# Updated Final Report

# Effects of Gasoline Ethanol Blends on Permeation Emissions Contribution to VOC Inventory From On-Road and Off-Road Sources

## Inclusion of E-65 Phase 3 Data and Other Updates

May 24, 2007

For:

**The American Petroleum Institute (API)**

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## Index of Acronyms and Abbreviations
## Used in this Report

| | |
|---|---|
| AIR | Air Improvement Resource, Inc. |
| API | American Petroleum Institute |
| ARB | (California) Air Resources Board |
| ASTM | American Society of Testing and Materials |
| CAA | Clean Air Act |
| CