Chevy	Silverado	E	1	6.25	1.75	0.00	9.61	0.00	no.7	M	38.95	20.51	1	0	1	6.44	0.30	0.00	1.62	0.00	6.60	0.06	0.00	0.32	0.00	6.58	0.06	0.00	0.34	0.00
LT3-07	1996	Mercury	Grd Marquis	1/4	0						no.7	R	20.00	11.12	0	0	0						6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-08	1988	Ford	Bronco	E	1	6.47	0.68	0.16	3.41	0.00	no.7	R	20.00	11.12	0	1	1	6.63	0.22	0.00	1.19	0.00	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-09	1990	BMW	325i	1/8	1	6.7	0.77	0.00	4.23	0.00	no.7	P	26.66	13.34	1	1	1	6.32	0.11	0.00	0.60	0.00	6.27	0.05	0.00	0.26	0.00	6.34	0.05	0.00	0.26	0.00
LT3-10	1998	Chevy	Tahoe	1/2	1	6.73	1.84	0.00	9.02	1.20	no.7	P	19.65	9.83	1	0	1	6.63	1.52	0.00	7.43	0.98	6.27	0.05	0.00	0.26	0.00	6.34	0.05	0.00	0.26	0.00
LT3-11	1991	Ford	Ranger	E	1	6.4	1.95	0.09	10.44	0.10	no.7	R	30.00	16.68	1	0	1	6.54	0.48	0.00	2.66	0.00	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-12	1998	Ford	Explorer	E	1	6.16	0.05	0.00	0.28	0.00	no.7	R	20.44	11.36	0	1	1	6.43	0.06	0.00	0.35	0.00	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-13	2001	Dodge	Intrepid	E	0						no.7	R	22.85	12.70	1	0	0						6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-14	1989	Mazda	MPV	E	0						no.7	R	20.00	11.12	0	?	0						6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-15	2001	Cadillac	SLS	3/8	1	6.16	0.08	0.00	0.27	0.00	no.7	M	23.67	12.47	1	0	1	6.34	0.19	0.00	0.34	0.78	6.60	0.06	0.00	0.32	0.00	6.58	0.06	0.00	0.34	0.00
LT3-16	1993	Infiniti	G20	1/2	1	6.6	2.02	0.00	10.62	0.51	no.7	R	11.29	6.27	1	0	1	6.61	1.19	0.00	6.30	0.26	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-17	1991	Honda	Civic	E	0						no.7	R	11.00	6.12	0	1	0						6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-18	1994	Ford	Ranger	1/4	1	6.32	0.06	0.00	0.30	0.00	no.7	R	19.00	10.56	1	0	1	6.54	0.06	0.00	0.35	0.00	6.66	0.08	0.00	0.42	0.00	6.66	0.07	0.00	0.37	0.00
LT3-19	1994	Ford	Aerostar	1/4	1	6.9	2.07	1.46	5.58	3.11	no.7	P	31.30	15.66	1	0	1	6.79	0.62	0.35	1.83	0.92	6.27	0.05	0.00	0.26	0.00	6.34	0.05	0.00	0.26	0.00
LT3-20	1992	Suburu	Loyale	E	0						no.7	P	10.00	5.00	0	0	0						6.27	0.05	0.00	0.26	0.00	6.34	0.05	0.00	0.26	0.00
LT3-21	1986	Ford	Bronco	1/4	1	6.69	1.36	0.00	7.46	0.00	no.8	R	20.00	12.51	0	1	1	6.69	0.66	0.00	3.62	0.00	6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-22	1998	Chevy	Camaro	E	1	6.34	1.80	4.45	0.62	0.23	no.8	P	24.75	13.76	1	1	1	6.90	0.28	0.56	0.31	0.10	6.40	0.04	0.00	0.24	0.00	6.44	0.05	0.00	0.25	0.00
LT3-23	1988	VW	Fox	E	0						no.8	R	10.00	6.25	0	1	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-24	1998	Toyota	4-Runner	E	0						no.8	R	20.00	12.51	0	1	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-25	2001	Volvo	V70	1/4	0						no.8	M	21.81	12.84	1	0	0						6.48	0.05	0.00	0.28	0.00	6.51	0.05	0.00	0.30	0.00
LT3-26	1986	Suburu	4WD Turbo	E	0						no.8	P	8.16	3.42	0	1	0						6.40	0.04	0.00	0.24	0.00	6.44	0.05	0.00	0.25	0.00
LT3-27	2000	GMC	Jimmy	E	0						no.8	R	20.31	12.70	0	1	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-28	1996	Chevy	Silverado	1/8	1	6.29	1.26	0.00	6.90	0.00	no.8	R	10.00	6.25	0	0	1	6.45	0.56	0.00	3.05	0.00	6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00

CaRFG3 Commingling Study Fuel Sampling Data

control	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
no.	year	make	model	gage	1st	rvp^1	O_2^1	eth^1	mtbe^1	tam^1	site	grd	cost	gal	fill	dif	2nd	rvp^2	O_2^2	eth^2	mtbe^2	tam^2	rvp^{am}	O_2^{am}	eth^{am}	mtbe^{am}	tam^{am}	rvp^{pm}	O_2^{pm}	eth^{pm}	mtbe^{pm}	tam^{pm}
LT3-29	1995	Toyota	Camry	E	0						no.8	R	23.40	14.63	1	0	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-30	1990	Mitsubishi	Montero	E	0						no.8	R	30.00	18.76	0	0	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-31	1993	Ford	Ranger	1/4	1	7.32	1.25	1.17	4.27	0.24	no.8	R	10.00	6.25	0	1	1	7.12	0.50	0.41	1.88	0.00	6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-32	1974	VW	Bug	3/4	1	6.51	0.05	0.00	0.26	0.00	no.8	M	4.05	2.39	0	0	1	6.51	0.05	0.00	0.27	0.00	6.48	0.05	0.00	0.28	0.00	6.51	0.05	0.00	0.30	0.00
LT3-33	1997	Pontiac	Grand Am	E	1	6.24	0.07	0.00	0.25	0.00	no.8	R	20.00	12.51	0	1	1	6.57	0.06	0.00	0.33	0.00	6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-34	2000	Chevy	Malibu	1/8	0						no.8	R	17.00	10.63	0	?	0						6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-35	1993	Nissan	4x4 PU	E	1	6.32	0.31	0.00	1.72	0.00	no.8	R	10.00	6.25	0	1	1	6.58	0.10	0.00	0.55	0.00	6.69	0.05	0.00	0.30	0.00	6.72	0.06	0.00	0.31	0.00
LT3-41	1993	Suburu	Impreza	E	0						no.9	R	8.81	5.01	0	1	0						6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-42	1995	Ford	Contour	1/4	1	6.32	0.25	0.00	1.35	0.00	no.9	R	20.00	11.36	0	1	1	6.50	0.07	0.00	0.36	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-43	2000	Calabria	Ski Boat	1/4	1	6.45	0.07	0.00	0.36	0.00	no.9	M	17.14	15.89	1	0	1	6.50	0.06	0.00	0.34	0.00	6.67	0.05	0.00	0.26	0.00	6.64	0.05	0.00	0.27	0.00
LT3-44	1990	Mercury	Sable	1/2	0						no.9	R	15.00	8.53	1	1	0						6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-45	1988	Toyota	4x4 PU	3/4	1	6.53	1.92	0.00	10.53	0.00	no.9	P	13.12	6.63	1	1	1	6.47	1.26	0.00	6.89	0.00	6.29	0.04	0.00	0.24	0.00	6.41	0.05	0.00	0.25	0.00
LT3-46	1999	Toyota	4x4 PU	1/4	1	7.22	0.50	1.22	0.27	0.00	no.9	P	10.00	5.05	0	0	1	7.08	0.47	1.14	0.27	0.00	6.29	0.04	0.00	0.24	0.00	6.41	0.05	0.00	0.25	0.00
LT3-47	2000	Toyota	Siena	1/4	0						no.9	M	27.65	14.72	1	1	0						6.67	0.05	0.00	0.26	0.00	6.64	0.05	0.00	0.27	0.00
LT3-48	1988	Jeep	Wagoneer	1/4	0						no.9	M	10.00	5.32	0	1	0						6.67	0.05	0.00	0.26	0.00	6.64	0.05	0.00	0.27	0.00
LT3-49	2000	Toyota	Rav 4	1/2	0						no.9	M	10.86	5.78	1	0	0						6.67	0.05	0.00	0.26	0.00	6.64	0.05	0.00	0.27	0.00
LT3-50	1986	Sazuki	Samarai	1/8	1	7.01	0.40	0.94	0.27	0.00	no.9	R	16.42	9.34	1	1	1	6.58	0.07	0.05	0.28	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-51	1998	BMW	328i	1/4	1	6.69	1.92	0.36	9.79	0.00	no.9	P	23.00	11.62	1	?	1	6.41	0.46	0.03	2.47	0.00	6.29	0.04	0.00	0.24	0.00	6.41	0.05	0.00	0.25	0.00
LT3-52	1993	Chevy	Silverado	1/4	1	6.72	1.08	0.00	5.93	0.00	no.9	R	29.00	16.48	1	1	1	6.61	0.42	0.00	2.33	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-53	1997	Nissan	Altima	1/2	0						no.9	R	11.00	6.25	0	0	0						6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-54	1977	Chevy	Suburban	1/4	1	6.44	2.01	5.14	0.53	0.00	no.9	P	55.60	28.10	1	1	1	6.93	0.90	2.24	0.37	0.00	6.29	0.04	0.00	0.24	0.00	6.41	0.05	0.00	0.25	0.00
LT3-55	1985	Jeep	Cherokee	1/4	1	6.51	0.79	0.00	4.34	0.00	no.9	R	5.00	2.84	0	0	1	6.53	0.62	0.00	3.42	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-56	1994	Chevy	S-10	1/4	1	6.03	0.06	0.00	0.33	0.00	no.9	R	22.11	12.57	1	0	1	6.41	0.05	0.00	0.29	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-57	1968	Ford	Mustang	1/4	1	6.22	1.98	0.00	10.85	0.00	no.9	R	19.91	11.32	0	1	1	6.51	0.41	0.00	2.23	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-58	1997	Toyota	Tacoma	1/2	1	6.77	0.73	0.09	3.58	0.10	no.9	R	5.00	2.89	0	1	1	6.72	0.46	0.04	2.43	0.00	6.66	0.05	0.00	0.29	0.00	6.58	0.06	0.00	0.31	0.00
LT3-59	1993	Toyota	4-Runner	3/4	1	6.4	0.05	0.00	0.28	0.00	no.9	M	8.51	4.53	1	0	1	6.37	0.05	0.00	0.28	0.00	6.67	0.05	0.00	0.26	0.00	6.64	0.05	0.00	0.27	0.00
LT3-60	2001	Kawasaki	ZRX1200R	E	1	6.79	1.53	0.58	6.03	1.31	no.9	P	7.02	3.55	1	0	1	6.56	0.54	0.15	2.24	0.47	6.29	0.04	0.00	0.24	0.00	6.41	0.05	0.00	0.25	0.00
BA1-01	1996	Chevy	Lumina	E	0						no.10	R	6.00	3.89	0	1	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-02	1994	Dodge	Dakota	1/4	0						no.10	R	19.29	12.53	1	0	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-03	2001	Toyota	Tacoma	E	1	6.61	2.11	0.00	11.55	0.00	no.10	R	23.18	15.06	1	0	1	7.12	1.54	0.00	8.42	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-04	1989	Mazda	MPV	1/4	0						no.10	R	18.74	12.18	1	0	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-05	2000	Dodge	Caravan	E	1	6.56	0.94	0.00	5.14	0.00	no.10	R	15.00	9.75	0	0	1	6.66	1.30	0.00	7.15	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-06	1990	Jeep	Wrangler	E	1	6.73	1.78	0.00	9.75	0.00	no.10	R	21.23	13.98	1	1	1	6.69	1.54	0.00	8.44	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-07	1994	Chevy	Silverado	E	1	6.73	1.30	0.00	7.11	0.00	no.10	R	10.00	6.50	0	1	1	7.27	1.39	0.00	7.62	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-08	1988	Dodge	Caravan	1/8	0						no.10	R	15.00	9.75	0	1	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-09	1987	Mazda	B2000	1/2	1	6.8	1.18	0.14	6.17	0.00	no.10	R	5.00	3.25	1	0	1	6.70	1.21	0.10	6.45	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-10	2001	Infiniti	i30	3/8	1	6.67	1.35	0.00	7.39	0.00	no.10	P	17.44	9.80	1	0	1	7.24	1.67	0.00	9.14	0.00	6.92	1.80	0.00	9.86	0.00	6.95	1.82	0.00	9.97	0.00

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control no.	vehicle information				got 1^{st}	rvp^{1}	wt%	volume %			refueling information						got 2^{nd}	rvp^{2}	wt%	volume %			rvp^{am}	wt%	volume %			rvp^{pm}	wt%	volume %		
	year	make	model	gage			O_2^{1}	eth^{1}	$mtbe^{1}$	tam^{1}	site	grd	cost	gal	fill	dif			O_2^{2}	eth^{2}	$mtbe^{2}$	tam^{2}		O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}		O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
BA1-11	1995	Chevy	Blazer	E	0						no.10	R	26.00	16.90	1	0	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-12	1978	Datsun	King Cab	1/4	1	6.61	1.31	0.00	7.20	0.00	no.10	R	8.00	5.20	0	0	1	6.63	1.39	0.00	7.62	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-13	1982	Toyota	PU	E	1	6.61	1.17	0.00	6.41	0.00	no.10	R	5.00	3.25	0	0	1	6.58	1.20	0.00	6.60	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-14	2001	Ford	Ranger	1/8	0						no.10	R	20.00	12.99	0	0	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-15	1999	GMC	Jimmy	E	0						no.10	R	18.00	11.70	0	1	0						6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-16	2000	VW	Jetta	E	1	6.38	0.19	0.00	1.02	0.00	no.10	R	7.00	4.55	0	1	1	6.58	1.03	0.00	5.66	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-17	1985	VW	Jetta	1/8	1	6.61	0.96	0.00	5.26	0.00	no.10	R	5.00	3.25	0	1	1	6.58	1.23	0.00	6.73	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-18	1995	Toyota	4-Runner	3/8	1	6.64	1.39	0.00	7.63	0.00	no.10	R	15.81	10.28	1	1	1	6.87	1.44	0.00	7.90	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-19	1979	Chevy	C-20	1/8	1	7.27	0.67	0.34	2.99	0.00	no.10	R	15.78	10.25	1	0	1	7.47	0.94	0.00	5.15	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-20	1983	Datsun	Sentra	1/4	1	7.21	1.04	0.00	5.71	0.00	no.10	R	12.29	7.99	1	1	1	7.09	1.26	0.00	6.93	0.00	6.82	1.40	0.00	7.68	0.00	6.69	1.41	0.00	7.76	0.00
BA1-21	1999	Cadillac	Eureka	1/4	0						no.11	R	27.00	16.89	1	1	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-22	1995	GMC		E	1	6.86	0.30	0.00	1.63	0.00	no.11	R	35.96	22.50	1	1	1	6.83	1.47	0.00	8.03	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-23	1985	Toyota	Cressida	3/8	1	6.79	1.41	0.00	7.71	0.00	no.11	R	10.00	6.26	0	1	1	6.79	1.49	0.00	8.17	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-24	1998	Dodge		E	0						no.11	R	48.36	30.24	1	1	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-25	1990	Mazda		E	0						no.11	R	20.80	13.00	1	1	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-26	2000	VW	Jetta VR6	E	1	6.63	1.60	0.00	8.78	0.00	no.11	R	22.84	14.28	1	0	1	6.74	1.59	0.00	8.70	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-27	2000	Porsche	Boxter	E	1	6.41	2.10	0.00	7.14	4.90	no.11	P	4.83	2.65	0	1	1	6.54	2.16	0.00	10.13	1.92	6.80	2.17	0.00	11.92	0.00	6.77	2.27	0.00	12.39	0.10
BA1-28	1993	Ford	Taurus	1/8	1	6.58	1.64	0.00	9.00	0.00	no.11	R	18.85	11.80	1	1	1	6.72	1.61	0.00	8.85	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-29	1997	Ford	Taurus	1/8	1	6.34	2.01	5.30	0.22	0.00	no.11	R	15.00	9.40	0	1	1	7.09	1.63	0.96	7.00	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-30	1993	Mazda	MPV	1/4	0						no.11	M	16.57	9.60	1	0	0						7.03	1.84	0.00	10.06	0.00	6.98	1.84	0.00	10.07	0.00
BA1-31	1997	Saab	900 SE	1/4	1	6.67	0.39	0.00	2.16	0.00	no.11	R	20.43	12.78	1	0	1	6.79	1.30	0.00	7.11	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-32	1990	Toyota	Cressida	5/8	1	6.66	2.12	0.00	11.34	0.34	no.11	P	9.73	5.35	1	0	1	6.63	2.12	0.00	11.35	0.27	6.80	2.17	0.00	11.92	0.00	6.77	2.27	0.00	12.39	0.10
BA1-33	1995	Chevy	Cavalier	1/2	1	6.82	1.82	0.00	9.97	0.00	no.11	R	10.45	6.54	1	1	1	6.95	1.61	0.00	8.80	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-34	1995	Ford	Contour	3/8	0						no.11	R	15.99	10.00	0	0	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-35	2001	Lincoln	Town Car	3/4	1	7.12	1.86	1.40	7.36	0.00	no.11	R	5.50	3.44	1	?	1	7.16	1.76	1.07	7.48	0.00	6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-36	1998	Chevy	Lumina	1/4	0						no.11	R	18.75	11.72	1	1	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-37	1996	Chevy	Tahoe	E	0						no.11	R	12.00	7.50	0	0	0						6.74	1.60	0.00	8.75	0.00	6.66	1.59	0.00	8.71	0.00
BA1-38	1972	Chevy	Nova	E	1	6.56	1.92	0.00	10.16	0.43	no.11	P	23.66	13.00	1	0	1	6.76	2.14	0.00	11.71	0.00	6.80	2.17	0.00	11.92	0.00	6.77	2.27	0.00	12.39	0.10
BA1-39	1999	Cadillac	D'Elegance	3/8	1	6.38	2.28	0.00	12.17	0.38	no.11	P	24.35	13.38	1	0	1	6.63	2.24	0.00	12.16	0.15	6.80	2.17	0.00	11.92	0.00	6.77	2.27	0.00	12.39	0.10
BA1-40	1979	Oldsmobile	Cutlass	E	1	6.69	2.16	0.00	11.82	0.00	no.11	P	20.00	11.00	0	0	1	6.41	2.08	0.00	11.41	0.00	6.80	2.17	0.00	11.92	0.00	6.77	2.27	0.00	12.39	0.10
BA2-01	2001	Chrysler	PT Cruiser	1/2	0						no.12	M	10.34	5.75	1	0	0						6.72	0.05	0.00	0.29	0.00	6.67	0.05	0.00	0.29	0.00
BA2-02	1969	Ford	Bronco	1/4	1	6.99	2.11	0.00	11.16	0.42	no.12	P	27.80	14.64	1	0	1	7.15	2.14	0.00	8.44	3.65	6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-03	2001	Jeep	Cherokee	1/4	0						no.12	R	22.63	13.32	1	0	0						6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-04	1984	Toyota	PU	E	1	6.7	2.11	0.00	7.33	4.71	no.12	P	23.29	12.26	1	0	1	7.03	2.15	0.00	8.17	4.02	6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-05	1991	Mazda	Miata	E	0						no.12	P	16.12	8.49	1	0	0						6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-06	1994	Toyota	Corolla	1/2	1	7.11	1.07	0.72	4.37	0.00	no.12	R	12.53	7.38	1	1	1	6.70	0.07	0.00	0.40	0.00	6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-07	1996	Mercedes	SL 320	1/4	1	7.09	1.49	0.00	8.17	0.00	no.12	P	28.72	15.12	1	0	1	6.76	1.51	0.00	8.23	0.00	6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02

CaRFG3 Commingling Study Fuel Sampling Data

control no.	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
	year	make	model	gage	1st	rvp[1]	O_2^1	eth[1]	mtbe[1]	tam[1]	site	grd	cost	gal	fill	dif	2nd	rvp[2]	O_2^2	eth[2]	mtbe[2]	tam[2]	rvp[am]	O_2^{am}	eth[am]	mtbe[am]	tam[am]	rvp[pm]	O_2^{pm}	eth[pm]	mtbe[pm]	tam[pm]
BA2-08	1986	Volvo	740 GLE	E	1	6.67	1.47	0.00	8.09	0.00	no.12	R	19.01	11.19	0	0	1	7.03	0.37	0.00	2.00	0.00	6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-09	1994	Buick	LaSabre	E	0						no.12	R	22.01	12.95	1	0	0						6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-10	1993	Dodge	Caravan	E	0						no.12	R	25.93	15.26	1	0	0						6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-11	1999	Mercedes	ML 430	1/2	1	6.77	2.09	0.00	11.18	0.31	no.12	P	20.86	10.99	1	0	0						6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-12	1991	Mercedes	500 SL	E	1	6.6	2.11	0.00	8.10	3.86	no.12	P	37.38	19.68	1	0	1	6.63	2.16	0.00	8.30	3.92	6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-13	1994	Ford	Bronco	E	1	7.67	0.98	0.00	3.47	2.13	no.12	R	10.00	5.89	0	0	1	6.58	0.41	0.00	1.46	0.89	6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-14	2000	VW	Jetta	1/4	1	6.74	2.14	0.00	11.60	0.10	no.12	M	19.47	10.82	1	1	1	6.57	0.58	0.00	3.18	0.00	6.72	0.05	0.00	0.29	0.00	6.67	0.05	0.00	0.29	0.00
BA2-15	1996	BMW	328i	E	1	7.11	0.05	0.00	0.29	0.00	no.12	M	24.44	13.58	1	0	1	6.56	0.05	0.00	0.28	0.00	6.72	0.05	0.00	0.29	0.00	6.67	0.05	0.00	0.29	0.00
BA2-16	1998	BMW	540i	E	0						no.12	M	33.75	18.76	1	0	0						6.72	0.05	0.00	0.29	0.00	6.67	0.05	0.00	0.29	0.00
BA2-17	1999	Dodge	Ram Van	1/4	0						no.12	R	44.80	26.37	1	1	0						6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-18	1985	BMW	325es	1/4	1	6.79	2.06	0.00	8.23	3.44	no.12	P	19.25	10.14	1	0	1	6.66	2.12	0.00	8.05	3.98	6.72	2.14	0.00	8.22	3.92	6.66	2.16	0.00	8.27	4.02
BA2-19	1988	Ford	Aerostar	E	0						no.12	R	10.00	5.89	0	1	0						6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-20	1969	Oldsmobile	Cutlass	E	1	6.64	1.81	0.00	9.94	0.00	no.12	R	28.76	16.93	1	1	1	6.63	0.24	0.00	1.32	0.00	6.83	0.04	0.00	0.22	0.00	6.76	0.04	0.00	0.22	0.00
BA2-21	1999	Chevy	Silverado	1/4	1	6.47	0.45	0.00	2.25	0.23	no.13	M	10.00	5.56	0	0	1	6.57	0.75	0.00	1.39	0.09	7.30	0.05	0.00	0.30	0.00	6.69	0.05	0.00	0.29	0.00
BA2-22	1967	Ford	Mustang	5/8	1	6.66	0.05	0.00	0.27	0.00	no.13	R	12.19	7.17	1	0	1	6.66	0.04	0.00	0.22	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-23	1999	Chevy	Tahoe	3/8	1	6.7	1.73	0.00	9.51	0.00	no.13	R	34.69	20.42	1	1	1	6.79	0.06	0.00	0.32	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-24	1997	Jeep	Cherokee	E	1	6.82	0.20	0.00	0.78	0.33	no.13	R	20.00	11.77	0	0	1	6.83	0.07	0.00	0.34	0.05	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-25	2001	Chevy	Silverado	1/8	1	6.76	1.69	0.07	9.09	0.00	no.13	R	32.65	19.22	1	0	1	6.82	0.45	0.00	2.45	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-26	1992	Mercedes	500 SEL	1/4	1	6.77	1.77	4.63	0.25	0.00	no.13	M	23.77	13.21	1	1	1	7.27	0.87	2.21	0.26	0.00	7.30	0.05	0.00	0.30	0.00	6.69	0.05	0.00	0.29	0.00
BA2-27	1993	BMW	325is	E	1	6.69	2.03	0.50	7.76	2.65	no.13	P	25.48	13.42	1	0	1	6.72	2.13	0.01	8.12	3.93	6.79	2.12	0.00	7.97	4.08	6.74	2.18	0.00	8.22	4.14
BA2-28	2000	Toyota	Tundra	1/2	1	6.69	0.14	0.00	0.79	0.00	no.13	R	23.56	13.87	1	0	1	6.67	0.09	0.00	0.48	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-29	1981	Volvo		1/2	1	6.8	1.95	0.04	7.84	3.06	no.13	P	16.75	8.82	1	0	1	6.87	2.04	0.00	7.95	3.62	6.79	2.12	0.00	7.97	4.08	6.74	2.18	0.00	8.22	4.14
BA2-30	1998	Audi	A4 2.8	1/2	1	6.76	1.69	0.00	6.84	2.68	no.13	P	19.07	10.04	1	0	1	6.72	2.17	0.00	8.16	4.15	6.79	2.12	0.00	7.97	4.08	6.74	2.18	0.00	8.22	4.14
BA2-31	1999	VW	Jetta	E	1	6.73	0.32	0.00	1.77	0.00	no.13	R	5.00	2.94	0	0	1	6.74	0.08	0.00	0.42	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-32	1988	Oldsmobile	Delta 88	E	1	6.89	1.68	2.02	5.09	0.00	no.13	M	15.00	8.34	0	1	1	7.09	0.38	0.37	1.35	0.00	7.30	0.05	0.00	0.30	0.00	6.69	0.05	0.00	0.29	0.00
BA2-33	1986	Nissan	PU	1/4	1	6.66	1.21	0.00	6.64	0.00	no.13	R	15.43	9.08	1	1	1	6.79	0.38	0.00	2.11	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-34	1993	Nissan	PU	1/8	1	6.63	0.05	0.00	0.30	0.00	no.13	R	20.43	12.02	1	0	1	6.79	0.00	0.00	0.00	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-35	1993	Jeep	Cherokee	1/4	1	6.58	0.35	0.00	1.92	0.00	no.13	M	31.50	17.51	1	0	1	6.66	0.14	0.00	0.75	0.00	7.30	0.05	0.00	0.30	0.00	6.69	0.05	0.00	0.29	0.00
BA2-36	1999	Chevy		1/4	1	6.73	0.22	0.00	1.21	0.00	no.13	M	26.29	14.61	1	1	1	6.74	0.08	0.00	0.44	0.00	7.30	0.05	0.00	0.30	0.00	6.69	0.05	0.00	0.29	0.00
BA2-37	1998	Toyota	Tacoma	E	1	6.73	2.09	0.00	7.74	4.12	no.13	P	29.53	15.55	1	0	1	6.74	2.12	0.00	7.98	4.05	6.79	2.12	0.00	7.97	4.08	6.74	2.18	0.00	8.22	4.14
BA2-38	1993	Volvo	850 GLT	E	1	6.63	0.06	0.00	0.34	0.00	no.13	R	20.00	11.77	0	0	1	6.77	0.05	0.00	0.25	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-39	1987	Toyota	PU	3/8	1	6.61	0.04	0.00	0.24	0.00	no.13	R	11.35	6.68	1	0	1	6.80	0.04	0.00	0.24	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA2-40	1993	Toyota	4-Runner	E	1	6.56	0.05	0.00	0.29	0.00	no.13	R	24.79	14.59	1	0	1	6.74	0.04	0.00	0.23	0.00	7.11	0.04	0.00	0.23	0.00	6.77	0.04	0.00	0.23	0.00
BA3-01	1987	Chevy	Cavalier	1/8	1	6.73	1.29	0.00	7.05	0.00	no.14	R	4.89	2.83	0	?	1	7.09	1.98	0.00	10.83	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-02	2001	Saturn	SL2	E	1	6.57	1.94	0.19	10.24	0.00	no.14	R	17.54	10.14	1	0	1	7.05	1.95	0.00	10.68	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-03	1990	Acura	Integra	E	0						no.14	R	18.67	10.80	1	0	0						6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-04	1996	Pontiac	Sunfire	1/4	1	7.02	1.97	1.07	8.63	0.00	no.14	R	10.00	5.78	0	1	1	7.27	1.92	0.41	9.66	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00

CaRFG3 Commingling Study Fuel Sampling Data

control no.	vehicle information				got	rvp^1	wt%	volume %			refueling information						got	rvp^2	wt%	volume %			rvp^{am}	wt%	volume %			rvp^{pm}	wt%	volume %		
	year	make	model	gage	1st		O_2^1	eth^1	mtbe^1	tam^1	site	grd	cost	gal	fill	dif	2nd		O_2^2	eth^2	mtbe^2	tam^2		O_2^{am}	eth^{am}	mtbe^{am}	tam^{am}		O_2^{pm}	eth^{pm}	mtbe^{pm}	tam^{pm}
BA3-05	1998	GMC	Jimmy	1/4	0						no.14	R	20.00	11.57	0	0	0						6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-06	1995	Rover	Land	E	0						no.14	R	10.00	5.78	0	1	0						6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-07	1985	Oldsmobile	Cutlass	1/4	1	6.57	2.00	0.00	10.96	0.00	no.14	R	5.00	2.89	0	0	1	6.98	1.99	0.00	10.89	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-08	1996	Plymouth	Voyager	1/8	1	7.43	1.72	0.62	8.16	0.00	no.14	R	23.00	13.30	1	1	1	6.89	1.89	0.17	10.03	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-09	1997	Dodge	Neon	E	0						no.14	R	3.00	1.74	0	1	0						6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-10	1997	Dodge	Caravan	1/8	1	6.53	1.91	0.38	9.71	0.00	no.14	R	31.97	18.49	1	0	1	6.79	1.91	0.00	10.48	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-11	2001	Chevy	S-10	E	0						no.14	R	10.00	5.78	0	?	0						6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-12	1983	Subaru	GL	1/4	1	6.8	1.97	3.44	3.80	0.00	no.14	M	17.02	9.30	1	1	1	7.19	1.84	1.19	7.70	0.00	6.87	1.83	0.00	10.04	0.00	6.87	1.86	0.00	10.21	0.00
BA3-13	1998	GMC	Safari	E	1	7.19	2.17	5.20	1.30	0.00	no.14	R	36.66	21.20	1	1	1	7.44	1.97	0.45	9.90	0.00	6.89	1.96	0.00	10.77	0.00	6.80	1.96	0.00	10.74	0.00
BA3-14	1995	Chevy	Suburban	1/8	1	6.89	1.91	0.00	10.26	0.22	no.14	P	20.09	10.41	0	1	1	6.76	1.80	0.00	9.74	0.15	6.93	1.76	0.00	9.57	0.11	6.93	1.81	0.00	9.79	0.13
BA3-15	1992	Mercury	Marquis	1/2	0						no.14	M	7.00	3.83	0	1	0						6.87	1.83	0.00	10.04	0.00	6.87	1.86	0.00	10.21	0.00
BA3-16	1998	Lincoln	Mark VIII	1/4	0						no.14	P	26.71	13.85	1	0	0						6.93	1.76	0.00	9.57	0.11	6.93	1.81	0.00	9.79	0.13
BA3-20	1992	Geo	Storm	E	0						no.15	R	13.45	7.82	1	0	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-21	1994	Chevy	Silverado	1/8	1	6.77	0.34	0.00	1.87	0.00	no.15	R	20.00	11.63	0	0	1	6.87	1.26	0.00	6.88	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-22	1995	Ford	Winstar	1/8	1	6.73	1.93	0.23	10.12	0.00	no.15	R	37.00	21.52	1	0	1	6.90	1.63	0.00	8.91	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-23	1991	Chevy	Caprice	1/2	0						no.15	R	26.25	15.27	1	0	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-24	2001	Toyota	Rav 4	E	0						no.15	R	21.04	12.24	1	0	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-25	1995	Ford	Escort	3/8	1	7.09	1.89	0.67	8.92	0.10	no.15	M	16.35	8.99	1	0	1	6.90	1.64	0.00	8.99	0.00	6.87	1.63	0.00	8.96	0.00	6.92	1.69	0.00	9.28	0.00
BA3-26	1996	Chevy	4x4	1/4	1	6.8	1.26	0.00	6.89	0.00	no.15	R	38.91	22.64	1	0	1	6.85	1.56	0.00	8.54	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-27	1990	BMW	K1 (bike)	E	1	6.5	2.13	0.00	10.96	0.81	no.15	P	6.99	3.65	1	1	1	6.86	1.81	0.00	9.68	0.24	7.01	1.75	0.00	9.59	0.00	6.98	1.74	0.00	9.54	0.00
BA3-28	1987	Mercury	Sable	3/8	0						no.15	R	5.00	2.91	0	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-29	1998	Chevy	Malibu	E	0						no.15	R	20.89	12.15	1	0	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-30	1989	Nissan	Axxess	E	0						no.15	R	15.00	8.73	0	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-31	1972	Chevy	Chevelle	1/4	1	6.79	1.58	0.39	7.86	0.00	no.15	R	5.40	3.14	0	0	1	6.87	1.58	0.14	8.40	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-32	2000	Ford	Escort	7/8	1	6.73	1.65	0.00	9.05	0.00	no.15	R	4.00	2.33	1	0	1	6.76	1.67	0.00	9.17	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-33	1989	Oldsmobile		1/4	0						no.15	R	9.00	5.24	0	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-34	1991	Chevy	Blazer	1/4	1	6.77	1.88	0.00	10.32	0.00	no.15	R	26.62	15.48	1	1	1	6.79	1.65	0.00	9.05	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-35	1995	Jeep	Cherokee	1/4	1	6.82	1.93	0.18	10.21	0.00	no.15	R	29.15	16.96	1	0	1	6.83	1.62	0.00	8.90	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-36	1992	Chevy	S-10	1/8	1	6.63	1.61	0.00	8.82	0.00	no.15	R	27.00	15.71	1	?	1	6.85	1.55	0.00	8.49	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-37	1996	Pontiac	Grand Am	1/2	0						no.15	R	11.26	6.55	1	0	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-38	1988	Ford	Taurus	E	0						no.15	R	6.00	3.49	0	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-39	2000	Jeep	Cherokee	1/2	1	6.74	0.58	0.00	3.18	0.00	no.15	R	13.60	7.91	1	1	1	6.82	0.95	0.00	5.23	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-40	1992	Ford	Escort	E	0						no.15	R	15.00	8.73	0	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-41	1998	Mercedes	ML 320	1/8	1	6.74	1.99	3.81	2.55	0.70	no.15	P	33.45	17.43	1	0	1	7.11	1.80	0.32	9.16	0.10	7.01	1.75	0.00	9.59	0.00	6.98	1.74	0.00	9.54	0.00
BA3-42	2000	Dodge	Dakota	1/2	1	6.67	1.72	0.00	9.43	0.00	no.15	R	16.01	9.31	1	1	1	6.74	1.67	0.00	9.17	0.00	7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00
BA3-43	1996	Saturn	SL2	E	0						no.15	M	19.31	10.62	0	0	0						6.87	1.63	0.00	8.96	0.00	6.92	1.69	0.00	9.28	0.00
BA3-44	1997	Ford	F-150	E	0						no.15	R	40.84	23.76	1	1	0						7.09	1.59	0.00	8.73	0.00	6.86	1.59	0.00	8.70	0.00

CaRFG3 Commingling Study Fuel Sampling Data

control no.	vehicle information				got 1^{st}	rvp^{1}	wt%	volume %			refueling information						got 2^{nd}	rvp^{2}	wt%	volume %			rvp^{am}	wt%	volume %			rvp^{pm}	wt%	volume %		
	year	make	model	gage			O_2^{1}	eth^{1}	mtbe^{1}	tam^{1}	site	grd	cost	gal	fill	dif			O_2^{2}	eth^{2}	mtbe^{2}	tam^{2}		O_2^{am}	eth^{am}	mtbe^{am}	tam^{am}		O_2^{pm}	eth^{pm}	mtbe^{pm}	tam^{pm}
LA1-01	2000	Honda	Accord	1/4	0						no.16	R	10.00	6.25	0	0	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-02	1985	Toyota	Van	E	0						no.16	P	15.00	8.38	0	0	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-03	1997	Isuzu	V8 EFI	3/4	1	6.57	1.93	0.00	10.03	0.61	no.16	R	14.91	9.33	1	?	1	6.74	2.13	0.00	11.60	0.12	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-04	1992	Mercury	Tracer	1/4	0						no.16	R	10.00	6.25	0	1	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-05	1997	Nissan	Maxima	E	0						no.16	M	6.00	3.55	0	0	0						6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-06	2001	Daewoo	Leganza	E	1	6.32	2.29	0.00	12.31	0.26	no.16	M	10.00	5.90	0	1	1	6.58	2.06	0.00	11.06	0.23	6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-07	1998	Chev	AstroVan	E	1	6.5	1.95	4.23	1.90	0.21	no.16	R	5.00	3.12	0	0	1	6.87	2.06	1.59	7.92	0.13	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-08	1988	Olds	Royale	E	0						no.16	R	10.00	6.25	0	1	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-09	1993	Toyota	PU	1/4	1	6.74	2.02	5.07	0.77	0.00	no.16	R	14.50	9.07	1	1	1	7.05	2.01	1.38	8.23	0.00	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-10	1985	Volvo	DL	1/8	1	6.6	2.02	0.00	10.58	0.55	no.16	M	19.30	11.43	1	0	1	6.64	1.98	0.00	10.58	0.32	6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-11	1984	Toyota	Camry	E	0						no.16	R	15.01	9.38	1	1	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-12	1998	Ford	Taurus	E	1	6.05	1.93	0.00	10.29	0.34	no.16	M	24.19	14.32	1	0	1	6.51	1.97	0.00	10.62	0.23	6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-13	1989	Toyota	Tercel	1/4	0						no.16	P	13.96	7.80	1	?	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-14	2001	Ford	Windstar	E	0						no.16	M	20.00	11.84	0	?	0						6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-15	1964	Chev	Fleetside	E	1	6.74	2.11	0.00	11.18	0.50	no.16	R	5.00	3.12	0	0	1	6.60	2.15	0.00	11.64	0.16	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-16	2000	Hyundai	Accent	E	0						no.16	R	5.00	3.12	0	1	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-17	1985	Chev	Caprice	1/8	1	6.67	2.12	0.00	11.47	0.16	no.16	M	20.00	11.84	0	0	1	6.64	1.98	0.00	10.66	0.19	6.70	1.97	0.00	10.56	0.26	6.66	1.97	0.00	10.60	0.23
LA1-18	1989	Mercedes	300E	E	1	6.54	1.98	0.00	10.55	0.34	no.16	P	10.00	5.59	0	1	1	6.66	1.98	0.00	10.57	0.33	6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-19	1978	Olds	Cutlass Spr	1/2	1	6.6	1.98	0.00	10.21	0.73	no.16	P	18.01	10.07	1	0	1	6.58	2.00	0.00	10.57	0.45	6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-20	1998	GMC	Safari	1/4	0						no.16	P	32.53	18.18	1	0	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-21	2001	Ford	Mustang	1/8	0						no.16	P	10.00	5.59	0	0	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-22	1993	Ford	F-350 PU	5/8	1	6.58	2.01	0.00	9.94	1.22	no.16	R	16.82	10.52	1	0	1	6.73	1.98	0.00	10.24	0.66	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-23	1998	VW	Beetle	E	1	6.34	1.97	0.00	10.32	0.51	no.16	P	22.33	12.50	1	0	1	6.69	1.98	0.00	10.47	0.43	6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-24	1997	Saturn	SC-2	1/2	1	6.61	2.07	0.00	10.50	0.92	no.16	R	7.12	4.45	1	0	1	6.58	2.11	0.00	11.09	0.53	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-25	1982	Chev	PU	1/8	1	6.76	2.07	0.00	10.09	1.41	no.16	R	22.07	13.80	1	0	1	6.64	2.14	0.00	11.54	0.24	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-26	1979	Ford	Econline	E	1	6.92	1.98	1.15	7.54	1.11	no.16	R	20.00	12.50	0	0	1	6.82	2.06	0.45	9.87	0.58	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-27	1963	Chev	Nova	E	0						no.16	P	3.56	1.99	0	0	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-28	1986	Cadillac	Deville	1/8	0						no.16	P	20.00	11.18	0	1	0						6.79	2.00	0.00	10.65	0.37	6.77	2.02	0.00	10.74	0.35
LA1-29	1985	Chev	S-10 Blazer	1/8	1	6.58	2.08	0.46	9.96	0.56	no.16	R	10.00	6.25	0	0	1	6.72	2.16	0.00	11.43	0.47	6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-30	2000	Jeep	Wrangler	1/8	0						no.16	R	20.00	12.50	0	0	0						6.77	2.10	0.00	11.08	0.48	6.74	2.04	0.00	11.06	0.12
LA1-31	1992	Nissan	240SX	E	0						no.17	R	22.20	13.88	1	1	0						6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-32	2001	Ford	F-250	E	0						no.17	R	54.50	34.06	1	0	0						6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-33	1987	Nissan	Maxima	E	0						no.17	M	6.00	3.51	0	1	0						6.45	2.42	0.00	13.27	0.00	6.92	2.33	0.00	12.78	0.00
LA1-34	1993	Plymouth	Voyager	1/4	0						no.17	R	7.00	4.37	0	1	0						6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-35	1982	Buick	Regal	E	1	6.41	2.32	0.00	12.73	0.00	no.17	P	20.00	11.12	0	1	1	7.16	2.46	0.00	13.48	0.00	7.03	2.38	0.00	13.03	0.00	6.99	2.43	0.00	13.33	0.00
LA1-36	1986	Ford	Mustang	1/8	1	6.74	2.26	0.00	12.40	0.00	no.17	R	5.00	3.13	0	?	1	6.72	2.37	0.00	13.00	0.00	6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-37	1999	Ford	Contour	1/4	0						no.17	R	16.00	10.00	0	0	0						6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00

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control	vehicle information				got		wt%	volume %			refueling information						got		wt%	volume %				wt%	volume %				wt%	volume %		
no.	year	make	model	gage	1^{st}	rvp^1	O_2^1	eth^1	$mtbe^1$	tam^1	site	grd	cost	gal	fill	dif	2^{nd}	rvp^2	O_2^2	eth^2	$mtbe^2$	tam^2	rvp^{am}	O_2^{am}	eth^{am}	$mtbe^{am}$	tam^{am}	rvp^{pm}	O_2^{pm}	eth^{pm}	$mtbe^{pm}$	tam^{pm}
LA1-38	1993	GMC	Sonoma	1/8	1	6.5	2.28	0.00	12.37	0.18	no.17	R	28.00	17.51	1	0	1	6.82	2.57	0.00	14.12	0.00	6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-39	2001	VW	Jetta 1.8T	E	1	6.76	2.05	4.03	3.05	0.00	no.17	R	6.25	3.90	0	0	1	7.14	2.28	1.21	10.02	0.00	6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA1-40	1989	Toyota	PU	1/4	0						no.17	R	12.70	7.94	1	0	0						6.85	2.33	0.00	12.76	0.00	6.92	2.44	0.00	13.40	0.00
LA2-01	1982	Toyota	PU	E	1	6.7	1.95	0.00	10.69	0.00	no.18	R	15.72	9.83	1	0	1	6.69	1.94	0.00	10.66	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-02	1976	Jaguar	XJS V12	E	1	5.76	1.90	0.00	10.42	0.00	no.18	M	10.00	5.96	0	1	1	6.82	1.95	0.00	10.71	0.00	6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-03	1987	Toyota	Camry	E	0						no.18	R	5.00	3.13	0	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-04	2000	Chevy	S-10 PU	E	0						no.18	M	25.00	14.89	1	0	0						6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-05	2001	VW	Passat	E	1	6.48	2.16	0.00	11.86	0.00	no.18	R	22.11	13.83	1	0	1	6.74	1.98	0.00	10.87	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-06	1995	Toyota	4-Runner	E	1	6.9	2.01	3.31	4.27	0.00	no.18	R	23.50	14.70	1	1	1	6.85	1.91	0.31	9.82	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-07	1986	Mercedes	300E	1/4	1	6.72	1.97	0.00	10.81	0.00	no.18	P	20.49	11.52	1	0	1	6.73	1.90	0.00	10.40	0.00	6.57	1.86	0.00	10.21	0.00	6.67	1.91	0.00	10.46	0.00
LA2-08	2000	Chevy	Cavalier	E	0						no.18	M	18.00	10.72	1	0	0						6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-09	1994	Ford	Escort	E	0						no.18	R	10.00	6.25	0	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-10	1996	BMW	740i	1/4	0						no.18	P	10.00	5.62	0	0	0						6.57	1.86	0.00	10.21	0.00	6.67	1.91	0.00	10.46	0.00
LA2-11	1997	Ford	PU	1/8	0						no.18	R	35.95	22.48	1	0	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-12	2000	Toyota	Tacoma	E	1	6.58	2.31	0.00	12.76	0.00	no.18	R	10.00	6.25	0	1	1	6.70	2.00	0.00	10.96	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-13	1992	Pontiac	Bonneville	1/4	0						no.18	R	12.00	7.50	0	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-14	1946	Buick	Sedan Super	1/2	1	6.66	1.93	0.00	10.40	0.22	no.18	M	14.00	8.34	1	0	1	6.66	1.89	0.00	10.37	0.00	6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-15	1986	Nissan	PU	1/8	0						no.18	R	5.00	3.13	0	0	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-16	1998	Toyota	4-Runner	E	0						no.18	R	20.26	12.67	1	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-17	2001	VW	Beetle	1/4	1	6.57	1.91	0.00	10.49	0.00	no.18	R	15.91	9.95	1	0	1	6.61	1.90	0.00	10.41	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-18	2001	Toyota	Tacoma	E	0						no.18	R	25.00	15.63	1	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-19	1086	Chevy	Nova	E	0						no.18	R	5.00	3.13	0	0	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-20	1995	Oldsmobile	Cutless	E	0						no.18	P	19.07	10.72	1	1	0						6.57	1.86	0.00	10.21	0.00	6.67	1.91	0.00	10.46	0.00
LA2-21	1988	Ford	Aerostar	1/2	1	6.61	2.20	0.00	12.07	0.00	no.18	R	10.00	6.25	0	1	1	6.57	1.99	0.00	10.89	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-22	1998	Toyota	Tacoma	3/8	1	6.7	2.29	0.00	12.57	0.00	no.18	R	10.00	6.25	0	0	1	6.66	2.08	0.00	11.42	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-23	1993	Jeep	Cherokee	E	1	6.32	2.26	0.00	12.30	0.10	no.18	R	10.00	6.25	0	1	1	6.54	1.90	0.00	10.43	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-24	1996	Toyota	T100	E	1	6.6	1.99	0.00	10.93	0.00	no.18	R	28.31	17.70	1	0	1	6.60	1.89	0.00	10.34	0.00	6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-25	2000	Chevy	S-10 PU	E	0						no.18	R	13.50	8.44	1	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-26	1994	Pontiac	Grand Prix	1/8	0						no.18	M	15.00	8.93	0	0	0						6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-27	1997	Ford	F150	1/8	0						no.18	R	15.00	9.38	0	1	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-28	1996	Toyota	4-Runner	E	0						no.18	M	20.00	11.91	0	0	0						6.70	1.93	0.00	10.59	0.00	6.77	1.93	0.00	10.59	0.00
LA2-29	1978	Ford	F150	E	0						no.18	P	29.67	16.68	1	0	0						6.57	1.86	0.00	10.21	0.00	6.67	1.91	0.00	10.46	0.00
LA2-30	1997	Saturn	SL	E	0						no.18	R	14.61	9.13	1	0	0						6.61	1.92	0.00	10.55	0.00	6.67	1.85	0.00	10.16	0.00
LA2-31	1974	Ford	F600	1/4	1	7.01	2.05	3.89	3.30	0.00	no.19	R	20.00	12.83	0	1	1	7.03	2.17	1.93	7.99	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-32	1992	Mazda	MPV	E	0						no.19	P	20.50	11.65	1	0	0						6.45	2.61	0.00	14.32	0.00	6.43	2.35	0.00	12.86	0.00
LA2-33	1982	Ford	F150	1/4	1	6.66	2.25	0.00	12.34	0.00	no.19	R	14.00	8.98	1	0	1	6.69	2.29	0.00	12.56	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-34	1999	Chevy	2500 Van	3/8	1	6.83	2.38	0.00	13.08	0.00	no.19	R	30.00	19.24	0	?	1	6.63	2.38	0.00	13.05	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00

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control no.	vehicle information				got 1^{st}	rvp^1	wt% O_2^1	volume %			refueling information						got 2^{nd}	rvp^2	wt% O_2^2	volume %			rvp^{am}	wt% O_2^{am}	volume %			rvp^{pm}	wt% O_2^{pm}	volume %		
	year	make	model	gage				eth^1	mtbe^1	tam^1	site	grd	cost	gal	fill	dif				eth^2	mtbe^2	tam^2			eth^{am}	mtbe^{am}	tam^{am}			eth^{pm}	mtbe^{pm}	tam^{pm}
LA2-35	1981	Honda	Civic	E	0						no.19	R	8.00	5.13	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-36	1990	Ford	Aerostar	1/4	1	7.09	2.27	0.00	12.43	0.00	no.19	R	9.00	5.77	0	0	1	6.66	2.36	0.00	12.94	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-37	1996	Chevy	Astro	1/8	1	6.28	2.37	0.00	13.00	0.00	no.19	M	15.00	9.04	0	0	1	6.43	2.37	0.00	13.01	0.00	6.50	2.44	0.00	13.38	0.00	6.57	2.40	0.00	13.18	0.00
LA2-38	1967	Volvo	P1800	E	0						no.19	R	6.00	3.85	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-39	1992	Nissan	240SX	1/8	1	6.48	2.25	0.00	12.35	0.00	no.19	R	10.00	6.41	0	0	1	7.28	2.33	0.00	12.80	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-40	1974	Chevy	Corvette	1/4	1	6.27	2.40	0.00	13.15	0.00	no.19	P	20.00	11.37	0	0	1	6.37	2.45	0.00	13.41	0.00	6.45	2.61	0.00	14.32	0.00	6.43	2.35	0.00	12.86	0.00
LA2-41	1995	Chevy	Astro	1/8	1	6.58	2.44	0.00	13.40	0.00	no.19	R	20.00	12.83	0	1	1	6.79	2.38	0.00	13.03	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-42	1988	Ford	Ranger	E	1	6.43	1.98	0.00	9.70	1.31	no.19	R	23.21	14.89	1	0	1	7.28	2.32	0.00	12.44	0.28	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-43	1989	Mazda	B2600i	E	1	7.01	1.97	0.00	10.79	0.00	no.19	R	23.15	14.85	1	0	1	7.19	2.31	0.00	12.65	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-44	1988	Lincoln	Mark VII	1/4	1	6.95	2.36	0.00	12.94	0.00	no.19	R	10.00	6.41	0	1	1	6.60	2.36	0.00	12.94	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-45	1995	Ford	Bronco	3/8	1	6.64	2.25	0.00	12.34	0.00	no.19	R	30.00	19.24	0	0	1	7.02	2.34	0.00	12.81	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-46	1992	Chevy	Corsica	E	0						no.19	R	8.00	5.13	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-47	1989	Buick	Park Ave	7/8	1	6.67	2.32	0.00	12.74	0.00	no.19	R	1.00	0.64	0	?	1	6.63	2.33	0.00	12.80	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-48	1987	Ford	F150	E	1	6.6	2.29	0.00	12.57	0.00	no.19	R	23.99	15.39	1	0	1	6.67	2.36	0.00	12.96	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-49	1979	Chevy	Nova	E	1	6.8	2.34	0.00	12.86	0.00	no.19	R	5.00	3.21	0	1	1	6.79	2.44	0.00	13.36	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-50	1986	Toyota	4-Runner	E	1	7.12	2.28	0.00	12.52	0.00	no.19	R	20.30	13.02	1	0	1	7.27	2.36	0.00	12.92	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-51	1990	Chevy	Astro	E	1	7.22	2.15	0.53	10.69	0.00	no.19	R	10.00	6.41	0	0	1	7.24	2.27	0.31	11.79	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-52	1986	Ford	Aerostar	1/8	1	6.66	2.34	0.00	12.84	0.00	no.19	R	18.25	11.71	1	0	1	6.70	2.36	0.00	12.92	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-53	1993	Chevy	S-10 PU	1/2	1	6.93	2.30	0.67	11.14	0.15	no.19	R	10.00	5.69	0	1	1	6.58	2.34	0.34	12.04	0.09	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-54	1999	Nissan	Quest	E	0						no.19	R	5.00	3.21	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-55	1995	Ford	F250	1/4	0						no.19	R	20.00	12.83	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-56	1993	Ford	Escort	1/4	0						no.19	R	5.00	3.21	0	?	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-57	1995	Ford	Crn Victoria	1/2	1	7.06	2.27	0.00	12.46	0.00	no.19	R	15.00	9.62	0	1	1	6.58	2.40	0.00	13.18	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-58	1994	Ford	Ranger	5/8	1	6.58	2.44	0.00	13.36	0.00	no.19	R	7.55	4.84	1	0	1	6.73	2.37	0.00	13.02	0.00	6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-59	1988	Mitsubishi	Van	E	0						no.19	R	12.00	7.70	0	0	0						6.79	2.36	0.00	12.96	0.00	6.79	2.44	0.00	13.39	0.00
LA2-60	1984	Chevy	Caprice	E	1	6.6	2.41	0.00	13.19	0.00	no.19	M	20.00	12.05	0	0	1	6.69	2.42	0.00	13.26	0.00	6.50	2.44	0.00	13.38	0.00	6.57	2.40	0.00	13.18	0.00

Appendix E:

"A Vehicle Fuel Tank Flush Effectiveness Evaluation Program," Lee J. Grant, Southwest Research Institute, SwRI Project 08-31088, August 20, 2001.

SwRI Project 08-31088
August 20, 2001

A report on

A VEHICLE FUEL TANK FLUSH EFFECTIVENESS EVALUATION PROGRAM

In response to:
CRC Project No. CM-138-01/1

Prepared for:

Coordinating Research Council, Inc.
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TABLE OF CONTENTS

I. INTRODUCTION

Southwest Research Institute (SwRI) conducted this vehicle test program at the request of the Coordinating Research Council (CRC) to investigate the effectiveness of vehicle fuel system flush procedures. Phase I of the program consisted of three flush procedures (A, B, and C) on five different vehicles as specified by CRC. A fuel with ethanol content was installed into the vehicle fuel tank, an initial sample was taken, the fuel flush technique was conducted, a four gallon fill was added to the tank to begin a driveability test, and a final fuel sample was taken. The ethanol content in the initial and final fuel samples was measured using the ASTM D 5599 method. After review of the results in Phase I, CRC directed SwRI to conduct Phase II consisting of four flush procedures on two of the original five vehicles.

II. BACKGROUND

To enhance air quality, oxygenated fuels have been introduced into "nonattainment" areas of the U.S. to reduce vehicle emissions. Since ethanol is a common oxygenate, work has been performed by CRC to determine what effect ethanol fuel blends have on vehicle driveability. During these evaluation programs, it has been necessary to change fuels in vehicle fuel systems from oxygenated to hydrocarbon-only fuels. It has become a concern within CRC of possible carryover of ethanol from potentially inadequate flushing techniques. Phase I of this program provides CRC with information to define ethanol carryover for flushing procedures designated A, B, and C. Phase II provides carryover data on modified C, E, modified E, and F procedures which were developed to enhance the fuel flush effectiveness.

III. TEST PROCEDURES

A. TEST FUELS

Two fuels were used for this program. Haltermann EEE emissions test fuel was designated as Fuel H. Fuel H and denatured ethanol were blended to yield Fuel E with approximately 10% ethanol by volume. Ten new 55-gallon drums were purchased for the program. Five drums were labeled and filled with Fuel E and five more with Fuel H. Should the CRC decide to conduct further tests, this was sufficient volume of Fuel E to run a duplicate set of flush procedures A, B, and C on each vehicle.

Two new hand fuel pumps were purchased and labeled for each fuel type for this program. One drum each of Fuel E and Fuel H was used to flush the hand pumps, the funnels, and the calibrated cans. These flush drums were removed from the area and not used for testing. The hand pumps were then installed in the appropriate test fuel drum and a sample of Fuel E and Fuel H were drawn and delivered to the SwRI Petroleum Research Department for analysis. Refer to the photograph in Appendix A of a 55-gallon drum of Fuel E, which was ready for test. The following is a table summarizing the analytical results on the test fuels.

Table 1 – Test Fuel Analyses

Test Method	Fuel E	Fuel H
ASTM D 4815 Oxygenate Content Ethanol (wt% / vol%)	10.18 / 9.62	Not Run
ASTM D 5599 Oxygenate Content Ethanol (wt% / vol%)	10.02 / 9.47	<0.01 / <0.01
ASTM D 4052 Specific Gravity	0.7493	0.7455

B. FUEL HANDLING CONTAINERS

For accuracy, the amount of fuel added to a vehicle was measured by calibrated fuel cans which have graduated necks to increase the accuracy of the volume measurement of the fuel. Refer to the photograph in Appendix A of two calibrated cans. One set of dedicated calibrated fuel cans, a one and a two gallon can, was labeled and used for adding Fuel E and another set of dedicated calibrated fuel cans was used for adding Fuel H. The cans were thoroughly flushed with the appropriate fuel prior to starting the test program. A glass 2000 ml graduated cylinder was used to measure the fuel removed during vehicle preparation for enhanced accuracy. Sterile 8 oz. glass sample containers were procured and pre-labeled. A line was scribed at the 75 ml level for filling the sample container to the proper sample level. Since these sample containers were sterile chemical laboratory quality, they were used in the as-received condition. New funnels were purchased for the program and labeled Fuel E and Fuel H. In Phase II, the glass containers were filled with the final sample fuel in case additional chemistry analytical information was requested.

C. VEHICLES

The test program was conducted on the five vehicles as specified by CRC and listed in Table 2. Only the Toyota Corolla and the Mitsubishi were retained and tested in Phase II. The vehicles for this program were manufactured in the 2000 model year except for the Chevrolet Cavalier which was a 1999 model. Vehicle tanks and lines were visually inspected for any damage during the vehicle preparation phase. No problems were found.

Table 2 – Test Vehicles

					Phase I – Flush Procedures		
	Model Year	Eng. Displ.	Tank Capac.*	Vehicle Identification Number	A	B	C
Ford Windstar	2000	3.8L	26.0 gal.	2FMZA5142YBB89386	1	1	1
Mitsubishi Galant	2000	2.4L	16.3 gal.	4A3AA46G41E141829	1	1	1
Chevrolet Cavalier	1999	2.2L	15.2 gal.	3G1JC5249X5815172	1	1	1
Nissan Maxima	2000	3.0L	18.5 gal.	JN1CA31DXYT543110	1	1	1
Toyota Corolla	2000	1.8L	13.2 gal.	1NXBR12E3YZ405041	2	1	1

* The fuel tank capacity was determined from an information search. It was not measured in this program.

D. VEHICLE PREPARATION

The test vehicles were parked in approximately the same position when Fuels E and H were drained to minimize tank angle variations that would change the amount of fuel that could be pumped from the tank. The test area was located outside, under an awning adjacent to the SwRI Automotive Fleet Laboratory. A ground rod was installed and tested for conductivity prior to the start of the program. The test fuel drums and the vehicles were properly grounded for safety during the program.

The Vehicle Preparation procedure was performed on each vehicle. The procedure is included in Appendix B. During the vehicle preparation the existing fuel was removed from the vehicle and the system residual fuel was measured. The *system residual fuel* is defined as the amount of fuel that remains in the vehicle fuel system after a fuel drain procedure is conducted using the vehicle fuel pump.

Each vehicle's electrical system was studied and relay contact points, which would activate the vehicle fuel pump while the engine was not running, were located,. A jumper circuit was used to activate the vehicle fuel pump for draining the fuel. The Ford Windstar had a Schrader valve in the fuel feed line and it was used for the fuel drain procedure on that vehicle. For testing the Toyota Corolla, the Mitsubishi Galant, and the Chevrolet Cavalier, the connector between the fuel line and the rail was disconnected to make fuel drains and to procure fuel samples. The connection of the fuel rail to the fuel feed line was not readily accessible on the Nissan Maxima. Thus, a Schrader valve was installed in the fuel return line and an on-off valve was installed in the fuel return line downstream of the Schrader valve.

The *fuel drain procedure* is defined as the removal of the fuel from the vehicle fuel system using the vehicle fuel pump. The drain procedure used on this program should be typical of the methods used in CRC field studies. To enhance the repeatability of the drain procedure for this program, the operators were instructed to continue running the fuel pump until the they were sure the fuel pump would not pick up any more fuel in the tank.

In the vehicle preparation phase, a fuel drain procedure to remove the existing fuel was performed. The fuel tank was removed from the vehicle and then the remaining fuel removed by tipping the tank and using an external fuel pump. The fuel lines, fuel rail, and injectors were disconnected and the lines blown out with compressed nitrogen. The fuel tank, fuel lines, and injectors were reassembled into the vehicle. One gallon of Fuel H was added to the tank. The engine was cranked until it just began to run and then the ignition was turned to the off position. In cases when the vehicle would not start because the fuel level in the tank was below the fuel pump pickup point, fuel was added in 1000 ml increments until the engine would begin to run.

A second fuel drain procedure was then conducted using the vehicle fuel pump. The amount of fuel removed was measured in a graduated cylinder. The difference in the amount of fuel added to the empty fuel system and the amount removed is the system residual fuel volume. According to the calculated predictions of the flush procedure results, the system residual fuel is a significant variable.

E. FLUSH PROCEDURES

In Phase I, flush procedures A, B, and C were performed per CRC specifications. When the results of Phase I had been reviewed, SwRI was asked to recommend new flush procedures and techniques that would potentially improve the flush effectiveness. After discussions with several CRC committee members, SwRI recommended the following enhancements:

1. Add more fuel to increase the dilution.
2. Drive the vehicles after adding fuel instead of conducting a 2-minute engine idle to ensure the fuel drained in the subsequent operation represented the average ethanol content in the vehicle fuel system. It was suspected that the fuel in the vehicle tank might be stratified, and fuel with lower than average ethanol content was being drained.

Phase 2 of the CRC Fuel Effectiveness Study was conducted on the Toyota Corolla and the Mitsubishi Galant. Flush procedures C modified, E, E modified, and F were conducted. An overview of all the flush procedures in the CRC Fuel Effectiveness Program is shown in Table 3. A more detailed table of the flush procedure definition is shown in Appendix C. The flush procedure checklists used by the SwRI Senior Technicians are included in Appendix D.

Table 3 – Flush Procedure Overview

	Flush Procedure						
	Phase I			Phase II			
Fuel Add	**A**	**B**	**C**	**C Mod.**	**E**	**E Mod.**	**F**
#1	2 gal.	1 gal.	2 gal.	2 gal.	4 gal.	4 gal.	8 gal.
Operation	Idle	Idle	Idle	10 mile	Idle	Idle *	Idle
#2	4 gal.**	1 gal.	2 gal.	2 gal.	4 gal.	4 gal.	4 gal.
Operation	-	Idle	Idle	10 mile	Idle	Idle *	Idle
#3	-	4 gal.**	4 gal.**	4 gal.**	4 gal.**	4 gal.**	4 gal.**
Operation	10 mile	10 mile	10 mile	10 mile	10 mile	10 mile	10 mile
Total Fuel	6 gal.	6 gal.	8 gal.	8 gal.	12 gal.	12 gal.	16 gal.

* During the 2-minute idle the vehicle was rocked from side to side for 15 seconds.

** The four-gallon fill is not part of the flushing procedure but rather the addition of fuel to begin a driveability test.

The vehicle fuel drain procedures were all accomplished with the same technique used in the vehicle preparation for that vehicle. Appropriately labeled calibrated cans were filled to the proper volume for adding fuel to the vehicles. The appropriately labeled funnels were installed into the vehicle filler necks when pouring fuel into the vehicle.

A vehicle route was developed to accumulate ten miles on the vehicles. The procedure is included in Appendix E. The mileage accumulation based on the odometers of the vehicles ranged from 9.8 to 10.4 miles. Due to the speed limit on the Southwest Research Institute campus and the traffic lights on the public roads outside the SwRI main gate, the average speeds for the mileage accumulation were less than 45 mph. Traffic density and traffic lights caused the speeds to vary from a minimum of 19.5 mph to a maximum of 40.4 mph. The arithmetic average of the speeds was 30.1 mph in Phase I and 31.1 mph in Phase II. Since the purpose of the mileage accumulation was to mix the fuel in the vehicle fuel system, the average speed for a ten-mile run is probably not significant to the flush procedure test.

The fuel samples were obtained into pre-labeled 8oz. sterile glass containers scribed at the 75ml level. Fuel was taken directly from the fuel line in the same manner as the fuel drains using the vehicle fuel pump to draw the fuel sample. A fuel sample was obtained by first drawing a purge sample into the sample container. Then the excess fuel greater than 75ml was poured back into the vehicle tank, retaining 75 ml in the sample container. In Phase II, the glass containers were filled with the final sample in case additional chemistry analytical information was requested. The samples were delivered to the SwRI Petroleum Research Department and each sample was analyzed for ethanol by volume percent using the ASTM D 5599 method.

IV. RESULTS

A. PHASE I

Phase I consisted of performing flush procedures A, B, and C on five vehicles. These evaluations were performed to the CRC specifications as prescribed in the original request for proposal. The results of the three flush procedures in Phase I on each vehicle are shown in Table 4. Sixteen flush procedure tests were conducted.

1.7%   4%   8.6%   6%   5.5%

Table 4 – Phase I Test Results Summary

Vehicle Manufacturer	Toyota	Ford	Mitsubishi	Chevrolet	Nissan
Model	Corolla	Windstar	Galant	Cavalier	Maxima
System Residual Fuel (Gal.)	.23	1.04	1.41	0.92	1.02
Flush Procedure A					
Initial Ethanol (vol%)	9.78	7.62	7.08	7.61	7.82
Final Ethanol (vol%)	0.48	0.51	1.37	0.81	0.70
Flush Effectiveness	95.1%	93.3%	80.6%	89.4%	91.0%
Flush Procedure B					
Initial Ethanol (vol%)	8.36	7.93	6.76	7.08	7.43
Final Ethanol (vol%)	0.69	0.45	1.27	0.60	1.12
Flush Effectiveness	91.7%	94.3%	81.2%	91.5%	84.9%
Flush Procedure C					
Initial Ethanol (vol%)	8.49	7.75	6.71	7.09	7.86
Final Ethanol (vol%)	0.65	0.24	0.75	0.32	0.43
Flush Effectiveness	92.3%	96.9%	88.8%	95.5%	94.5%
Flush Procedure A (Rerun)					
Initial Ethanol (vol%)	8.57				
Final Ethanol (vol%)	0.60				
Flush Effectiveness	93.0%				

Volume percentages by ASTM D 5599

Note that the system residual fuel volumes for the Ford Windstar, the Mitsubishi Galant, and Nissan Maxima were greater than one gallon.

The Toyota Corolla flush procedure A was conducted twice. The Toyota vehicle preparation was conducted with Fuel E. Therefore, the first Flush Procedure A on the Toyota started with essentially 100% Fuel E in the vehicle. All the other flush procedures in the program, including the second Toyota Corolla flush procedure A test, commenced with the Fuel H from the vehicle preparation or the fuel from the previous flush procedure conducted on that vehicle.

B. PHASE II

Flush procedures C Modified, E, E modified, and F were developed to increase the flush effectiveness. The results are shown in Table 5.

Table 5 – Phase II Results Summary

Vehicle Manufacturer	Toyota	Ford	Mitsubishi	Chevrolet	Nissan
Model	Corolla	Windstar	Galant	Cavalier	Maxima
System Residual Fuel (Gal.)	0.23	1.04	1.41	0.92	1.02
Flush Procedure C Modified					
Initial Ethanol (vol%)	6.89		6.59		
Final Ethanol (vol%)	0.01		0.45		
Flush Effectiveness	99.9%		93.2%		
Flush Procedure E					
Initial Ethanol (vol%)	8.89		6.85		
Final Ethanol (vol%)	0.49		0.36		
Flush Effectiveness	94.5%		94.7%		
Flush Procedure E Modified					
Initial Ethanol (vol%)			6.84		
Final Ethanol (vol%)			0.21		
Flush Effectiveness			96.9%		
Flush Procedure F					
Initial Ethanol (vol%)	9.12		6.70		
Final Ethanol (vol%)	0.01		0.24		
Flush Effectiveness	99.9%		96.4%		

C. CALCULATED PREDICTIONS

For each flush procedure in each vehicle, the ethanol volume percentage was predicted using a calculation based on the system residual fuel of the vehicle and the ethanol volume percentage in the initial fuel sample. For these calculations the following assumptions were made:

1. The resulting volume of adding two blends together was equal to the arithmetic sum of the two volumes of the original blends.
2. Losses of fuel in the form of vapor through the evaporative canister and evaporative emission system were assumed to be zero.
3. During vehicle driving cycles and sample procurement the amount of ethanol removed from the vehicle system is proportional to the total concentration of ethanol in the vehicle system.

A sample calculation for the Chevrolet Cavalier Flush Procedure A is shown below. The numbers in parenthesis correspond with the flush procedure task numbers in Appendix C. The system residual fuel (*SRF*) for the Chevrolet Cavalier was measured as 0.92 gallons. The volume percentage of ethanol in the initial fuel sample is 7.61%. The volume of ethanol (VE) in gallons in the vehicle fuel system by calculation after task #2 is:

$$VE(2) = [4 + SRF][7.61\%] = 0.374 \text{ gallons}$$

The volume of ethanol in the vehicle system after task #5 is calculated below. Note that the volume of fuel in the vehicle system after task #5 is the system residual fuel volume (0.92 gallons).

$$VE(5) = [0.374][SRF]/[4 + SRF] = 0.0699 \text{ gallons}$$

The volume of ethanol in the system after task #6 is the same as the amount after task #5. Two gallons of Fuel H are added to the vehicle system, but Fuel H has no ethanol content. The total volume of fuel in the vehicle fuel system after task #6 is 2 gallons plus the system residual fuel volume (0.92 gallons), which equals 2.92 gallons. After task #11 there is again 0.92 gallons of fuel in the vehicle fuel system and the volume of ethanol is calculated below.

$$VE(11) = 0.0699[SRF]/[2 + SRF] = 0.022 \text{ gallons}$$

After adding the 4 gallons of Fuel H in task #12, there are a total of 4.92 gallons of fuel in the vehicle system. However, the volume of ethanol is still 0.022 gallons. Thus, the volume percentage of ethanol based on this calculation is:

$$\text{Ethanol (vol\%)} = 0.022/[4 + SRF] = 0.45\%$$

In the same manner all the flush procedure test results were predicted by calculation. Please refer to Appendix F.

V. DISCUSSION

A. SUMMARY

Phase I provides CRC with an indication of the effectiveness of flush procedures A, B, and C in each of the vehicles tested. The reported results with the exception of flush procedure A in the

Toyota Corolla, are single point results. The statistical variation of the flush procedure evaluation test is not known. The results of Phase I raised two major questions:

1. What flush procedures and/or techniques could be employed to improve the flush effectiveness? The Mitsubishi Galant had the highest residual fuel volume (worst case for flush effectiveness) of 1.41 gallons. Starting with a fuel containing 6.59 volume percent ethanol, flush procedure C (theoretically the most effective procedure in Phase I) had a final fuel sample with 1.37 volume percent ethanol. The flush effectiveness was 80.6%. The Phase II goal was to develop a procedure to reduce the final sample ethanol volume percent.
2. The measured ethanol volume percent results were in the "order of magnitude range", but were generally higher (less fuel flush effectiveness) than the calculated results. The measured ethanol volume percent results of the Ford Windstar were the closest to the calculated results. The Toyota Corolla had the lowest residual fuel amount of 0.23 gallons. Theoretically, the fuel flushes with the Toyota Corolla for procedures A, B, and C should have been more efficient than the same procedure in the other vehicles. However, the flush procedure C result with the Toyota Corolla was the least effective with the exception of the Mitsubishi Galant. The Toyota had a flush procedure C measured result of 0.65 volume percent, but the predicted result by calculation was 0.0%. The question was, "Why was the measured fuel flush effectiveness worse than the calculated predictions?"

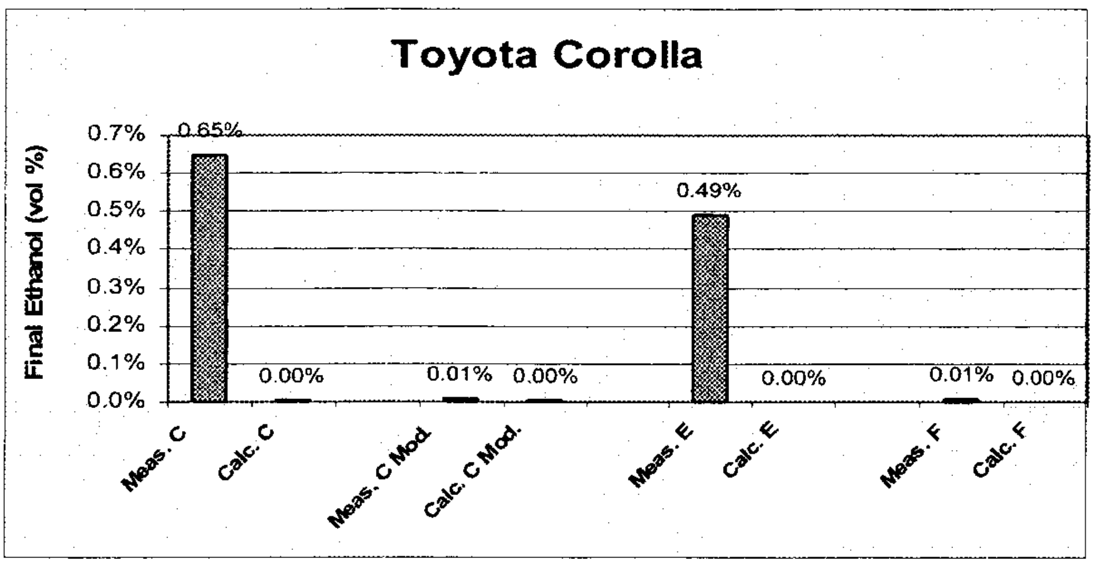
Phase II was conducted to answer the questions noted above. The following is a discussion of the findings of Phase II. All the results are displayed graphically in Appendix G.

1. Fuel flush effectiveness can be improved by adding more fuel, performing more complete fuel drains, or performing more fuel drains. The cost of the flush fuel is a concern, so it was a goal to minimize the amount of additional fuel required. The time to perform fuel drains and fuel additions is also a concern. It was decided the optimum means to improve the effectiveness was to add more fuel rather than add more drain procedures. Flush procedure E uses a total of 12 gallons of flush fuel and flush procedure F uses 16 gallons of flush fuel. Potentially a fuel drain procedure could be more efficient by removing more fuel or in essence reducing the system residual fuel amount. The fuel tank could be removed from the

vehicle and the fuel drained with an external pump. However, the time and facilities (example: vehicle hoist) were a concern with this technique. On some vehicles a small diameter hose could potentially be pushed through the filler neck and residual fuel could be drained with an external pump. However, the fuel tank configuration including the baffles on some vehicles would prohibit this technique. Therefore, it was not considered for Phase II.

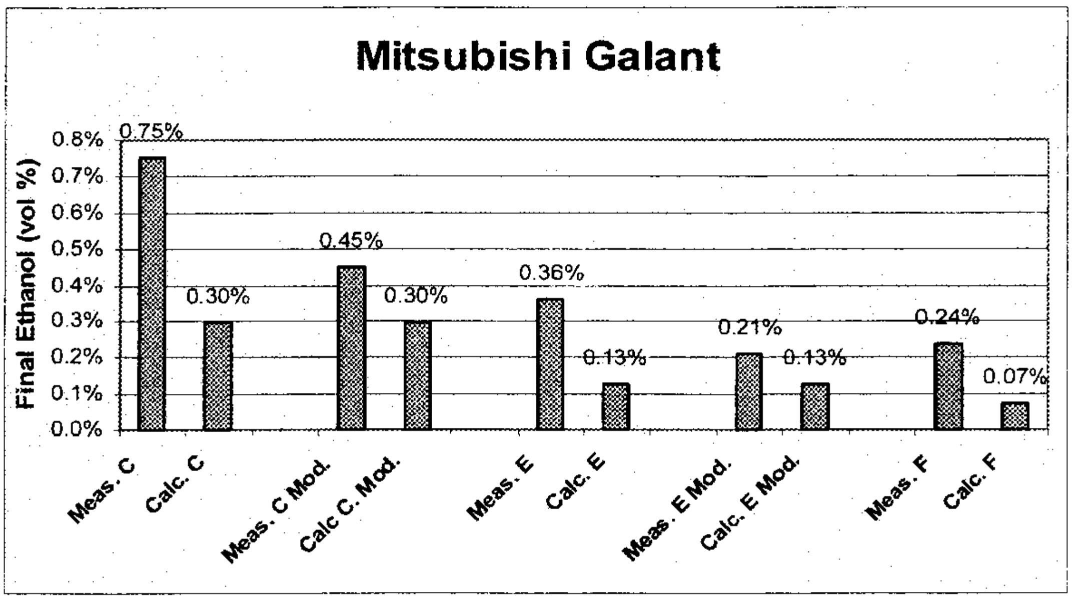
A flush procedure D was discussed, which was the same as flush procedure A except more fuel was added after the first fuel drain. The amount of fuel required for a procedure D to equal the theoretical flush effectiveness of flush procedure E was significantly greater than the 12 gallons of fuel used in flush procedure E. In most cases the amount of fuel required in flush procedure D would have exceeded the fuel tank capacity. Therefore, flush procedure D was not conducted in Phase II.

Figure 1 – Toyota Corolla Procedure C and Phase II Results



In Figures 1 and 2 note the decrease in the final ethanol volume percent from procedure C to procedure E and then further improvement with procedure F. With regards to procedures C, E, and F the measured result is not as low as the calculated prediction except the Toyota Corolla procedure F. In the case of the Toyota Corolla the predicted results for procedures C, E, and F were less than 0.01% ethanol by volume based on the low relatively low residual fuel value. Procedure F measured result in the Toyota was 0.01%.

Figure 2 – Mitsubishi Galant Procedure C and Phase II Results



2. SwRI had the idea that the two minute idle step was not sufficient to completely mix the fuel in the tank after the fuel was added. Note there are two idle steps in flush procedures B, C, E and F. If the mixing was not complete, then the fuel removed in the next drain step might have less ethanol by volume percentage than the average of all the fuel in the vehicle system. It was theorized that this was a contributing factor to the disagreement of the predicted results and the measured results. The C modified flush procedure was developed to ensure complete mixing of the fuel in the vehicle system after adding flush fuel. In the C modified procedure the two minute idles were replaced by the ten mile driving procedure.

   Members of the CRC were concerned about the time and labor involved in performing the ten-mile drive procedures or even a potentially shorter procedure. The CRC directed SwRI to conduct a modified E flush procedure. In this procedure the vehicle is idled twice for 2 minutes. During each two minute idle step the rear-end of the vehicle is rocked from side to side for 15 seconds. This operation was accomplished with one person on either side of the vehicle.

Refer to Figures 1 and 2. The C modified procedures conducted on the Toyota Corolla and the Mitsubishi Galant resulted in lower measured results than the comparable procedure C measured result. It is concluded that this is due to the mixing of the fuel in the fuel system during the ten-mile drives in the modified C procedures, which replaced the 2 minute idle steps. In the case of the C modified procedure conducted on the Toyota Corolla, the measured result was 0.01% ethanol by volume, which is essentially equal to the predicted result of 0.0%. The measured procedure E modified result on the Mitsubishi Galant was 0.21% which is less than the procedure E result but not as low as the predicted result of 0.13% ethanol by volume.

B. TEST VARIATION

Except for the repetition of Flush Procedure A in the Toyota Corolla all the flush effectiveness tests were single point data. This section is a discussion of a few items that would affect the test variability. The amount of fuel removed in a drain procedure is a variable. With the Nissan Maxima parked in the same spot, a short repeatability study with the same operator was performed. The fuel drained into the graduated cylinder was poured into the tank and measured three times. The amount of fuel removed for each trial is listed in Table 6.

Table 6 – Drain Procedure Repeatability

Trial Number	Amount of Fuel Removed
1	1060 ml
2	1020 ml
3	1025 ml

Based on this data, the repeatability of the drain procedure appears to be good. However, in practice, tank angle could cause variation. The last 400-500 ml drained very slowly. Often the fuel stream was temporarily reduced to droplets before the pump would pick up more fuel. A different technician may have decided to discontinue the fuel drain procedure with the residual fuel amount plus 400-500 ml of fuel left in the vehicle system. This would have an adverse affect on the reproducibility.

To determine the system residual fuel volume the technicians removed as much of the fuel from the vehicle fuel system as possible before adding a known quantity of Fuel H. Some amount of fuel may have been inadvertently left in the tank or the fuel lines.

The ASTM D 5599 test method has a published reproducibility for ethanol by weight percent value based on the true value of the sample. This is also a source of variation as shown below in both the initial sample and the final sample of a flush test procedure.

Table 7 – D 5599 Reproducibility

Component Weight Percent	Reproducibility
0.20%	0.07%
0.50%	0.16%
1.00%	0.27%
5.00%	0.98%
10.00%	1.70%

VI. CONCLUSIONS

1. The residual fuel left in the system after draining is a major factor affecting fuel flushing effectiveness.
2. It is important to allow the vehicle fuel pump to continue to run when performing the draining operation until no more fuel can be drained.
3. During the flushing procedure, the tank needs to be agitated after each fuel loading to ensure that the residual fuel is mixed with the incoming charge to improve the flushing efficiency.
4. Flushing Procedure E Modified provided the best flushing efficiency at minimum flushing fuel addition.
5. A calculation method was developed to predict the theoretical flushing efficiency, which assisted in assessing and understanding the various flushing procedures.

Appendix F:

Fuel Tank Capacity Estimation and Theoretical RVP Derivation

Appendix F:

Fuel Tank Capacity Estimation and Theoretical RVP Derivation:

The field data recorded the initial fuel tank level, amount of fuel dispensed, and RVP of fuel in the tank and of dispensed fuel. Theoretical RVP was computed using the following formula:

$$RVP_{theoretical} = \frac{(V_{initial} + V_{heel}) * RVP_{remaining\ fuel} + V_{dispensed} * RVP_{dispensed}}{(V_{initial} + V_{heel} + V_{dispensed})}$$

The above formula is readily used for fillup case since the amount of fuel dispensed can be converted to fraction of fuel tank capacity (i.e., 100% less initial fuel tank level), as shown in the diagram below.

However, in the cases of non-fillup observations, the formula cannot be used without fuel tank capacity information. Unfortunately, this information was not part of the field data. As a result, staff estimated non-fillup fuel tank capacity based on the fillup cases observed. First, the fillup data were categorized into 2 vehicle classes: passenger vehicle and light duty truck, including minivan, and their average tank capacity were computed as 16 and 24 gallons for passenger car and light-duty truck, respectively. Staff then compared Ford model vehicle averages computed using this methodology to information provided by Ford Motor Company data, and the results were close. Using the average tank capacities computed, staff estimated the fraction of fuel dispensed for non-fillup case.

Appendix G:

Descriptive Statistics for Fueling Events that Dispensed Non-Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline

Descriptive Statistics for Fueling Events that Dispensed Non-Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline

Statistics	Initial vehicle fuel tank sample				Dispensed fuel sample				Final vehicle fuel tank sample			
	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)
Mean	6.63	1.42	0.02	7.32	6.73	1.14	0.00	6.04	6.71	1.24	0.00	6.49
Median	6.63	1.81	0.00	9.00	6.74	1.41	0.00	7.72	6.67	1.44	0.00	7.62
Mode	6.73	#N/A	0.00	#N/A	6.79	2.40	0.00	13.17	6.63	1.39	0.00	7.62
Standard Deviation	0.27	0.82	0.08	4.43	0.14	0.98	0.00	5.21	0.21	0.87	0.01	4.70
Range:	2.25	2.40	0.50	13.16	0.73	2.44	0.00	13.37	1.15	2.57	0.14	14.12
Minimum	5.76	0.04	0.00	0.24	6.28	0.04	0.00	0.22	6.32	0.00	0.00	0.00
Maximum	8.01	2.44	0.50	13.40	7.01	2.48	0.00	13.59	7.47	2.57	0.14	14.12
Count	165	165	165	165	165	165	165	165	165	165	165	165

Appendix H:

Descriptive Statistics for Fueling Events that Dispensed Ethanol-Blended Gasoline into Ethanol-Blended Gasoline

Descriptive Statistics for Fueling Events that Dispensed Ethanol-Blended Gasoline into Ethanol-Blended Gasoline

Statistics	Initial vehicle fuel tank sample				Dispensed fuel sample				Final vehicle fuel tank sample			
	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)
Mean	6.76	2.01	5.27	0.30	6.84	2.13	5.68	0.14	6.79	2.13	5.59	0.31
Median	6.76	2.01	5.26	0.29	6.83	2.14	5.68	0.17	6.77	2.12	5.58	0.26
Mode	#N/A	#N/A	#N/A	#N/A	6.76	2.27	6.00	0.23	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.06	0.06	0.16	0.26	0.10	0.16	0.37	0.11	0.06	0.11	0.33	0.11
Range:	0.14	0.12	0.38	0.63	13.71	4.25	11.34	0.23	0.13	0.24	0.75	0.23
Minimum	6.69	1.95	5.08	0.00	6.76	1.98	5.34	0.00	6.74	2.03	5.22	0.23
Maximum	6.83	2.07	5.46	0.63	6.95	2.27	6.00	0.23	6.87	2.26	5.97	0.47
Count	4	4	4	4	4	4	4	4	4	4	4	4

Appendix I:

Descriptive Statistics for Fueling Events that Dispensed Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline

Descriptive Statistics for Fueling Events that Dispensed Ethanol-Blended Gasoline into Non-Ethanol-Blended Gasoline

Statistics	Initial vehicle fuel tank sample				Dispensed fuel sample				Final vehicle fuel tank sample			
	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)
Mean	6.48	1.09	0.06	5.79	6.84	2.09	5.57	0.14	6.98	1.79	3.79	2.08
Median	6.43	1.19	0.00	6.06	6.79	2.08	5.49	0.11	6.96	1.85	3.88	1.84
Mode	6.28	#N/A	0.00	10.21	6.91	1.98	5.34	0.00	6.90	#N/A	#N/A	1.17
Standard Deviation	0.36	0.80	0.14	4.43	0.09	0.11	0.28	0.11	0.18	0.33	1.00	1.75
Range:	1.61	2.22	0.47	12.17	0.27	0.29	0.66	0.25	0.87	1.31	3.19	5.90
Minimum	5.80	0.04	0.00	0.21	6.68	1.98	5.34	0.00	6.69	0.90	1.96	0.03
Maximum	7.41	2.26	0.47	12.38	6.95	2.27	6.00	0.25	7.56	2.21	5.16	5.93
Count	29	29	29	29	29	29	29	29	29	29	29	29

Appendix J:

Descriptive Statistics for Fueling Events that of Dispensed Non-Ethanol-Blended Gasoline into Commingled Gasoline

Descriptive Statistics for Fueling Events that Dispensed Non-Ethanol-Blended Gasoline into Commingled Gasoline

Statistics	Initial vehicle fuel tank sample				Dispensed fuel sample				Final vehicle fuel tank sample			
	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)
Mean	6.94	1.71	2.05	4.94	6.71	1.12	0.00	6.13	6.96	1.31	0.69	5.71
Median	6.97	1.96	1.31	4.32	6.77	1.63	0.00	8.93	6.97	1.70	0.39	7.59
Mode	7.01	#N/A	#N/A	0.27	6.79	2.40	0.00	13.17	6.90	#N/A	0.00	#N/A
Standard Deviation	0.25	0.54	1.48	3.40	0.21	1.03	0.00	5.62	0.22	0.83	0.66	4.35
Range:	1.09	1.91	4.10	10.88	0.69	2.36	0.00	12.95	0.69	2.27	2.21	11.78
Minimum	6.34	0.40	0.53	0.25	6.31	0.04	0.00	0.22	6.58	0.07	0.00	0.26
Maximum	7.43	2.30	4.63	11.14	7.00	2.40	0.00	13.17	7.27	2.34	2.21	12.04
Count	24	24	24	24	24	24	24	24	24	24	24	24

Appendix K:

Descriptive Statistics for Fueling Events that of Dispensed Ethanol-Blended Gasoline into Commingled Gasoline

Descriptive Statistics for Fueling Events that Dispensed Ethanol-Blended Gasoline into Commingled Gasoline

Statistics	Initial vehicle fuel tank sample				Dispensed fuel sample				Final vehicle fuel tank sample			
	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)	RVP (psi)	O_2 (wt%)	EtOH (vol%)	MTBE (vol%)
Mean	6.93	1.35	2.77	1.73	6.85	2.08	5.54	0.15	6.96	1.79	4.38	0.89
Median	6.93	1.45	2.83	0.44	6.89	2.01	5.37	0.11	6.89	1.85	4.71	0.29
Mode	7.02	#N/A	#N/A	3.90	6.95	2.01	5.37	0.00	6.89	#N/A	4.87	0.24
Standard Deviation	0.29	0.54	1.53	2.16	0.08	0.11	0.27	0.11	0.33	0.30	0.93	1.20
Range:	1.31	1.67	4.39	6.69	0.23	0.31	0.71	0.35	1.65	1.29	3.48	4.15
Minimum	6.25	0.39	0.51	0.22	6.73	1.98	5.34	0.00	6.56	0.95	2.42	0.00
Maximum	7.56	2.06	4.91	6.91	6.95	2.29	6.06	0.35	8.21	2.23	5.90	4.15
Count	25	25	25	25	25	25	25	25	25	25	25	25

Appendix L:

"Addition of Non-Ethanol Gasoline to E10 – Effect on Volatility", Ted Aulich and John Richter, University of North Dakota Energy & Environmental Research Center, Grand Fork, North Dakota, July 15, 1999.

Energy & Environmental Research Center

Addition of Nonethanol Gasoline to E10 – Effect on Volatility

Ted Aulich, John Richter
University of North Dakota Energy & Environmental Research Center
Grand Forks, North Dakota, July 15, 1999

To investigate the effect on volatility of mixing or "commingling" nonethanol gasoline with "E10" (a blend of 10% ethanol and 90% gasoline), the University of North Dakota Energy & Environmental Research Center (EERC) measured the Reid vapor pressure (Rvp) of a series of gasoline–E10 blends. The two base fuels used to prepare the commingled test fuels were a Minnesota Summer 1998 E10 and a Minnesota Autumn 1998 gasoline that contained no ethanol. Prior to performance of the commingling investigation, a short series of experiments was performed to look at the volatility effect of low-level ethanol addition using a Minnesota Summer 1998 nonethanol gasoline. Table 1 provides data on the three fuels. All Rvp measurements were performed according to American Society for Testing and Materials (ASTM) Procedure D5191, fuel composition data were obtained via ASTM D1319, and ethanol contents were determined using ASTM D4815.

Table 1 – Base Fuel Properties

Fuel Type	Rvp, psi	Olefins Content, vol%	Aromatics Content, vol%	Saturates Content, vol%	Ethanol Content, vol%
Summer E10	9.91	3.3	22.2	64.8	9.7
Autumn Gasoline	9.85	6.7	28.2	65.1	0.0
Summer Gasoline	8.69	16.3	20.9	62.8	0.0

Figure 1 illustrates the effect on volatility of blending low levels of ethanol in gasoline, and indicates the initial occurrence of a 0.93-psi Rvp increase over base fuel at an ethanol content of about 2 vol%. This characteristic "ethanol bump" can range from about 0.9 psi to 1.5 psi, depending on base fuel chemistry, and is at a maximum over an ethanol content range of about 2 to 12 vol%. At ethanol contents exceeding about 12 vol%, the effect of the bump gradually decreases with increasing ethanol content (1,2). The effect of the ethanol bump on commingling is described by the data in Table 2 and illustrated in Figure 2. Because of fuel volume limitations, these data are the result of single-point analyses. While duplicate or triplicate analyses are required for derivation of statistically valid and defendable conclusions, the data are sufficient to illustrate the commingling trend. As shown in Figure 2, Rvp increases steadily with increasing gasoline addition until reaching a maximum at an approximate 80/20 gasoline/E10 mix, and then decreases rapidly. In addition to measured Rvp values, Figure 2 also shows 1) a line representing an "idealized Rvp baseline" that would result from blending two hydrocarbon-only fuels with Rvp values of 9.91 and 9.85 psi, and 2) an "ethanol-free" Rvp baseline that would result from blending two hydrocarbon-only fuels with Rvp values of 8.98 psi (the estimated Rvp of the E10 base gasoline, calculated by subtracting 0.93 psi from the E10 Rvp of 9.91) and 9.85 psi.

Figure 2 corroborates the occurrence of a significant ethanol bump at 2 vol%. The figure shows that maximum Rvp occurs at an 80/20 mix, which corresponds to a commingled fuel ethanol content of about 2 vol%. Figure 2 and other data (1,2) indicate that Rvp is fairly constant over an ethanol content range of about 2 to 12 vol%. Based on all of these data, it appears likely that use of a

Figure 1. Volatility Effect of Ethanol Addition to Gasoline

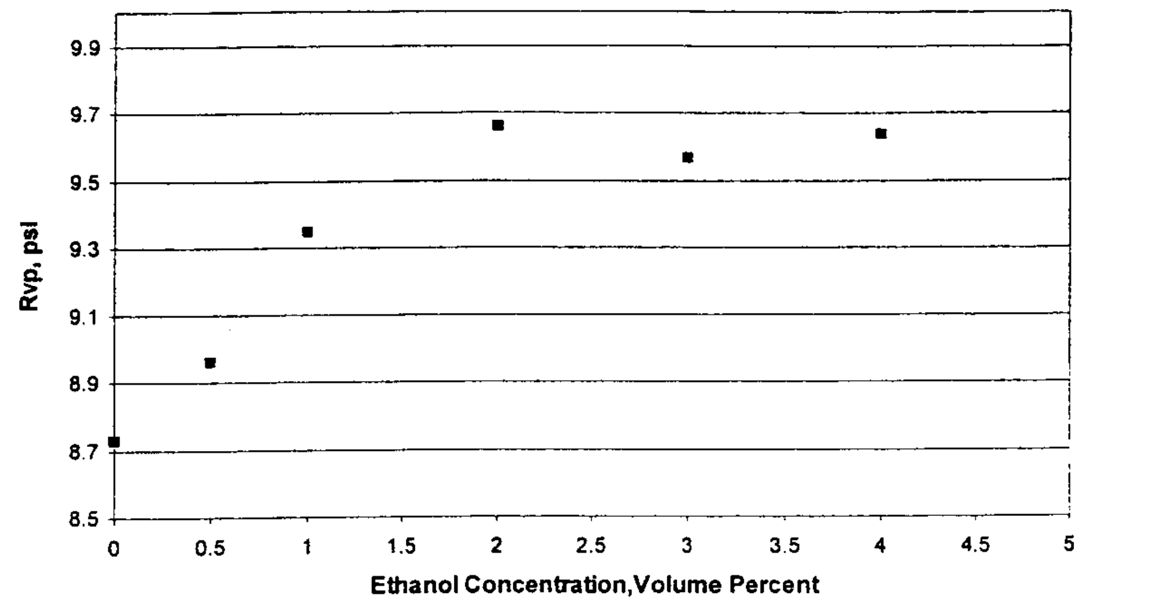


Figure 2. Addition of Nonethanol Gasoline to E10 Volatility Effect

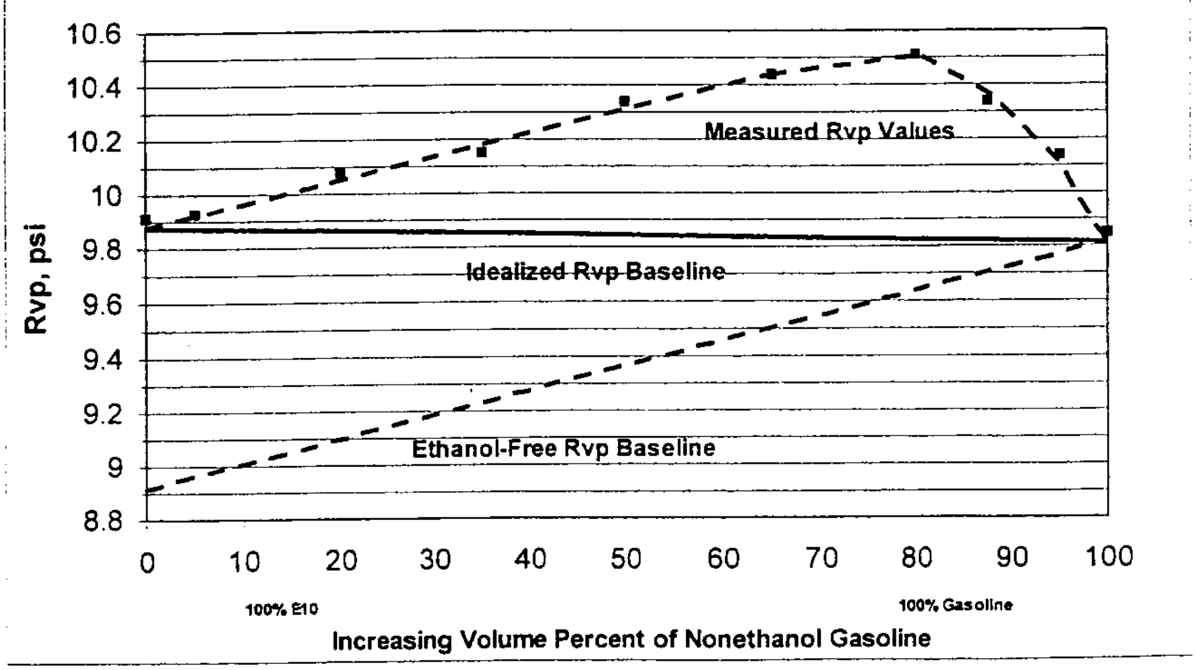
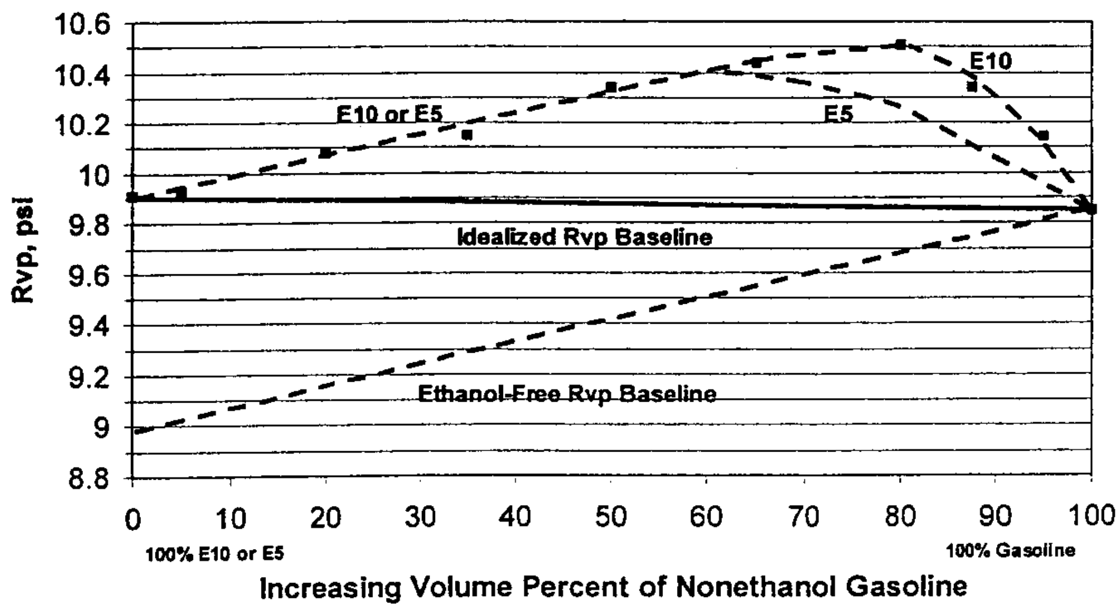


Figure 3. Addition of Nonethanol Gasoline to E5 Theoretical Volatility Effect



For more information: Ted Aulich at 701-777-2982 or taulich@eerc.und.nodak.edu lower ethanol-content blend would push the Rvp maximum toward the y-axis, thereby reducing the maximum. Although the measured-value line and the ethanol-free baseline should remain essentially parallel for fuel combinations to the left of the Rvp maximum (corresponding to commingled fuel ethanol contents of about 2 vol% and higher), a lower ethanol-content blend should produce a reduction of Rvp (compared to E10) for fuel combinations to the right of the Rvp maximum (corresponding to ethanol contents of 2 vol% and lower). The net effect would be shrinkage of the area between the measured-values line and the idealized baseline, which means an overall reduced Rvp elevation impact. Although this impact needs to be quantified empirically, a theoretical E5 impact is illustrated in Figure 3.

The limited investigations described here indicate the need for further data acquisition to establish statistically valid conclusions regarding vapor pressure effects of commingling. The effect of ethanol content should be evaluated to establish whether use of lower ethanol-content blends (such as 5.7 vol%, which corresponds to an oxygen content of 2%) could significantly reduce the overall commingling-derived Rvp elevation effect. The effect of gasoline composition should also be evaluated, because the work described here was performed using only conventional gasolines with limited variation in contents of olefins, aromatics, and saturates. Data is needed for a variety of EPA Phase 2 RFG and California Air Resources Board Phase 3 RFG fuels.

Table 2 – Volatility Effect of Nonethanol Gasoline Addition to E10

E10 Content, vol%	Gasoline Content, vol%	Rvp, psi
100	0	9.91
95	5	9.93
80	20	10.08
65	35	10.15
50	50	10.34
35	65	10.44
20	80	10.51
12	88	10.34
5	95	10.14
0	100	9.85

References

1) Aulich, T.R., X. He, A.A. Grisanti, C.L. Knudson, Gasoline Evaporation–Ethanol and Nonethanol Blends, *Journal of the Air & Waste Management Association*, August 1994.

2) Furey, R.L., Volatility Characteristics of Gasoline–Alcohol and Gasoline–Ether Fuel Blends, Society of Automotive Engineers Paper Number 852116, 1985.

Appendix M:

The UCD Simulation Model Code and User's Manual

Input and Output Specifications for a Simulation Program to Estimate the Potential Range of the Emission Effect of Ethanol in Gasoline due to Commingling

David M. Rocke
University of California, Davis

March 27, 2000

The simulation program *comming* is a DOS/Windows executable that takes an input file with lines each of which specifies a run, and produces a text output file with the results. Table 1 gives the definitions of the input variables, and Table 2 gives the definitions of the output variables. The program is executed from the command line in DOS or in a windows shortcut as

```
comming < infile.txt > outfile.txt
```

where `infile.txt` is an existing input file and `outfile.txt` is the name of the output file to be created. A single run should take no more than one or two seconds per run. For example, a 216 line input, which produces 216 runs of the program, took less than 6 minutes on a 233MHz Pentium II.

The output variable `meanrvp` is the mean RVP increase over the same mixture of gasolines with no added oxygenate. The output variable `mean2rvp` is the mean RVP increase that would occur with the same gasolines (one oxygenated and one not) but with no commingling. The difference is the commingling effect. For example, the run shown in the tables had a 90% market share for ethanol gasoline with a base RVP of 7 and 5.7% ethanol. The other 10% of the market is RVP 7 non-oxygenated gasoline. The addition of the ethanol without commingling raises the fleet average RVP by 1.055 PSI. With commingling, this becomes 1.136 PSI, so the commingling effect is 1.136 - 1.055 = .081 PSI.

Table 1: Input variable specifications for program *comming*

Program Variable	Description	Example
ethpct	Percentage of ethanol in the ethanol fuel	5.7
rvpbase	Base RVP of the non-oxygenated fuel	7
ethrvpbase	Base RVP of the ethanol fuel before blending ethanol	7
npurch	Number of purchase events per vehicle in the simulation	100
npers	Number of individuals simulated	1000
thetap	θ = Market share of ethanol gasoline	0.9
alphapbetap	$\alpha + \beta$ where the distribution of the purchase probability p_i for individual i is Beta(α, β)	10
thetal	Mean fraction of the tank used before fillup	0.3
alphapbetal	$\alpha_l + \beta_l$ where the distribution of the tank fraction used is Beta(α_l, β_l)	5
thetaff	Mean fraction of the time that the tank is filled	0.8
alphapbetaff	$\alpha_{ff} + \beta_{ff}$ where the distribution of the probability of filling the tank π_i for individual i is Beta(α_{ff}, β_{ff})	5
thetaf	Mean fill fraction when the tank is not filled completely	0.6
alphapbetaf	$\alpha_f + \beta_f$ where the distribution of the tank fraction filled is Beta(α_f, β_f)	2

Table 2: Output variable specifications for program *comming*

Output Variable	Description	Example
ethpct	Percentage of ethanol in the ethanol fuel	5.7
rvpbase	Base RVP of the non-oxygenated fuel	7
ethrvpbase	Base RVP of the ethanol fuel before blending ethanol	7
alphap	α where the distribution of the purchase probability p_i for individual i is Beta(α, β)	9.0
betap	β where the distribution of the purchase probability p_i for individual i is Beta(α, β)	1.0
alphall	α_l where the distribution of the tank fraction used is Beta(α_l, β_l)	1.5
betal	β_l where the distribution of the tank fraction used is Beta(α_l, β_l)	3.5
alphaff	α_{ff} where the distribution of the probability of filling the tank π_i for individual i is Beta(α_{ff}, β_{ff})	4.0
betaff	$\alpha_{ff} + \beta_{ff}$ where the distribution of the probability of filling the tank π_i for individual i is Beta(α_{ff}, β_{ff})	1.0
alphaf	α_f where the distribution of the tank fraction filled is Beta(α_f, β_f)	1.2
betaf	β_f where the distribution of the tank fraction filled is Beta(α_f, β_f)	.8
meanrvp	Mean RVP increase of all gasoline burned in the simulation	1.136
mean2rvp	RVP increase with the same market share and no commingling	1.055
sdrvp	Standard deviation of the RVP increase across all tank fills	.136

The UCD Simulation Model
FORTRAN Code

```
      program    comming

      use msimsl

      implicit none
      integer    npurch,npers,iseed
      real*8     theta,alphapbeta,alphap,betap,alphal,betal
    real*8      thetap,alphapbetap
    real*8      thetal,alphapbetal
    real*8      thetaf,alphapbetaf
    real*8      thetaff,alphapbetaff
    real*8      alphaf,betaf,alphaff,betaff,pi0,ppurch
    real*8      rannum(10)
    real*8      tankcap,tankpct,ethpct,tankfill,tanklev,tanklevold
    real*8      rvpbase,ethrvpbase,tankrvpbase
    real*8      meanrvp,sdrvp,mean2rvp
    integer     initpurch,i,j
      real*8,    dimension (:,:) , allocatable :: rvpvec,gasusedvec
      real*8,    dimension (:,:) , allocatable :: ethpctvec,rvpbasevec
    real*8      rvpboost
    external    rvpboost

    npers=1000
    do while(npers.gt.0)
    iseed = 2345872
    call rnset(iseed)

    read*,ethpct,rvpbase,ethrvpbase,npurch,npers,thetap, &
          alphapbetap,thetal,alphapbetal,thetaff,alphapbetaff, &
          thetaf,alphapbetaf
    alphap = thetap*alphapbetap
    betap = alphapbetap-alphap
    alphal = thetal*alphapbetal
    betal = alphapbetal-alphal
    alphaff = thetaff*alphapbetaff
    betaff = alphapbetaff-alphaff
    alphaf = thetaf*alphapbetaf
    betaf = alphapbetaf-alphaf
    if (npers.le.0) exit

    allocate(rvpvec(npers,npurch))
    allocate(gasusedvec(npers,npurch))
    allocate(ethpctvec(npers,npurch))
    allocate(rvpbasevec(npers,npurch))

    tankcap=20.0
    initpurch=20

    do i=1,npers
!
!   generate for individual i the proportion ppurch
!   of times that eg is purchased, the probability pi0
```

```
!   that the tank is filled completely.
!
        call drnbet(1,alphap,betap,rannum)
        ppurch = rannum(1)
        call drnbet(1,alphaff,betaff,rannum)
        pi0=rannum(1)
!
!   initial tank fill, random choice from g and eg
!
        tanklev=tankcap
        if (drnunf().lt.ppurch) then
            tankpct = ethpct
            tankrvpbase=ethrvpbase
        else
            tankpct = 0
            tankrvpbase=rvpbase
        endif
!
!   first initpurch fills are not counted
!
        do j=1,initpurch
!
!   how much has been used?
!
            tanklevold=tanklev
            call drnbet(1,alphal,betal,rannum)
            tanklev = rannum(1)*tanklev
!
!   fill to what level?
!
            if (drnunf().lt.pi0) then
                tankfill=tankcap-tanklev
            else
                call drnbet(1,alphaf,betaf,rannum)
                tankfill = rannum(1)*(tankcap-tanklev-1)+1
            endif
!
!   fill with what kind of gasoline?
!
            if (drnunf().lt.ppurch) then
                tankpct = tankpct*(tanklev+1)+ethpct*tankfill
                tankpct=tankpct/(tanklev+tankfill+1)
                tankrvpbase = tankrvpbase*(tanklev+1)+ethrvpbase*tankfill
                tankrvpbase=tankrvpbase/(tanklev+tankfill+1)
            else
                tankpct = tankpct*(tanklev+1)
                tankpct=tankpct/(tanklev+tankfill+1)
                tankrvpbase = tankrvpbase*(tanklev+1)+rvpbase*tankfill
                tankrvpbase=tankrvpbase/(tanklev+tankfill+1)
            endif
            tanklev=tanklev+tankfill
        enddo
!
!   next npurch fills are recorded
!
        do j=1,npurch
!
```

```
!    how much has been used?
!
         call drnbet(1,alphal,betal,rannum)
         tanklevold=tanklev
         tanklev = rannum(1)*tanklev
         gasusedvec(i,j)=tanklevold-tanklev
         ethpctvec(i,j)=tankpct
         rvpbasevec(i,j)=tankrvpbase

!
!    fill to what level?
!
             if (drnunf().lt.pi0) then
                 tankfill=tankcap-tanklev
             else
                 call drnbet(1,alphaf,betaf,rannum)
                 tankfill = rannum(1)*(tankcap-tanklev-1)+1
             endif
!
!    fill with what kind of gasoline?
!
             if (drnunf().lt.ppurch) then
                 tankpct = tankpct*(tanklev+1)+ethpct*tankfill
                 tankpct=tankpct/(tanklev+tankfill+1)
                 tankrvpbase = tankrvpbase*(tanklev+1)+ethrvpbase*tankfill
                 tankrvpbase=tankrvpbase/(tanklev+tankfill+1)
             else
                 tankpct = tankpct*(tanklev+1)
                 tankpct=tankpct/(tanklev+tankfill+1)
                 tankrvpbase = tankrvpbase*(tanklev+1)+rvpbase*tankfill
                 tankrvpbase=tankrvpbase/(tanklev+tankfill+1)
             endif
             tanklev=tanklev+tankfill
         enddo
     enddo
     do i=1,npers
     do j=1,npurch
         rvpvec(i,j)=rvpboost(ethpctvec(i,j),rvpbasevec(i,j))
     enddo
     enddo
     meanrvp=0
     do i=1,npers
     do j=1,npurch
         meanrvp=meanrvp+rvpvec(i,j)
     enddo
     enddo
     meanrvp=meanrvp/(npers*npurch)
     sdrvp=0
     do i=1,npers
     do j=1,npurch
         sdrvp=sdrvp+(rvpvec(i,j)-meanrvp)**2
     enddo
     enddo
     sdrvp=sqrt(sdrvp/(npers*npurch-1))
       mean2rvp=rvpboost(ethpct,ethrvpbase)*thetap
     print 1000,ethpct,rvpbase,ethrvpbase,alphap,betap,alphal,betal,  &
                alphaff,betaff,alphaf,betaf,meanrvp,mean2rvp,sdrvp
```

```
1000 format(11f9.5,3f8.5)
     deallocate(rvpvec,gasusedvec,ethpctvec,rvpbasevec)
     enddo
     end

     real*8 function rvpboost(ethpct,rvpbase)
     implicit    none
     real*8      ethpct,rvpbase,a,b,c,d,denom,rvpmax,rvpadj
         rvpmax=1.11
         a=1/rvpmax
         b=1.845515595
         c=-0.764052039
         d=0.837257974
         denom=a+b*ethpct+c*ethpct**2+d*ethpct**3
         rvpboost=1.11-1.0/denom
         rvpadj=.05*(8.4-rvpbase)
         rvpboost=rvpboost*(rvpmax+rvpadj)/rvpmax
     return
     end
```

Appendix N:

Consumer Ethanol Fuel Purchase Propensity

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Consumers Ethanol Fuel Purchase Propensity

One of the tasks in estimating commingling impacts was considering non-loyal consumers' ethanol purchase propensity, which defines the likelihood of purchasing ethanol-blended gasoline in a mixed ethanol and non-ethanol gasoline marketplace.

In the loyal consumers' case, the issue is straightforward. The consumers are grouped into two extremes: those who always buy ethanol-blended gasoline (100 percent ethanol purchase propensity) or those who always buy non-ethanol gasoline (0 percent ethanol purchase propensity), by the virtue of adherence to a fuel brand. The corresponding ethanol market share scenario being analyzed determines the proportions of these subgroups. For example, if ethanol market share were 25 percent of the total gasoline market pool, for example, loyal consumers belonging to the first extreme "always buy ethanol-blended gasoline" would be 25 percent of the total loyal consumers while the rest would belong to the other extreme "always buy non-ethanol fuel."

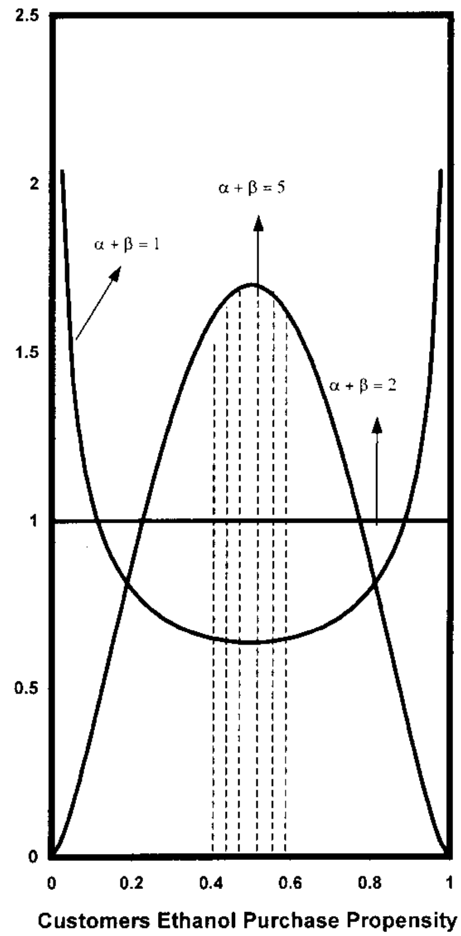
Unlike loyal consumers, ethanol purchase propensity for non-loyal consumers could not be observed in the field, nor could it be deduced from the gasoline brands they purchased; there is no source for such data. As a result, the model randomly assigned each non-loyal consumer with a fixed ethanol purchase propensity value that lies between the two extreme values of loyal consumers, i.e., between 0 percent and 100 percent. From the propensity values assigned, a frequency distribution plot illustrates the relative number of non-loyal consumers who fall into a predefined range (e.g., 5 percent). On average, the overall non-loyal consumers purchase propensity value must equal the corresponding ethanol market share scenario being modeled.

For a given market share, the distribution of non-loyal consumers ethanol purchase propensity was assumed to follow three kinds of beta distributions ($\alpha+\beta$ equals 1, 2, or 5). A distinct feature that distinguishes these distributions is the frequency in which each propensity value is assigned. If a majority of non-loyal consumers is assigned a similar propensity value, it means they behave similarly. As a result, the frequency distribution plot shows a spike around that value. This approach leads to higher commingling impacts, and is called a more conservative scenario ($\alpha+\beta=5$). For example, if ethanol market share were 50 percent and everyone had similar purchase propensity behavior, then for this scenario the non-loyal consumers would be tightly clustered around 50 percent ethanol purchase propensity mark. These consumers would always be equally likely to go to either ethanol or non-ethanol fuel stations. As a result, the potential commingling impacts for this approach is highest since significant amount of mixing of the two fuels is expected to take place.

In contrast, a less conservative scenario ($\alpha+\beta=1$) assigns more non-loyal consumers around 90 percent and 10 percent propensity values than a more conservative scenario ($\alpha+\beta=5$). That means, although consumers use several brands of gasoline, one of the brand will be use more than the others. Overall, this approach represents a more diverse consumer behavior, so a lower commingling impact will result. In this report, staff assumes that the base case scenario ($\alpha+\beta=1$) lies between the more conservative and less conservative scenarios. In fact, the base case scenario assumes that non-loyal consumers are uniformly distributed between 0 and 100 percent propensity values.

The following figure graphically illustrates the above three scenarios. A series of beta distribution curves was plotted with a mean at 0.5 that indicates a 50 percent ethanol market share case where a maximum commingling impact is expected to occur. The shaded area under each curve represents the proportion of non-loyal consumers who are assumed to have ethanol purchase propensity between 40 percent and 60 percent. The more conservative scenario assumes 32 percent of consumers fall into this category while the base case and less conservative scenarios assume 20 percent and 13 percent, respectively.

Customers Ethanol Purchase Propensity Distribution
For 50% Ethanol Market Share
(Beta Distribution, $\alpha+\beta$ = 1, 2, or 5)



Appendix O:

Simulation Model Output

Table O-1
Estimated RVP Increases By Region For Various Ethanol Blends And Market Shares
Using The 2001 ARB Field Study Input Parameters
Base Case Scenario (Beta Distribution, $\alpha+\beta=2$)
(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	RVP Increase Due To Commingling (psi)		
				Lake Tahoe	Bay Area	Los Angeles
25	6	6.71	5.74	0.152	0.145	0.135
30	6	6.71	5.74	0.159	0.162	0.151
35	6	6.71	5.74	0.181	0.158	0.161
40	6	6.71	5.74	0.176	0.160	0.173
45	6	6.71	5.74	0.182	0.173	0.167
50	6	6.71	5.74	0.186	0.173	0.172
55	6	6.71	5.74	0.179	0.172	0.174
60	6	6.71	5.74	0.171	0.172	0.159
65	6	6.71	5.74	0.154	0.160	0.148
25	7.7	6.71	5.74	0.169	0.162	0.151
30	7.7	6.71	5.74	0.178	0.180	0.170
35	7.7	6.71	5.74	0.201	0.177	0.180
40	7.7	6.71	5.74	0.196	0.180	0.193
45	7.7	6.71	5.74	0.202	0.193	0.187
50	7.7	6.71	5.74	0.207	0.193	0.192
55	7.7	6.71	5.74	0.199	0.191	0.193
60	7.7	6.71	5.74	0.189	0.190	0.177
65	7.7	6.71	5.74	0.171	0.177	0.165

Table O-2

Estimated RVP Increases By Region For Various Ethanol Blends And Market Shares

Using The 2001 ARB Field Study Input Parameters

More Conservative Scenario (Beta Distribution, $\alpha+\beta=5$)

(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	RVP Increase Due To Commingling (psi)		
				Lake Tahoe	Bay Area	Los Angeles
25	6	6.71	5.74	0.186	0.190	0.175
30	6	6.71	5.74	0.204	0.199	0.186
35	6	6.71	5.74	0.219	0.206	0.203
40	6	6.71	5.74	0.218	0.223	0.210
45	6	6.71	5.74	0.226	0.217	0.217
50	6	6.71	5.74	0.228	0.213	0.215
55	6	6.71	5.74	0.224	0.215	0.209
60	6	6.71	5.74	0.218	0.199	0.202
65	6	6.71	5.74	0.195	0.190	0.187
25	7.7	6.71	5.74	0.208	0.212	0.196
30	7.7	6.71	5.74	0.228	0.223	0.209
35	7.7	6.71	5.74	0.245	0.231	0.227
40	7.7	6.71	5.74	0.244	0.248	0.235
45	7.7	6.71	5.74	0.252	0.243	0.242
50	7.7	6.71	5.74	0.253	0.238	0.239
55	7.7	6.71	5.74	0.249	0.239	0.232
60	7.7	6.71	5.74	0.241	0.222	0.224
65	7.7	6.71	5.74	0.215	0.210	0.208

Table O-3

Estimated RVP Increases By Region For Various Ethanol Blends And Market Shares

Using The 2001 ARB Field Study Input Parameters

Less Conservative Scenario (Beta Distribution, $\alpha+\beta=1$)

(Draft)

Ethanol Market Share (%)	Ethanol Content (%vol)	Base RVP Non-Oxy Fuel (psi)	Base RVP Ethanol Fuel (psi)	RVP Increase Due To Commingling (psi)		
				Lake Tahoe	Bay Area	Los Angeles
25	6	6.71	5.74	0.104	0.105	0.092
30	6	6.71	5.74	0.130	0.122	0.105
35	6	6.71	5.74	0.126	0.124	0.115
40	6	6.71	5.74	0.138	0.127	0.129
45	6	6.71	5.74	0.133	0.125	0.126
50	6	6.71	5.74	0.144	0.137	0.124
55	6	6.71	5.74	0.135	0.129	0.125
60	6	6.71	5.74	0.132	0.121	0.112
65	6	6.71	5.74	0.119	0.123	0.111
25	7.7	6.71	5.74	0.117	0.117	0.104
30	7.7	6.71	5.74	0.144	0.135	0.118
35	7.7	6.71	5.74	0.141	0.138	0.129
40	7.7	6.71	5.74	0.153	0.142	0.143
45	7.7	6.71	5.74	0.149	0.140	0.141
50	7.7	6.71	5.74	0.159	0.152	0.139
55	7.7	6.71	5.74	0.150	0.144	0.139
60	7.7	6.71	5.74	0.146	0.135	0.126
65	7.7	6.71	5.74	0.132	0.136	0.124

Appendix P:

"Analysis Of Commingling Due To Ethanol Blends," Gary Z. Whitten, Systems Application International, May 1999.

ANALYSIS OF COMMINGLING DUE TO ETHANOL BLENDS

Gary Z. Whitten
Systems Applications International
May 1999

The U.S. EPA revised its treatment of commingling effects due to ethanol in late 1993 as part of the proposed Renewable Oxygenate Rule (ROR) for Reformulated Gasoline (RFG). The new appraisal was originally published in the Regulatory Impact Analysis (RIA) for Reformulated Gasoline (Draft of 17 December 1993). Most of the information was subsequently published in 1994 as SAE Paper No. 94076. The original EPA appraisal of the commingling effect is available in a memorandum dated 29 December 1987 from C. Harvey to P. Lorang. According to the EPA's revised estimate, commingling seems like a greater problem than it did in the original EPA appraisal. However, as discussed below, the update on commingling appears to be significantly exaggerated, which means that this issue remains uncertain and controversial.

The previous EPA estimates of commingling were built into the MOBILE model based on the 1987 memorandum. The MOBILE 5a model was used at SAI to evaluate commingling and the maximum impact (when the market share is 50 percent with blends containing 10 percent ethanol). The effect appeared to be small, typically equivalent to only about a 0.1 psi boost in RVP. However, this impact estimate is based on clear gasoline as the alternate fuel. If the alternate fuel has MTBE, then the RVP boost due to commingling is reduced to only about 0.05 psi. Considering that the blending of ethanol is often considered to boost RVP by nearly 1 psi, the commingling effect appeared to be small and comparable to the experimental uncertainties in either the vapor pressure increases due to ethanol or the ability to measure any RVP value.

Both the original and the revised commingling evaluations are largely based on an ARCO paper, which includes an analysis of commingling of alcohol blends containing methanol (i.e., oxinol). The ARCO paper was presented at the 1985 Houston meeting of the National Petroleum Refiner Association by J.M DeJovine, W.J. Piel and J.H. Baudino; the paper was entitled "Evaporative Emission Studies (Gasoline Methanol)." Oxinol mixed with clear gasoline can increase RVP by 1.4 psi with as little as 15 percent of the methanol-containing fuel present. The authors of the ARCO paper claimed that the most probable maximum fleet-wide impact by oxinol due to commingling would be only a 0.16 psi increase in RVP. Since ethanol is usually considered to increase RVP approximately 1 psi compared to 1.4 psi by oxinol and since this increase is not reached until over 20 percent from E10 blends mixed with clear gasoline, then the expectation, based on the ARCO study would be an E10 commingling impact on fleet-wide RVP of less than 0.1 psi. Also since the ethanol impact is known to be significantly diminished if the alternate fuel contains MTBE, then the commingling expectation could be reduced further. Finally, if, as the EPA argues, that ethanol used in the RFG program will most often be only 5.7 percent (i.e., not E10), then the commingling would again be reduced even further still. Yet the revised EPA estimate for ethanol shows fleet-wide impacts as high as 0.4 psi increases in RVP. Hence, the revised commingling estimate by the EPA is arguably 10 times worse than what might be expected from the ARCO analysis even though the EPA still claims to base its estimate on the ARCO study.

According to the figures in the 1993 RIA, the EPA re-evaluation seems to show effects on a per gallon ethanol basis as great as a full extra 1 psi increase in RVP (or even greater) depending on the assumed market share. Given the large discrepancy with previous estimates of commingling, it is very important that this re-evaluation be technically sound and carefully reviewed by the technical community.

A commingling effect of ethanol blends can exist whether the ethanol is match or splash blended. An 8 RVP blend with 10 percent ethanol can be mixed (i.e., commingled) with an 8 RVP clear gasoline to produce essentially a 9 RVP mixture over a wide range of mixing ratios. This occurs because the nominal 1 psi boost in RVP can appear with as little as 2 percent ethanol in the final mixture, but the RVP boost does not appreciably increase when the ethanol content is raised to 10 percent. For example, switching from a 10 percent blend to clear gasoline when the tank is 0.2 full will dilute the ethanol volume down to 2 percent yet retain nearly the full 1 psi RVP boost.

The important variables in commingling are many, and no comprehensive studies have been performed to date, that can be used to independently verify all the parts to the EPA's revised analysis. From our examination of that analysis, it appears that at virtually each step the EPA has arbitrarily chosen to interpret or modify data so that commingling estimates are maximized. The variables are below.

Customer Loyalty

According to the EPA, two sets of data are available on brand loyalty. The first, noted above, was submitted to the EPA in 1981 by ARCO as part of the oxinol waiver request. The EPA attempted to plot various loyalty curves in their Figures 1 through 3 of the RIA (reproduced here). The four available ARCO data points are plotted in the EPA's Figure 3 as cumulative percentage values with straight lines connecting the four points, plus straight lines from zero to the lowest data point and from 100 percent down to the highest data point. This set of straight lines is the only objective graphical presentation of loyalty data given by the EPA. Our Figure 3a shows two other possible curves (A and B) that pass through the data. The EPA created two new loyalty curves (2 and 3) that compound misinterpretation upon misrepresentation of the ARCO data as given in EPA Figures 1 and 2. The EPA appears to treat the cumulative ARCO data as if they were a population distribution (or what is sometimes called frequency distribution). A distribution plot is the derivative of a cumulative plot and, vice versa, the cumulative plot represents the integral of a distribution plot. We have also included Figure 6 from the ARCO paper cited above. Note that the ARCO plot is a "bar" graph and the EPA version of the same data is a "line" graph.

The most important single ARCO data point is that 63 percent of the population claims to be 75 percent (or higher) brand loyal. It means that the area under the population distribution plot should be 63 percent of the total area under the plot. This single ARCO data point also means that 63 percent of the population use the same brand in at least three out of four trips to buy gasoline. It would be consistent with this data point to interpret the fourth fill-up as random. However, the EPA claims that this (63 percent) data point (as they have plotted it in their Figure 1) implies something about an inordinately high percentage of the population being 100 percent brand loyal. We see no merit to such a claim. The ARCO paper does not make any claim about 100 percent loyalty. In fact, the ARCO paper states "This survey indicated that consumers are quite brand loyal and that 63% of those surveyed bought their favorite brand at least 75% of the time."

The EPA's Figures 1 and 2 are similar to frequency distribution plots. In such plots the ARCO data point of 63 percent (with 75 or higher percent loyalty) would imply only that the area under the curve between 75 and 100 on the x-axis is 63 percent of the total population. There is no information given in the ARCO data on the distribution of brand loyalty between 75 and 100 percent, we only know that 63 percent of the customers are in this box. The ARCO data does not and need not provide any information on 100 percent loyalty.

We have reproduced (as our Figure 3a) the curves from the EPA's Figure 3 (cumulative plot). Our Curve A, shown in Figure 3a, passes through the ARCO data and, in line with the EPA's concern, shows a negligible fraction of the population maintaining 100 percent loyalty. Note that Curve A addresses EPA's concern without resorting to the creation of totally new loyalty curves. Only the curve between the 75 percent loyal point (see Figure 3a) and 100 percent loyalty is significantly affected in our Curve A, while the EPA's Curves #2 and #3 affect all points on the cumulative plot. That is, in creating their Curves #2 and #3, the EPA have essentially thrown out the entire ARCO survey just to "fix" the distribution at and near 100 percent loyalty. We have also fitted a curve (Curve B) at the other extreme with a high population at 100 percent loyalty, which still preserves the ARCO data. Curve B will be used below as a sensitivity test. Note that while Curve A addresses EPA's concern over 100 percent loyalty, Curve B is still consistent with some new NPD data showing 37.8 percent of the population claiming to use only one brand.

Since the distribution-type plots should be the derivative of the cumulative plots, we have constructed the plot shown in our Figure 2a from the finite differences (at 5 percent intervals) of the curves shown in Figure 3a. It is very important to note that the two curves developed by the EPA bear little relation to the ARCO data as the EPA has plotted them in EPA Figures 1, 2 and 3. The EPA calls its Curve #2 "an attempt to retain the general trend of the ARCO data yet adjust for the concept that there would be a decrease in the percentage of owners with high loyalties (80% to 100%)." In their computer model, COMMINGLE, the EPA states that Curve #2 is "fitted to the ARCO data." The y-axis "percentage" values in the EPA's Figures 1 and 2 appear to show that Curve #2 follows the ARCO data up to 75 percent loyalty, yet our Figure 2a shows that Curve #2 never follows the ARCO data.

It must be remembered that the only reason the EPA gave for creating Curves #2 and #3 was the belief that EPA Figure 1 implied some "seemingly large percentage of customers that have 100% brand loyalty." Yet we have just shown in our Figure 2a that there is really no such problem with 100 percent brand loyalty. Our Curve A uses the ARCO data as is and still has essentially zero population at 100 percent loyalty. It is, therefore, our conclusion that all further references to Curves #2 and #3 in the EPA's overall analysis should be discarded.

The EPA, however, claims that a second data set, from the NPD Group Incorporated, supports its assumptions creating Curve #2. The NPD data show that 37.8 percent always use one brand and an additional 51.2 percent use two or three brands. Thus, 89 percent use three or fewer brands. We find this wholly consistent with the ARCO data point showing 63 percent using one brand in at least three of four gasoline purchases. If the fourth fill-up in the ARCO data is considered random, then several other brands could be involved. Yet the EPA considers that the NPD data on using two or three brands indicates a loyalty of only 40 to 60 percent. The only way to convert two brands to something like 50 percent brand loyalty would be to assume a random (e.g., fifty-fifty) distribution between the two brands. We see no basis, especially in view of the ARCO data, to make such an assumption to convert the NPD data to brand loyalty data. Other than the 37.8 percent who claim only one brand, the rest of the NPD data cannot objectively be converted to brand loyalty data unless the complete antithesis of "loyalty" (i.e., randomness) is assumed.

Refueling Patterns

The importance of commingling depends on the amount of gasoline left in the tank and how much is added to the tank when a customer does change from an ethanol blend to some other gasoline. The EPA Figures 4 and 5 show some actual data taken from a General Motors survey of over 1100 refueling events. In constructing its new commingling model the EPA has here too chosen to modify actual data for unsupported reasons. These unnecessary modifications further exaggerate the 1993 revised estimates of the commingling effect. The EPA made two modifications to the data shown in EPA Figure 4 and a further modification to the data used to construct EPA Figure 5.

One apparently arbitrary EPA modification is to assume that the zero gauge indication before refueling really means a 10 percent heel. That is, the EPA has arbitrarily added 10 percent of tank capacity to all readings. This means that there can be no percentage of the population which drive with the indicator needle below the zero gauge level or ever run out of gasoline. We also test the sensitivity of this assumption below using the commingling model. The next modification, shown in EPA Figure 4, is a smoothing of the data because the EPA believes the unevenness in the real data at the 0.2 fraction of tank capacity point may reflect anomalies in the method of reporting. We believe that with 1100 refueling events a statistically sound variance can be computed and this should be consistent with the EPA smoothing function. As noted above, the critical region for commingling from 10 percent ethanol blends occurs near the 0.2 fraction for refueling. That is, below this 0.2 fraction the RVP boost drops rapidly to zero. The EPA appears to have biased the commingling estimate by first shifting all the data above an arbitrary 10 percent heel, and then smoothing down by some 35 percent the reported data at the critical 0.1 gauge reading (0.2 fraction of tank capacity with heel).

EPA Figure 5 illustrates the next EPA modification of real data. This figure was constructed for refilling from a zero gauge reading (0.1 left in tank due to heel). The EPA appears to claim that the full fill-up must be over-represented because people watch their gas gauge and stop refueling when the gauge indicates full. It is our understanding that a very large fraction of the population instead use the shut-off valve on the refueling pump as an indication of a full tank. Many people also turn the ignition key off when refueling, which renders most gauges inoperative. Moreover, most new vehicles have a time-delay gauge circuit to prevent rapid needle fluctuations so that the gauge (if it were being used during filling) would not register full until a few minutes <u>after</u> the tank were actually full. Hence, we do not accept EPA's rationale for reducing the real data on full tank refueling. Although in California, at least, it is against the law to "top off" a tank once the shut-off valve has stopped the fueling process, we are aware that "topping off" rarely exceeds 10 percent of tank capacity. Yet the EPA arbitrarily cuts nearly in half the reported 43 percent of the population who attempt to completely fill their tanks, and furthermore, some of this cut (20 percent of the total population) is then apportioned downward beyond the next 0.1 fraction of tank capacity (see EPA Figure 5). All three of these EPA modifications to real or missing data (the 10% heel, the reduction of the population refueling with a gauge reading of only 0.1 fraction of tank capacity, and cutting nearly in half the population getting a full tank) serve to bias upwards the estimate of commingling by reducing the dilution by the new gasoline coming into the tank during refueling.

Vapor Pressure Curves

The last part of the commingling equation concerns the vapor pressure boost created in the tank after refueling. There are three general factors in the ethanol-induced vapor pressure effect: (1) the maximum increase, (2) the shape of function between zero and the maximum increase, and (3) the effect of a cosolvent such as MTBE.

The maximum increase in vapor pressure from adding ethanol to gasoline has an interesting history. In 1987, when the EPA last evaluated commingling, the maximum increase in RVP was believed to be 0.76 psi based on data submitted to the EPA by the ethanol industry. In 1988 the API added several higher values to the database which raised the average ethanol-related RVP boost to a nominal 1 psi. The API also used a regression analysis, which indicated a small dependence on the base RVP (28 June 1988 API letter to C. Gray of the EPA). The following regression equation, which is presumably based on the API letter, is taken from EPA's MOBILE 5a model:

$$RVP_{increase} = 1.5532 - 0.07598 * RVP_{nonoxy}$$

At the RFG base RVP of 8.1 psi, this equation gives a 0.94 psi boost for an ethanol blend.

A study by L. Wu at the University of North Dakota (UND) shows two important points related to this issue. First as much as 0.2 psi of the RVP boost can come from some highly volatile denaturants used in commercial fuel ethanol. Second the study found that water contamination before or during the measurement procedure can impart additional RVP increases as high as 0.5 psi. The workers at UND were unable to reproduce any of the highest API values unless the ethanol was both denatured by the most volatile hydrocarbons (e.g., butane) and contaminated by water.

Nevertheless the EPA, for the 1993 revisions to their commingling model, chose to use some data they had just received from General Motors that gave the highest average ethanol boost yet in RVP. We have plotted in our Figure 9, the General Motors data cited in Table #4 of the RIA. We note that Figure 9 shows that considerable scatter exists in these data points. Yet the EPA has ignored the UND results and even the previous equation in favor of the General Motors data.

The COMMINGLE Model

The EPA sent a copy to SAI of the 1993 computer model, COMMINGLE, used to develop EPA's revised estimates of the commingling effect. We have several important observations as follows:

1 Coding errors of major impact were found. For example, the averaging of RVP increases is supposed to be over 1000 trips, but a coding error uses only the last trip (fixing this error speeds the running time by a factor of two). The initial RVP is not given for the first trip. Also the option to use GM or smoothed GM filling data is reversed (although the model seems to give the same result for either option).

2 Simple quality assurance (QA) tests produced incorrect results. For example, zero and 100 percent market share inputs gave commingling effects, as did using 100 percent brand loyalty.

3 The program is hard-coded for 10 percent ethanol blends. This was surprising because the EPA had claimed that 5.7 percent ethanol blends would often be used in the RFG program. We would expect the commingling effect to be non-linear, in that commingling of a 5.7 percent blend would be much less than half the commingling effect of a 10 percent blend.

4 The computer model treats the refueling habits of each owner using random numbers to

follow 100 refueling events for 1000 individual owners. Each owner gets a new set of random numbers to select the refueling pattern in the course of the 100 refueling events. It seems possible that any given owner will have a specific refueling pattern rather than a random pattern. For example, according to the GM data the largest fraction (specifically about 43 percent) of the overall population fill their tanks all the way. That is, the individual owners in that 43 percent probably appear to fill their tanks virtually all the time.

5 Regarding the other side of the refueling pattern, those owners who take their tanks down to some gauge reading (e.g., zero or 0.1), probably do so virtually all the time. The computer model, on the other hand, treats each owner like the random population at large. That is, each and every owner fills up all the way only 43 percent of the time and take their tanks down to a different gauge reading every trip. For owners who always completely fill their tanks and always run the gauge down to a very low level (e.g., below indicated zero, like the Whitten family), the effects of commingling would be minimal even with little loyalty to a given brand. At the other end, commingling would be largest for owners who never completely fill the tank and always stop for gas when the gauge is still reading quite high. However, the former pattern may be more prevalent than the latter. Although no data were found to substantiate this, it seems reasonable to assume that individual owners tend toward a specific pattern in a way not unlike brand loyalty. That is, there is a "loyalty" to a specific refueling pattern, which is not addressed in the treatment of commingling now in the EPA computer code.

With the code errors fixed the commingling effect is half what the original code predicted for an RFG scenario with 8.1 psi RVP and 30 percent market share using EPA's interpretation of the ARCO and GM data. The result for the "fixed" model is a commingling effect of only 0.07 psi while the original model gives an effect of 0.14 psi.

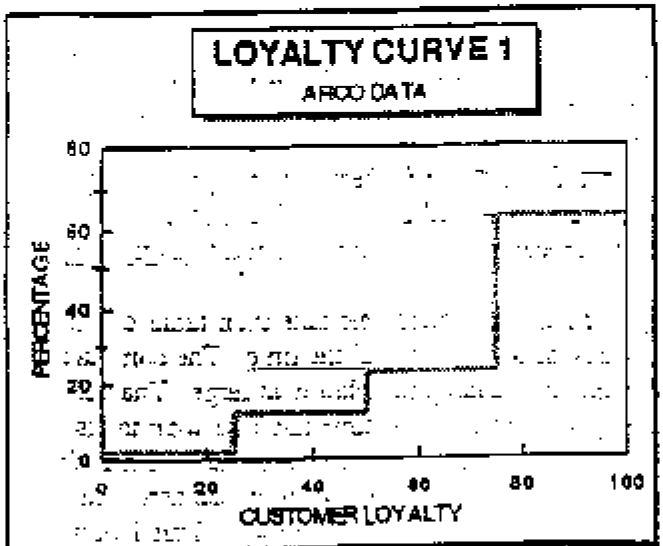


Figure 1 - Arco Brand Loyalty Data

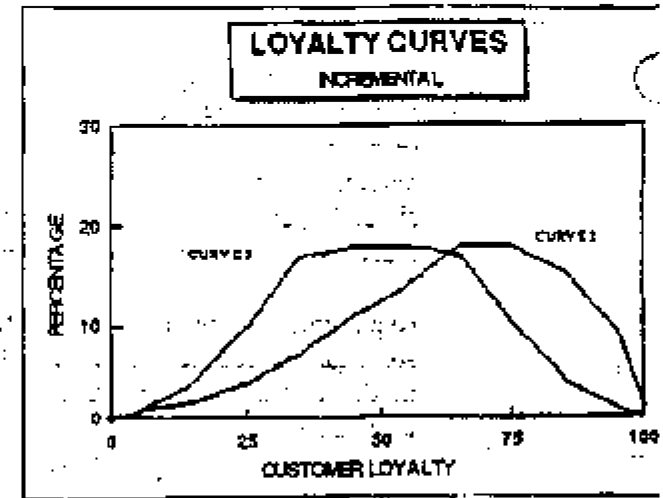


Figure 2 - Additional Brand Loyalt Curves

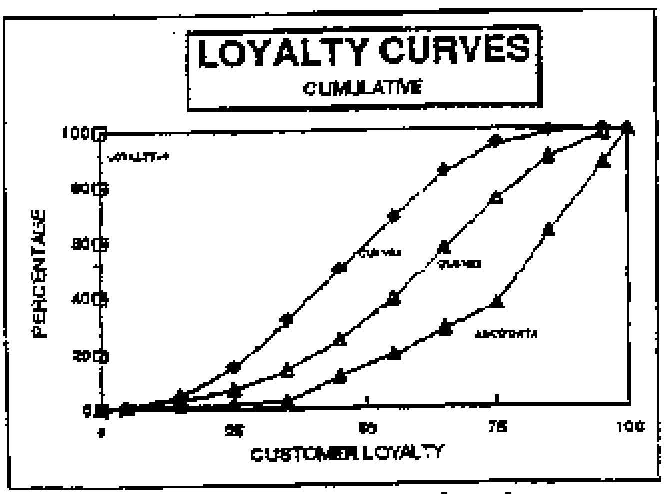


Figure 3 - Cumulative Loyalty Curves

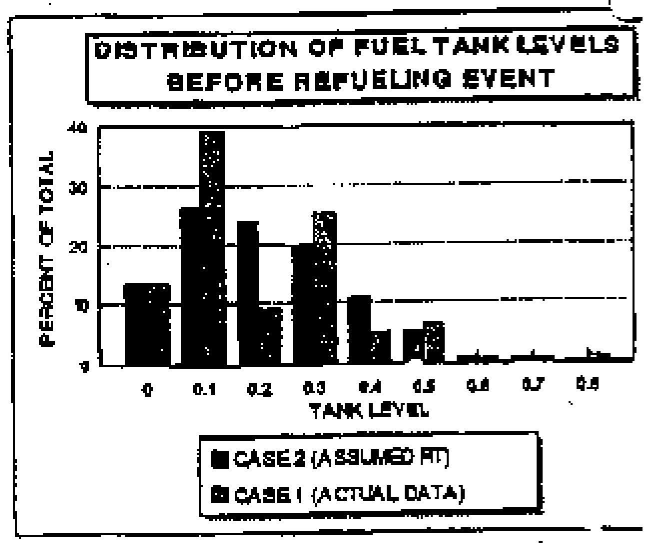


Figure 4 - Pre-Fueling Tank Levels

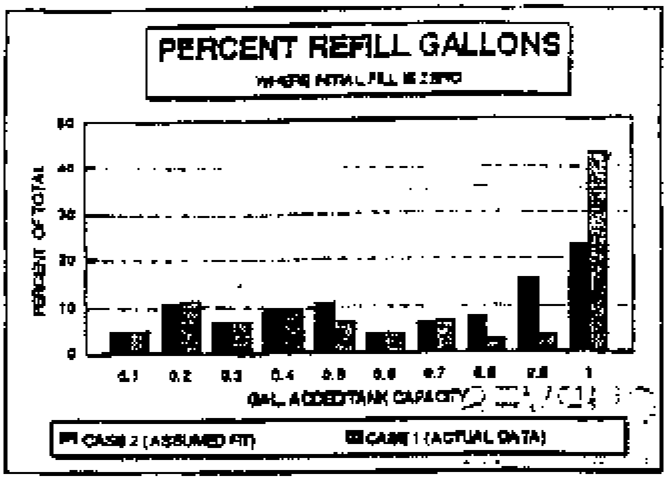


Figure 5 - Tank Fill Amounts for an "Empty" Tank

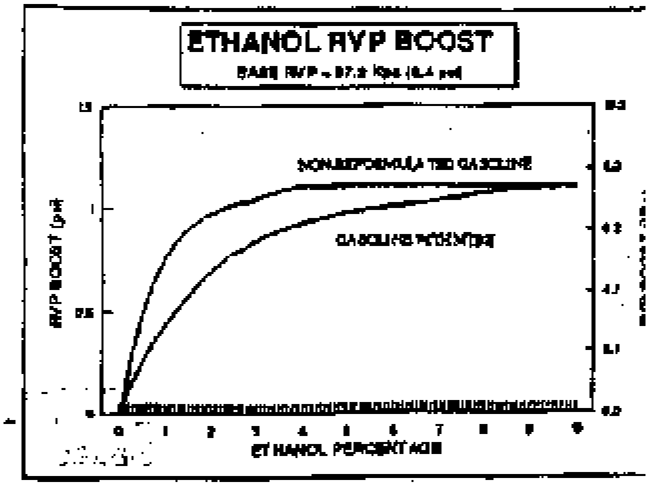


Figure 6 - Experimental RVP Boost, an 8 psi RVP Fuel

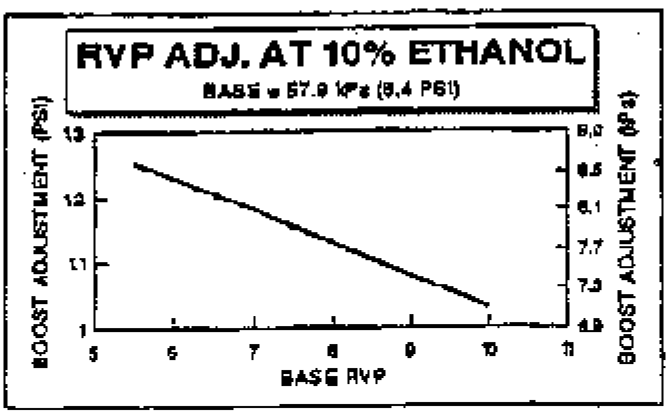
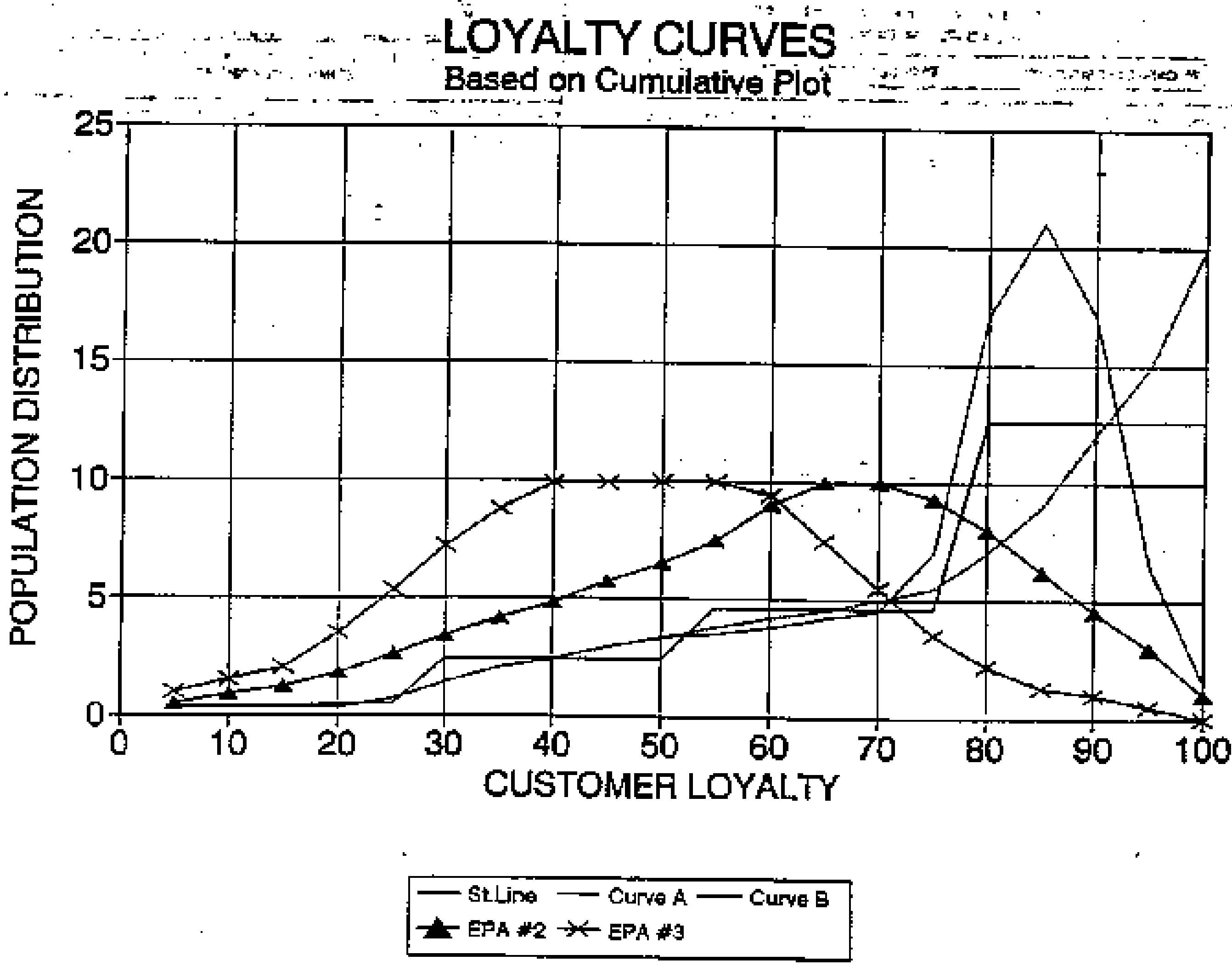
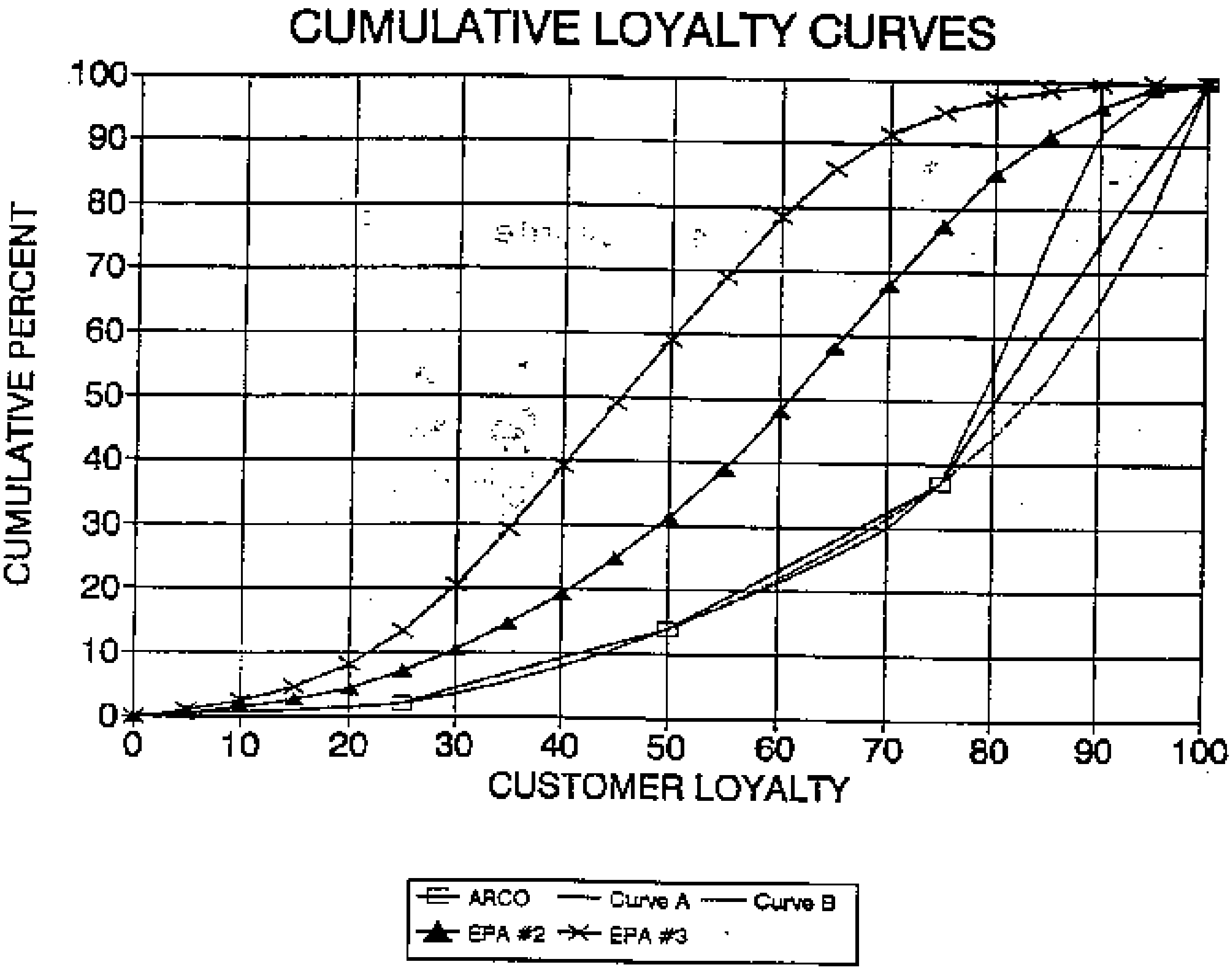


Figure 7 - RVP Boost Adjusment



LOYALTY CURVES
Based on Cumulative Plot
POPULATION DISTRIBUTION
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100
CUSTOMER LOYALTY
St.Line
Curve A
Curve B
EPA #2
EPA #3

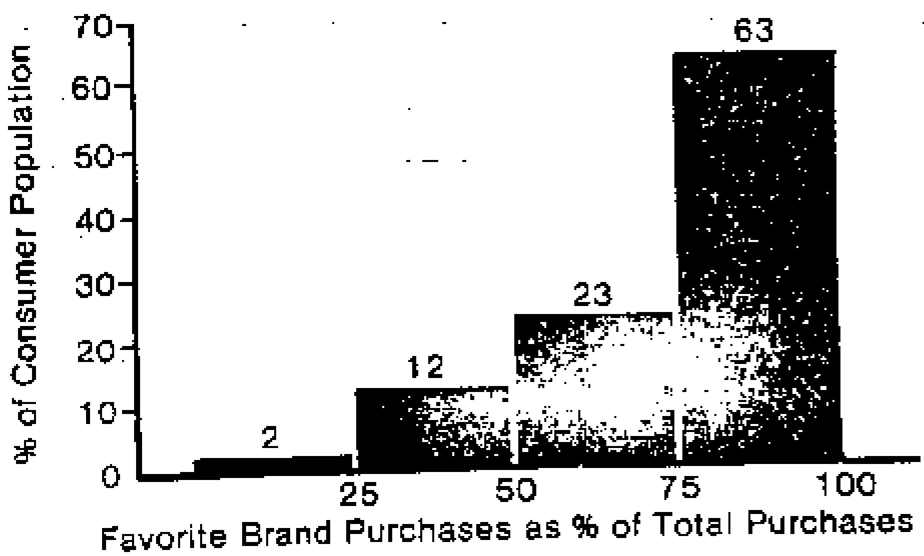
Figure 2a



CUMULATIVE LOYALTY CURVES
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
CUSTOMER LOYALTY
ARCO
Curve A
Curve B
EPA #2
EPA #3

Figure 3a

Figure 6
Population Profile of Consumers' Purchasing Loyalty to Their Favorite Brand of Gasoline



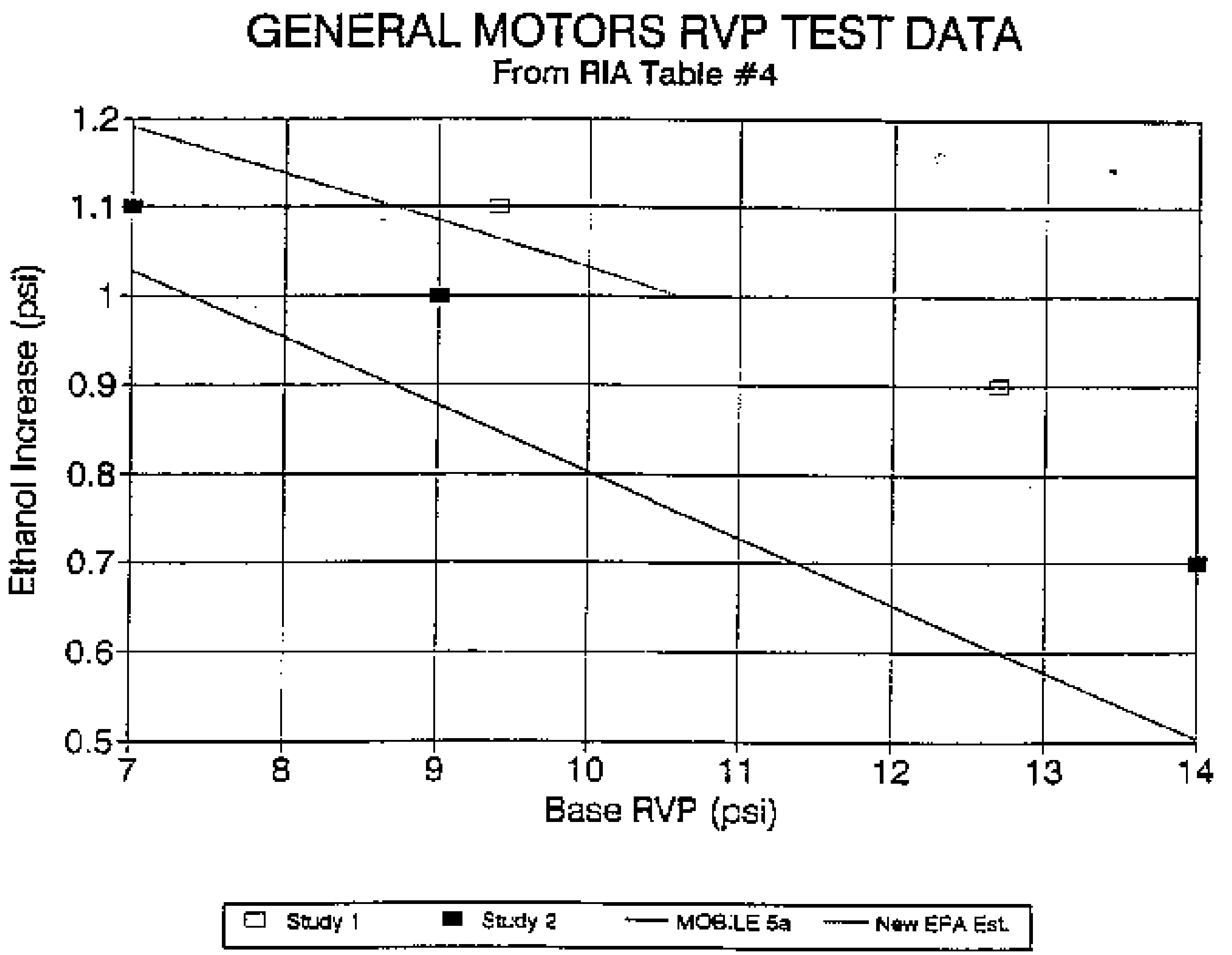

GENERAL MOTORS RVP TEST DATA
From RIA Table #4
Ethanol Increase (psi)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
7
8
9
10
11
12
13
14
Base RVP (psi)
Study 1
Study 2
MOBILE 5a
New EPA Est.

Figure 9

Appendix Q:

U.S. EPA Analysis of Commingling Impacts of California Waiver Request from Federal Oxygen Requirement

We agree that additional data are necessary to allow the emissions modeling that would support and quantify the ethanol permeation effect. CARB's Resolution 99-39 requires CARB to conduct research on permeation and calls for a progress report in October, 2000 (which has been completed) and a final report on the results of permeation testing by December, 2001. A contract is also planned that includes a literature search for the ethanol permeation rates of fuel system materials, collection of information regarding fuel system materials that will be in use in year 2003, distribution of vehicles in that year's fleet, and an estimate of the fleet-wide effect of permeation emissions. Until more data regarding these factors is developed, it is not possible to better characterize the permeation effect.

2. Commingling effect

When ethanol is mixed with gasoline, a non-linear increase in Reid Vapor Pressure (RVP) occurs. For example, if gasoline with an RVP of 8.0 psi is mixed with non-denatured ethanol (which alone has an RVP of 2.4 psi) in a 90 percent gasoline/10 percent ethanol mixture, the RVP of the resulting mixture is approximately 9.1 psi, a 1.1 psi RVP increase.[65] Because of this RVP boost associated with ethanol blending, a blendstock with a sufficiently low RVP must be used to achieve the desired RVP in the ethanol-blended gasoline. The initial amount of ethanol added to non-oxygenated gasoline results in greater incremental increases in RVP than subsequent amounts. This non-linear increase makes small amounts of ethanol very important to RVP.

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65 SAE paper 940765, "In-Use Volatility Impact of Commingling Ethanol and Non-Ethanol Fuels" Peter J. Caffrey and Paul A. Machiele, US EPA.

An RVP boost will also occur when ethanol-blended gasoline is mixed with non-oxygenated or ether-oxygenated gasoline. For example, the RVP of a mixture containing equal volumes of a 7 psi ethanol-oxygenated RFG blend and a 7 psi non-oxygenated RFG blend would be greater than 7 psi. When an ethanol-oxygenated gasoline is mixed with an MTBE-oxygenated gasoline the resulting increase in RVP is somewhat smaller than it is when an ethanol-oxygenated gasoline is mixed with a non oxygenated gasoline. Mixing of ethanol-oxygenated gasoline with other gasoline is called commingling and the associated RVP boost is called the commingling effect. Federal and California regulations prohibit or restrict commingling in the distribution system. These restrictions do not apply to commingling in vehicle fuel tanks, however. In the discussion that follows, commingling refers to the mixing of ethanol-gasoline with non-ethanol gasoline in vehicle fuel tanks.

The commingling effect is of concern because non-exhaust hydrocarbon emissions from vehicles increase with increasing RVP. Commingling has not been an issue within Federal RFG areas in California because there has been virtually no ethanol used in these areas.[66] With the requirement of 2.0 weight percent oxygen content in effect, the phase-out of MTBE in California could result in some commingling of ethanol and MTBE oxygenated gasolines if MTBE and ethanol were both used during the phase-out period. Commingling would no longer be a significant issue once the phase-out of MTBE is complete, if all gasoline sold within federal RFG areas was then ethanol-oxygenated gasoline, as expected. (Some commingling within federal RFG areas could still occur in theory, however, when a vehicle is refueled both inside and outside of a federal RFG area; however, in California this is unlikely to involve a substantial

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66 RFG surveys, which collected samples from retail stations in Los Angeles, San Diego and Sacramento confirm this.

fraction of the gasoline). In the case of an oxygen waiver, however, ethanol-oxygenated and non-oxygenated RFG could share the market within federal RFG areas in California. In the waiver scenario, we would expect the incidence of commingling to be substantially higher than in the other scenarios described. Consequently, a waiver of the oxygen content requirements may cause an increase in non-exhaust HC emissions due to commingling.[67]

Although mixing of ethanol with gasoline produces a nominal 1.0 psi RVP boost over a wide range of ethanol blending volumes, the actual average RVP increase that will occur in a mixed ethanol/non-oxygenated market would be, under any foreseeable set of conditions, significantly less than 1.0 psi.[68] The effect of commingling on average RVP depends on a number of factors.

Various models estimate the commingling effect under differing input assumptions about the amount of ethanol used, base RVP of the fuels, and consumer refueling habits.[69] Perhaps the most important factors for predicting the commingling effect in an ethanol/non-oxygenated market are brand loyalty (i.e., to what extent consumers refuel with one brand, several brands or many brands of gasoline), and market share (i.e., the fraction of the gasoline sold in an area that

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67 This would be true either for a complete waiver of the oxygen requirements, or any partial waiver which includes removal of the per-gallon minimum oxygen requirement (1.5 weight percent) allowing some non-oxygenated CaRFG3 in federal areas.

68 The term "average RVP increase" refers to the actual increase in RVP caused by commingling in a subset of the entire gasoline pool, averaged over the entire gasoline pool.

69 Specifically, SAE paper 940765, cited earlier, describes a model developed by Caffrey and Machiele of EPA. Also, Dr. D.M. Rocke, University of California at Davis, developed a probability model ("UCD model") to study commingling. A description of the model developed by Dr. D. M. Rocke, University of California at Davis for CARB is available at http://www.arb.ca.gov/cbg/carfg3/Comming1.PDF. The computer code for the model is available at http://www.arb.ca.gov/cbg/carfg3/Comming.PDF.

contains ethanol).[79] Both the EPA model and D.M. Rocke's probability model indicate that when "loyalty" is held constant, the commingling effect peaks at or near 50 percent ethanol market share. (For the EPA model the effect peaks at 30 to 50 percent market share, depending on the model parameters selected.) These models also show that as loyalty decreases at a constant market share, i.e. as consumer refueling choices become more random, the commingling effect increases.

Although these models may accurately predict the magnitude of the commingling effect for a given set of input conditions, the conditions that would be applicable to the Federal RFG areas in California if a waiver were granted are largely unknown. CARB staff has estimated the likely commingling effect to be about 0.1 psi in a ethanol/non-oxygenated market with an oxygen waiver in effect. (See Docket A-2000-10, Document II.D.18-b). The assumptions used in their analysis included ethanol in 100 percent of premium gasoline and 46 percent of regular gasoline. They further assumed no grade switching. Thus, they assumed that commingling could occur only in vehicles using regular gasoline. They assumed that regular gasoline made up 75 percent of the gasoline pool, with the remaining 25 percent premium. Additionally, they assumed that 63 percent of regular grade customers switch brands, potentially resulting in commingling. Using a "simplified" analysis they calculated the RVP boost for each possible outcome under two scenarios (three refills with initial tank volume at quarter tank level and 4 refills at half tank level) and averaged the results for each scenario. They estimated the RVP increase of the gasoline pool by multiplying the average result by the commingling probability (63 percent) and the regular grade market share (75 percent). Average increases (above 7 psi) were 0.12 psi for

[79] With the assumption that a given brand will not sell both ethanol and non-ethanol gasoline in the same geographic area

the 1/4 tank scenario and 0.16 psi for the half tank scenario. These calculations were based on ethanol content of 10 volume percent (about 3.5 weight percent oxygen) in ethanol oxygenated gasoline. CARB determined, based on the UCD commingling model, that the boost with 5.7 volume percent ethanol content RFG (about 2.0 weight percent oxygen) would be about 80 percent of the boost with 10 volume percent. Consequently, they applied an 80 percent adjustment factor to their 10 volume percent RVP boost estimates to estimate the boost if 5.7 volume percent ethanol content oxygenated RFG were used. Resultant estimates were 0.10 psi average RVP increase for the quarter tank scenario and 0.13 psi for the half tank scenario.

The commingling effect under a waiver is difficult to forecast, depending on oxygenated/non-oxygenated market share, the oxygen content used in ethanol-oxygenated RFG, brand loyalty and other factors related to owner refueling behavior. Considering available information, however, we are concerned that CARB's 0.1 psi estimate of the commingling average RVP effect is likely to be low, even given many of CARB's underlying assumptions.

EPA (Caffrey and Machiele) developed a model to help assess the average in-vehicle RVP increases that could occur if ethanol-oxygenated gasoline were commingled with non-oxygenated (or MTBE-oxygenated) gasoline during vehicle refueling.[71] CARB's oxygenate use and grade split assumptions result in an overall oxygenated CaRFG3 share of about 60 percent. EPA's model using this 60% oxygenated market share, CARB's 7 psi RVP base and a loyalty curve (curve 2) which the model's authors felt "may be the best representation of customer

71 SAE paper 940765, "In-Use Volatility Impact of Commingling Ethanol and Non-Ethanol Fuels" Peter J. Caffrey and Paul A. Machiele, US EPA.

brand loyalty available for this model" estimated an RVP increase of 0.24 psi.[72] This model assumes that ethanol content would be 10 volume percent. Applying the 80 percent adjustment factor used by CARB to estimate the RVP boost with 5.7 percent ethanol, the average RVP increase is 0.19 psi.

CARB also assumed that all premium gasoline would be ethanol-oxygenated so that commingling would occur only within regular grade gasoline. EPA's model, with the other parameters identical, but with the market share at 46 percent, CARB's regular grade assumption, estimated an average RVP increase of 0.28 psi. If the 80 percent factor is applied to adjust to 5.7 percent ethanol content, the expected average RVP increase for regular grade is 0.22 psi. Assuming that this applies to the 75 percent regular grade portion of the pool, the overall average RVP increase would be about 0.17 psi.

MathPro's refinery modeling for EPA estimated ethanol oxygenated market shares between 26 percent and 65 percent for various waiver scenarios. For waiver scenarios where oxygen content was 2.0 weight percent, oxygenated market shares ranged from 26 percent to 50 percent. MathPro's refinery modeling also predicted an as-blended RVP of about 6.6 psi for oxygenated and non-oxygenated CaRFG3 in these 2.0 weight percent oxygen scenarios. EPA's commingling model, with a base RVP of 6.6 psi estimated an average RVP increase of 0.27 psi from commingling at 26 percent ethanol market share, and a 0.28 psi average RVP increase at 50 percent market share (with other model parameters as in previous runs.) Adjusting these

72 See the SAE paper for discussion of loyalty curve data. For the EPA model runs relating to the waiver evaluation, user-specified parameters selected were owners=1000, fills=100 (simulating 1000 owners refueling 100 times), loyalty curve= 2, fill curve=3, tank heel=0.1. The model was run for a non-reformulated gasoline scenario in order to simulate commingling of non-oxygenated gasoline and ethanol-oxygenated gasoline rather than MTBE and ethanol gasolines.

estimates to 5.7 percent ethanol content using the 80 percent factor results in an average RVP increase of about 0.22 psi.

If the overall market share of ethanol oxygenated gasoline was 50 percent, and it was assumed, as CARB suggests, that ethanol was used in 100 percent of premium, the ethanol market share in regular grade (with a 25/75 premium/regular split) would be around 33 percent. EPA's model estimated an average RVP increase of 0.29 psi at 33 percent market share with the other parameters as above. Adjusting for 5.7 percent ethanol, and applying this increase to 75 percent of the gasoline pool results in an average RVP increase of about 0.17 psi. If the oxygenated market share was 26 percent and ethanol was used in 100 percent of premium, with CARB's assumptions, virtually no oxygen would be used in regular gasoline. Consequently, under these conditions the average RVP increase due to commingling could be negligible. CARB's commingling analysis considered a scenario where ethanol was used in 100 percent of premium and zero percent of regular, with the only commingling coming from a small amount of grade switching. CARB estimated a commingling effect under this scenario of around 0.02 psi. While it is possible that this scenario could occur, CARB's own evaluation of the commingling effect does not identify this as the likely commingling scenario.

EPA has also examined the Sierra Research report prepared for the American Methanol Institute. Sierra Research modified the EPA commingling model to allow variation of the ethanol content of ethanol-oxygenated gasoline and to allow different base RVPs for the ethanol-oxygenated and non-oxygenated portions of the gasoline pool. Sierra Research generated RVP boost curves as a function of ethanol market share for a scenario in which a 6.9 psi RVP ethanol blend was used in conjunction with a 6.5 psi RVP non-oxygenated fuel. Sierra Research estimated minimum, maximum and average commingling impacts at various market shares. EPA understands the minimum curve estimates the commingling impact when gasoline containing 5.75 volume percent is used, the average curve with 7.8 percent and the maximum curve with 10 percent. The minimum curve peaks at around 0.2 psi and is fairly flat, with the RVP boost close to 0.2 psi for ethanol market shares between about 30 to 70 percent. This curve is at or above 0.1 psi between about 15 and 90 percent market share. EPA has not validated the modifications to the model. Additionally, MathPro's refinery modeling does not indicate that there will be a substantial difference in RVP between ethanol-oxygenated and non oxygenated CaRFG3 in a shared market. However, Sierra's analysis does conclude that the commingling effect, if ethanol is used at 5.7 volume percent, is likely to be around 0.2 psi over wide range of market shares.

We believe, in the absence of better information that it is at least, if not more, reasonable to assume for waiver evaluation that the commingling effect would be around an average RVP increase of 0.2 psi rather than 0.1 psi. CARB estimated the commingling effect by calculating a small number of refueling iterations under a set of assumptions that would tend to produce an RVP boost estimate at the lower end of the range of likely RVP increases (i.e., 100 percent ethanol use in premium gasoline, no grade switching, and ethanol content at 5.7 volume percent). Furthermore, EPA's analysis indicates that even with these assumptions concerning ethanol use, content and grade switching, the commingling effect is still likely to be about 0.17 psi which is closer to 0.2 psi than 0.1 psi. Also, if any of CARB's assumptions do not strictly hold, the commingling effect is likely to increase above this estimate.

EPA acknowledges that the octane characteristics of ethanol may result in preferential use in premium gasoline, that many owners do not switch grades, and that RFG suppliers may well elect to use ethanol at 5.7 volume percent. There are, however, to our knowledge no hard data to support CARB's assumptions with respect to ethanol use in 100 percent of premium gasoline and the total absence of grade switching. EPA's model also shows that the magnitude of the commingling effect increases as brand loyalty decreases. Under "no loyalty" conditions, the model predicts commingling effects of up to about 0.4 psi. Adjusting this result with the 80 percent factor shows that a commingling effect in excess of 0.3 psi could occur when ethanol is used at 5.7 volume percent. While a "no loyalty" assumption is extreme and is not likely to approximate owner behavior, this result shows that there is a potential for the commingling effect to exceed 0.2 psi. Since commingling is very sensitive to variables such as brand loyalty which have been only crudely estimated, a plausible case can be made for commingling effects ranging from an average RVP increase of 0.1 to 0.3 psi.

In order to offset the effect of commingling, the CaRFG3 regulations contain a 0.1 psi reduction from Phase 2 in the RVP flat limit (from 7.0 to 6.9 psi). This 6.9 psi flat limit is applicable to refiners electing to use the predictive model evaporative compliance option. It appears, based on available information, that most, if not all, refiners are likely to utilize the evaporative compliance option with or without a waiver. Thus, the absence or presence of a waiver is unlikely to result in a difference in the utilization of this option. Moreover, CARB is committed by resolution and state law, to conduct additional evaluations of the commingling effect. Through Resolution 99-39, CARB is required to evaluate the real-world emissions impact of commingling in 2003 and beyond, and report its findings and recommendations to the Board by December 2001. CARB will investigate the expected prevalence of ethanol and non-oxygenated CaRFG3 by supplier, grade and geographic area. CARB will also collect information on refueling patterns, brand and grade loyalty as well as samples of actual in-use fuels. California state law (Senate Bill 989) requires that CaRFG3 maintain or improve upon emissions and air quality benefits achieved by California Phase 2 RFG in California as of January 1, 1999. Therefore, if CaRFG3's more stringent RVP limit does not offset the commingling effect, this law would require CARB to take additional measures to assure there would be no real-world increase in HC emissions. There is some uncertainty about the mitigative measures that California can and will apply if the magnitude of the commingling effect exceeds CARB's expectations. CARB would first have to assess the magnitude of the commingling effect, and then determine what can be done to offset this effect. It does not appear that California would be required by state law or resolution to take any action unless it determined that the commingling effect exceeds the 0.1 psi that was anticipated. Thus, any mitigative action would likely only serve to maintain the equivalent of the 0.1 psi waiver to no waiver differential.

CARB intends to conduct a field study to evaluate the expected real world emissions impact of commingling CaRFG3 containing ethanol with CaRFG3 not containing ethanol. However, according to the draft protocol for CARB's commingling study, (as modified March 31, 2001; see Docket A-2000-10, Document Number II-D-81) we anticipate that the study will be conducted at retail gasoline facilities in northern California that are currently marketing non-MTBE gasoline. Thus, even if the CARB commingling study accurately evaluates commingling effects within the study area, it is somewhat uncertain that these results will be applicable to the South Coast Air Quality Management District. The magnitude of the commingling effect is highly sensitive to brand loyalty, which conceivably could differ significantly from area to area. The magnitude of the RVP boost is mitigated somewhat by the presence of MTBE. A commingling study done prior to the elimination of MTBE could potentially underestimate the effects of commingling on RVP. The focus of EPA's waiver analysis has been to estimate the emissions effect of the waiver in the SCAQMD after MTBE has been phased out. Potentially, CARB could conclude from a field study that the commingling impact is sufficiently addressed, when in fact it is not in the area and time of concern.

It is also not clear whether the 0.1 psi RVP adjustment adopted by CARB should be treated, for purposes of evaluating California's waiver request, as offsetting the VOC emissions associated with commingling. The 0.1 psi reduction in RVP applies regardless of whether a waiver is granted, hence the emissions benefit of the reduction occurs whether or not a waiver is granted while the commingling emissions occur only if a waiver is granted. Consequently, EPA estimated the effect of commingling RVP increases on VOC emissions for each of the twelve scenarios considered, assuming commingling RVP increases of 0.1 and 0.2 psi.[73]

EPA used the equation from the Sierra Research report, cited earlier, to estimate the percent increase in evaporative VOC emissions that could be expected relative to the "as-blended" state for each scenario and each level of commingling RVP increase. We then applied these percent change factors to our estimates of the "as-blended" evaporative VOC emissions

73 For purposes of this decision EPA does not need to decide whether it is appropriate to offset the expected increase in emissions from commingling with the 0.1 psi RVP reduction adopted by CARB. This is because even if the 0.1 psi offset is applied, as discussed below, VOC reductions are too uncertain to resolve what effect of a waiver would have on ozone.

inventory to estimate the increase in evaporative tons/day associated with each scenario.[74] Table 28 below gives our estimates of commingling VOC increases attributable to on-road vehicles assuming various levels of RVP increase due to commingling.

Table 28 Estimated South Coast On Road Commingling VOC Increases With Waiver (tons/day)

No Waiver Oxy Level	Waiver Oxy Level	Nationwide MTBE Use	Unocal Patent	VOC 0.1psi boost	VOC 0.2 psi boost
2.0	2.0	Reduced	Patent not avoided	5.55	11.22
2.7	2.7	Reduced	Patent not avoided	5.15	10.41
2.7	2.0	Reduced	Patent not avoided	5.15	10.41
2.0	2.0	Continues	Patent not avoided	5.55	11.22
2.7	2.7	Continues	Patent not avoided	5.25	10.61
2.7	2.0	Continues	Patent not avoided	5.15	10.41
2.0	2.0	Reduced	Patent avoided	5.38	10.57
2.7	2.7	Reduced	Patent avoided	5.22	10.54
2.7	2.0	Reduced	Patent avoided	5.17	10.45
2.0	2.0	Continues	Patent avoided	5.39	10.89
2.7	2.7	Continues	Patent avoided	5.26	10.63
2.7	2.0	Continues	Patent avoided	5.18	10.47

3. CO effect of decreasing oxygen

Removing oxygen from gasoline will tend to increase emissions of CO for the on-road vehicle fleet. CARB in its February 7, 2000 submission has estimated the expected CO emissions from representative non-oxygenated gasoline, as well as gasoline containing 2.0

74 Again, using the "2.7,2.7,continues,patent avoided" scenario as an example, we calculated an 8.21 ton/day VOC decrease due to the "as-blended" RVP difference, resulting in an "as-blended" waiver evaporative VOC inventory of 130.79 tons/day (139.0-8.21). The average RVP, based on the MathPro RVP and marketshare estimates, is 6.68 psi (6.60x35%+6.73x65%). Using the Sierra Research equation, we estimated a 4.02 percent increase (69.449/66.763-1) in evaporative VOCs with a 0.1 psi boost to 6.78 psi. Applying this to the "as-blended" evaporative inventory yields an estimate of 5.26 tons/day (130.79x4.02%) increase in evaporative emissions from on-road vehicles if the commingling effect is 0.1 psi.

weight percent oxygen, both of which would meet the CaRFG3 standards. CARB estimates that reducing gasoline oxygen content from 2.0 weight percent to zero would result in an estimated increase of 4.6 percent in CO. This CARB-estimated increase does not take into account mitigative effects claimed by CARB of reducing the sulfur content from 20 ppm to 10 ppm and reducing T50 from 211° F to 205° F to offset the increase in exhaust VOC. According to CARB's February 7, 2000 submission, (available in Docket A-2000-10, or at http://www.arb.ca.gov/cbg/Oxy/way/oxyway.htm) the net result of removing oxygen from California gasoline would be an increase in CO of about 2.7 percent (95 tons per day divided by 4,995 tons per day). (CARB felt that reduction of sulfur and T50 were necessary in order for the non-oxygenated fuel to meet the CaRFG3 regulations.)

We used CARB's assumptions regarding oxygen effect on CO (as detailed in Appendix G of its staff report for the CaRFG3 rule) in calculating CO increases.[75] For conservatism, we did not adjust the CO increases for sulfur or T50 reductions.[76] We split the CO increase among the Tech 3, Tech 4 and Tech 5 categories as CARB did, assuming that there would be no change in CO as a result of oxygen reduction in Tech 5 vehicles (which CARB assumed as well).[77]

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75 More specifically, we used the percent CO reductions per weight percent increase in oxygen reported in Appendix G, Table 4 of CARB's staff report on CaRFG3. (Appendix G available at: http://www.arb.ca.gov/regact/carfg3/appg.pdf). These factors were converted to percent CO increases per weight percent reduction in oxygen to calculate increases due to oxygen removal. CARB did report CO increases per weight percent oxygen reduced in other tables in the appendix. These factors differ slightly.

76 Reductions in T50 and sulfur may result in lower CO emissions. However, we are uncertain of the basis for the quantitative estimates of these effects contained in Appendix G of the CARB staff report, and cannot provide alternative estimates. (Appendix G available at: http://www.arb.ca.gov/regact/carfg3/appg.pdf). We also note that comparison of certain MathPro modeling cases indicates that sulfur may be higher in non-oxygenated CaRFG3 than oxygenated CRFG3.

77 Separate reductions were reported for MY86-90 and MY91-95. We combined these into a single factor to represent Tech 4 vehicles using statewide tons per day estimates contained in Table 3, Appendix G of CARB's staff report on CaRFG3, as weights. (Appendix G available at: http://www.arb.ca.gov/regact/carfg3/appg.pdf). The factors expressed as CO percent changes per percent increase in oxygen, and parenthetically as changes per percent decrease in oxygen are -5.07% (5.34%) for

In our assessment of a waiver's effect on CO we included the effect, where applicable, of reduced oxygen content in oxygenated CaRFG3 (i.e., 2.0 percent versus 2.7 percent oxygen by weight). Table 29 below summarizes our estimates of the on-road CO increases expected under various scenarios (in tons per day).

Table 29: Estimated South Coast On Road CO Emission Inventory Changes With Waiver

No Waiver Oxy Level (wt. %)	Waiver Oxy Level	Nationwide MTBE Use	Unocal Patent	CO Increase (tons/day)
2.0	2.0	Reduced	Patent not avoided	71.96
2.7	2.7	Reduced	Patent not avoided	92.27
2.7	2.0	Reduced	Patent not avoided	112.53
2.0	2.0	Continues	Patent not avoided	55.45
2.7	2.7	Continues	Patent not avoided	61.58
2.7	2.0	Continues	Patent not avoided	95.36
2.0	2.0	Reduced	Patent avoided	81.92
2.7	2.7	Reduced	Patent avoided	83.13
2.7	2.0	Reduced	Patent avoided	123.48
2.0	2.0	Continues	Patent avoided	55.35
2.7	2.7	Continues	Patent avoided	53.88
2.7	2.0	Continues	Patent avoided	95.36

Oxygen removal is also likely to increase CO emissions from off-road vehicles. EPA's estimate of off-road oxygen effects is discussed in detail in Section III.C.4, below.

4. Off-road vehicles and engines

Changes in fuel formulation are expected to affect emissions of off road vehicles and engines (off-road sources) as well as on-road vehicles. Directionally, a decrease in fuel oxygen,

Tech 3, and -3.16% (3.26%) for Tech 4. We used 244 tons/day CO to represent on-road gasoline vehicle South Coast emissions in 2005 without a waiver. We allocated 14.2% to Tech3, 44.3% to Tech4, and 41.5% to Tech5, based on Appendix G, Table 3.

all else constant, would be expected to increase exhaust HC and CO emissions and decrease NOx emissions for both off-road sources and on-road vehicles. Emission models such as CARB's predictive model and EPA's Complex Model, however, were based solely on emissions test data from on-road vehicles. These models may not accurately quantify the response of off-road sources to changes in fuel properties, because of substantial differences in engine and emission control technology between the two categories. There is no comparable fuel effects model for off-road sources nor are there extensive test data available to characterize fuel effects on off-road source emissions.

CARB staff used the Tech 3 portion of the predictive model, which represents older on-road vehicles, as a tool to estimate exhaust emission effects from off-road sources. CARB noted in their February 7, 2000 letter that the Tech 3 model may represent the exhaust emissions effect from larger four-stroke off-road sources reasonably well. CARB recognized that the model's usefulness may be very limited in predicting emissions effects for smaller engines and in two-stroke engines responsible for the majority of reactive organic gas emissions from off-road sources.

We share CARB's concern about the limited ability of the predictive model to represent off-road source emissions. The Tech 3 portion of the predictive model is intended to be representative of older closed-loop three-way catalyst vehicles. This technology is not representative of the current off-road source fleet.

As an alternative, we have used information in an EPA document, Report No. NR-003, to estimate the changes in the exhaust emissions from off-road sources that would result if a waiver were granted.[78] This report concluded that the fuel effects on exhaust VOC, NOx and CO emissions for off-road sources are mainly due to changes in oxygen content. The report estimated emission effects (in percent change in emissions per percent of fuel oxygen added) for four-stroke engines based on tests of 13 engines. These effects were -4.5% for HC, +11.5 percent for NOx and -6.3 percent for CO. The report estimated emission effects for two-stroke engines as -0.6 percent for HC, +18.6 percent NOx, and -6.5 percent for CO based on tests of one engine.

We combined the four-stroke and two-stroke effects into a single set of effects by weighting them according to statewide two-stroke and four-stroke emission fractions of ROG, NOx and CO calculated from emission inventories for 2005.[79] The weighted percent changes per percent increase in oxygen are -2.25 percent for HC, +12.62 percent for NOx and -6.33 percent for CO.

RVP is expected to be the fuel property most influential in determining evaporative emissions from off-road sources. MathPro's modeling for EPA shows that the as-blended RVP of CaRFG3 is likely to decrease with an oxygen waiver. We have assumed the same percentage emissions decreases for evaporative emissions from off-road sources and on-road vehicles . We realize that some evaporative emission increases due to commingling could potentially occur in off-road as well as on-road vehicles and engines. In our analysis we assumed the same range of possible RVP increases and applied the same percent change factors and calculation method used

78 "Exhaust Emission Effects of Fuel Sulfur and Oxygen on Gasoline Nonroad Engines", Report No. NR-003, November 21, 1997. Christian E. Lindhjem, U.S. EPA

79 See analysis in memo to docket on A-2000-10, Document Number II-B-[illegible]

to evaluate commingling emission increases in on-road vehicles. We have not attempted to quantify any permeation emission changes associated with off-road sources.

We have estimated the likely off-road source emissions impacts of a waiver on NOx, ROG and CO for the comparison scenarios that we have included in our on-road analysis. Given the assumptions discussed above, it is obvious that off-road NOx is predicted to decrease, while CO and exhaust ROG emissions are predicted to increase with a waiver under all scenarios (since oxygen decreases). Evaporative ROG emissions are predicted to decrease with a waiver under all scenarios (since as-blended RVP decreases). Our estimates of the impact of the waiver on off-road emissions should be considered with some caution. Clearly, the small amount of engine test data and simplified analysis used to develop estimates of oxygen effects on off-road emissions are not comparable to the large body of data and sophisticated analysis used to estimate fuel property emissions effects in on-road vehicles. Furthermore, we were unable to obtain inventory information which explicitly identified the gasoline portion of South Coast off-road emissions, and needed to make certain assumptions to derive these estimates.[80]

We have added these off-road source estimates to the on-road estimates for each of the scenarios to produce a total estimate of emission effects. These total estimates include exhaust and evaporative emission effects, including commingling and permeation. We realize that there is considerable uncertainty associated with our estimate of the effect of a waiver on off road sources. We believe, however, that we have made a reasonable effort to quantify these emissions, and to consider whether the inclusion of the emission estimates of off-road sources

80 Our 2005 no-waiver baseline off road inventory estimates in tons/day were NOx=25.51, exhaust ROG=95.39, evaporative ROG=25.18, and CO=1073.34. See analysis in memo in Docket A-2000-10, Document Number II-B-1.

changes the conclusions that we would reach based on analysis of on-road impacts only. The off-road estimates are shown below in Table 30 and the total estimates are summarized in Table 31 in Section III.D.

Table 30: Estimated South Coast Off Road Emission Inventory Changes With Waiver

				Emission Inventory Changes (tons/day)				
No Waiver Oxy Level	**Waiver Oxy Level**	**Nationwide MTBE Use**	**Unocal Patent**	**NOx**	**VOC no comm.**	**VOC 0.1 psi boost**	**VOC 0.2 psi boost**	**CO**
2.0	2.0	Reduced	Patent not avoided	3.34	2.32	3.33	4.35	101.28
2.7	2.7	Reduced	Patent not avoided	-3.89	1.33	2.26	3.22	132.82
2.7	2.0	Reduced	Patent not avoided	-4.94	2.17	3.10	4.06	161.1
2.0	2.0	Continues	Patent not avoided	-2.57	1.65	2.66	3.68	77.83
2.7	2.7	Continues	Patent not avoided	-2.59	1.00	1.95	2.92	88.53
2.7	2.0	Continues	Patent not avoided	-4.78	1.45	2.41	3.37	135.58
2.0	2.0	Reduced	Patent avoided	-3.80	1.96	2.93	3.93	115.18
2.7	2.7	Reduced	Patent avoided	-3.50	1.44	2.39	2.35	119.54
2.7	2.0	Reduced	Patent avoided	-5.34	2.68	3.62	4.57	176.75
2.0	2.0	Continues	Patent avoided	-2.57	0.98	1.96	2.95	77.63
2.7	2.7	Continues	Patent avoided	-2.27	0.57	1.62	2.60	77.48
2.7	2.0	Continues	Patent avoided	-4.28	1.66	2.60	3.56	115.58

D. Effect of total emission changes

The changes in NOx, VOC, and CO inventories are based upon refinery modeling predictions of the most economic levels of oxygen use for both a waiver and non-waiver scenario considering various possible developments regarding nationwide MTBE use and the Unocal patent (as discussed in Section III.A.2). Table 31 below summarizes the effect of a waiver on NOx and VOC and CO inventories for twelve of sixteen possible "no waiver"/"waiver" comparison scenarios which can be constructed from MathPro's modeling for EPA. Table 31 incorporates consideration of all exhaust and evaporative emission changes from on-road vehicles (including commingling and permeation), as well as changes in off-road source emissions.

In Table 31 the columns for VOC emissions reflect the estimated impact of a waiver on actual VOC emissions (in tons/day), considering exhaust and evaporative emissions, including commingling and permeation, from on-road and non-road vehicles. The columns differ based on the estimates of average increase in RVP associated with commingling. For example, "VOC 0.1 psi boost" would reflect the impact of a waiver on the VOC inventory if commingling increases the average RVP by 0.2 psi, but this increase is treated as partially offset by CARB's adoption of a 0.1 psi reduction in RVP.[81] The column "VOC no boost" would reflect the impact on the VOC inventory if commingling increases RVP by 0.1 psi, and this increase is treated as fully offset by CARB's adoption of a 0.1 psi reduction.

8 This column would also reflect the impact of a waiver on the VOC inventory if commingling increases the average RVP of the gasoline by 0.1 psi and the impact is not offset.

Table 31: Waiver Impacts at Various Commingling-Related RVP Boosts

				Waiver Case Oxygen Market Shares and Oxy Levels			Emission Inventory Changes (tons/day) (On road, off road and all exhaust and evaporative VOC such as permeation and commingling)				
No Waiver Oxy Level	Waiver Oxy Level	Nationwide MTBE Use	Unocal Patent	% Oxyfuel	% Non-Oxyfuel	Year-round Oxygen Avg	NOx	VOC no boost[82]	VOC 0.1 psi boost[83]	VOC 0.2 psi boost[84]	CO
2.0	2.0	Reduced	Patent not avoided	35	65	1.0	-6.60	-4.02	2.54	9.23	173.13
2.7	2.7	Reduced	Patent not avoided	40	60	1.5	-2.53	-15.24	-9.15	-1.94	225.19
2.7	2.0	Reduced	Patent not avoided	35	65	1.0	9.61	-16.23	-10.14	3.93	274.24
2.0	2.0	Continues	Patent not avoided	50	50	1.3	-5.08	-4.10	2.46	9.15	133.16
2.7	2.7	Continues	Patent not avoided	60	40	1.9	-4.68	-9.72	-3.51	2.81	150.12
2.7	2.0	Continues	Patent not avoided	50	50	1.3	-8.21	-16.35	-10.26	-4.05	230.93
2.0	2.0	Reduced	Patent avoided	26	74	0.9	-7.20	-9.05	-2.69	3.79	197.11
2.7	2.7	Reduced	Patent avoided	46	54	1.6	-7.08	-12.12	-5.96	0.33	202.67
2.7	2.0	Reduced	Patent avoided	26	74	0.9	-10.89	-15.55	-9.44	3.20	300.22
2.0	2.0	Continues	Patent avoided	50	50	1.3	-4.84	-8.17	-1.80	4.69	134.14
2.7	2.7	Continues	Patent avoided	65	35	2.0	-4.78	-9.35	-3.13	3.20	131.36
2.7	2.0	Continues	Patent avoided	50	50	1.3	-8.71	-14.73	-8.61	-2.36	230.93

82 This scenario is equivalent to a 0.1 psi RVP boost from commingling completely offset by California's 0.1 psi adjustment to its standards. For purposes of this decision EPA does not need to decide whether it is appropriate to offset the expected increase in emissions from commingling with the 0.1 psi RVP reduction adopted by CARB, as even if the 0.1 psi offset is applied, as discussed in III.D., VOC reductions are too uncertain to resolve what effect a waiver would have on ozone.

83 Equivalent to a 0.2 psi RVP boost from commingling offset by California's 0.1 psi adjustment to its standards resulting in a net commingling effect of 0.1 psi.

84 Equivalent to a 0.3 psi RVP boost from commingling offset by California's 0.1 psi adjustment to its standards resulting in a net commingling effect of 0.2 psi.

Table 31 shows that there would be a net NOx decrease and CO increase with the waiver under all scenarios. It also shows a VOC increase with the waiver for two of the twelve scenarios at 0.1 psi commingling average RVP increase and for seven scenarios at 0.2 psi commingling increase. This table also includes an estimate of a "Year-round Oxygen Average".[85]

Table 32 summarizes the individual components of the VOC change associated with the waiver. This table illustrates that the impact of a waiver on VOC emissions is considerably more complex to model than the impact of a waiver on either NOx or CO emissions. Thus, there is significant uncertainty as to the overall VOC effect of a waiver–in both the amount and the direction of the effect.

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85 This average was estimated considering likely oxygenate usage patterns during the winter season in the absence of a mandate. For purposes of this analysis, year-round oxygen averages for the waiver cases are calculated based upon the summertime market share and oxygen levels modeled in the MathPro report and assume wintertime oxygenated gasoline use patterns in San Diego and Sacramento to be the same as summertime use patterns and wintertime oxygen use in Los Angeles to be at 2.0 weight percent in all gasoline as required under the state's wintertime oxygenated gasoline program. In fact, there is reason to believe that these wintertime oxygen use patterns would be the most likely wintertime use patterns to emerge in a waiver scenario. MathPro has concluded this in its analysis for EPA.

Table 32: Components of Total VOC Change [86]

No Waiver Oxy Level	Waiver Oxy Level	Nationwide MTBE Use	Unocal Patent	On-Road VOC Changes					Non-Road VOC Changes			
				Exhaust	As-Blended Evap	0.1psi Commingling	0.2 psi Commingling	Permeation	Exhaust	As-Blended Evap	0.1psi Commingling	0.2 psi Commingling
2.0	2.0	Reduced	Patent not avoided	2.05	-3.32	5.55	11.22	-5.3	2.92	-0.60	1.01	2.03
2.7	2.7	Reduced	Patent not avoided	2.81	-13.08	5.15	10.41	6.3	3.70	-2.37	0.94	1.89
2.7	2.0	Reduced	Patent not avoided	2.44	-13.08	5.15	10.41	7.8	4.54	-2.37	0.94	1.89
2.0	2.0	Continues	Patent not avoided	1.47	-3.32	5.55	11.22	-3.9	2.25	-0.60	1.01	2.03
2.7	2.7	Continues	Patent not avoided	1.58	8.10	5.25	10.61	-4.2	2.47	-1.47	0.96	1.92
2.7	2.0	Continues	Patent not avoided	1.85	-13.08	5.15	10.41	-6.6	3.85	-2.37	0.94	1.89
2.0	2.0	Reduced	Patent avoided	2.33	-7.56	5.38	10.87	-5.8	3.33	-1.37	0.98	1.97
2.7	2.7	Reduced	Patent avoided	2.56	-10.45	5.22	10.54	-5.7	3.33	-1.89	0.94	1.91
2.7	2.0	Reduced	Patent avoided	2.83	-12.59	5.17	10.45	-8.5	4.96	-2.28	0.94	1.90
2.0	2.0	Continues	Patent avoided	1.78	-7.03	5.39	10.89	-3.9	2.25	-1.27	0.98	1.97
2.7	2.7	Continues	Patent avoided	1.86	-8.21	5.26	10.63	-3.7	2.16	-1.49	0.96	1.92
2.7	2.0	Continues	Patent avoided	2.28	-12.08	5.18	10.47	6.6	3.85	-2.19	0.94	1.90

86 The sum of these components, in some cases, differ trivially from the totals shown in the previous table due to rounding.

In its February 7, 2000 submission CARB asserts that ozone impacts from increases in CO emissions (because of the decrease in oxygen in gasoline) would be offset by the corresponding VOC decreases. CARB argued that the accompanying decrease in VOC emissions (because of the reduction of permeation losses associated with diminished use of ethanol) would serve to offset these CO increases. While California's petition included an analysis generally intended to support this conclusion, that analysis relied heavily upon relative reactivity factors (developed by Dr. Carter of the University of California, Riverside).[87] Even using the relative reactivity approach that California employs, it is not at all clear that the changes in CO and VOC that occur with a waiver of the oxygen content requirement would be neutral with respect to ozone. Specifically, our examination of 12 scenarios shows that 2 of the scenarios result in a VOC increase even at 0.1 psi commingling effect, and therefore no offset of CO emissions. The 10 remaining scenarios each show a VOC decrease; however, 30 to 50 percent of these scenarios show VOC decreases that would be inadequate (using California's relative reactivity factors) to offset the CO increase.[88] Consequently, at the very least, there is a significant question regarding whether the combination of VOC and CO emission changes

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87 In the past, the Agency has not relied upon the use of such relative reactivity factors for evaluating the impact of emissions on ozone formation [see 63 FR 43792 and 65 FR 42924].

88 CARB used reactivity factors of 2.21 g ozone/g VOC (representing evaporative VOC emissions) and 0.065 ozone/g CO, as developed by Dr. Carter. Since reductions in VOC are associated with evaporative emissions (i.e., reduced RVP of non-oxygenated fuel as predicted by MotoPro, and decreased permeation losses due to reduced use of ethanol), the reactivity factor associated with evaporative VOC is more representative than a weighted reactivity factor representing exhaust and evaporative VOC. Using the reactivity factor for evaporative VOC results in a relationship of one ton of VOC equivalent to 32 tons of CO: that is for each 32 ton increase in CO, a one ton reduction in VOC would provide an offset in terms of ozone neutrality in terms of the Carter reactivity factors. Using a weighted reactivity of 50 percent exhaust and 50 percent evaporative emissions results in a reactivity factor of 2.6 g ozone/g VOC, and a relationship of one ton of VOC equivalent to 40 tons of CO. Using the factor of 2.6 g ozone/g VOC results in 30 percent of the scenarios in which there are VOC decreases failing to offset the CO increases; using 2.1 g ozone/gVOC results in 50 percent failure.

associated with a waiver would have a neutral or even a detrimental impact on ozone even using California's relative reactivity approach. Based on all the evidence before the Agency, it is reasonable to believe that if a waiver were granted to California, there would be an expected reduction in NOx, an increase in CO, and significant uncertainty about the overall change in VOCs. The evidence is not clear what impact the emissions changes from a waiver would have on ozone and does not clearly show whether a waiver would reduce, not affect, or even increase ozone..

All three of the pollutants discussed above influence ozone formation. The atmospheric chemistry is complex, but directionally we would expect NOx reductions to reduce ozone formation, CO increases to contribute to ozone formation, and VOC emissions to either increase or reduce ozone, depending on whether VOC emissions increase or decrease. In order to determine the direction of the overall impact on ozone from the changes in these three pollutants, we must consider the expected change in each of them and the overall balance that results from the directionally different impacts on ozone.

EPA does not believe that the evidence provided by California and developed through its own analyses clearly demonstrates what effect a waiver would have on ozone. This is because: 1) there are three pollutants whose emission rates would be altered by a waiver, and all three affect ozone formation, 2) these pollutants are not equivalent, on a ton-for-ton basis, in their effects on ozone formation, and 3) while NOx will decrease with a waiver, CO is expected to go up and VOC may go up or down resulting in an uncertain impact on ozone.

EPA has carefully evaluated all of the information in front of it, including information submitted by CARB, other interested parties, and developed by EPA. After considering what effect a waiver might have on the properties of California reformulated gasoline, and the effect this change in fuel properties would have on emissions from highway and off-road sources, EPA concludes that there has been no clear demonstration as to what effect a waiver would have on ozone. There is significant uncertainty associated with determining the expected emissions impact of a waiver, largely based on uncertainty regarding the expected impact on VOCs produced when gasoline containing ethanol is mixed with other gasolines in the marketplace. As a result, there is significant uncertainty in balancing the emissions impacts of the three different pollutants involved, each of which affect ozone, and determining their overall effect on ozone. This uncertainty has not been resolved, even using the approach suggested by CARB.[89]

89 We need not discuss the technical issues associated with an expected reduction in NOx and any associated reduction in PM.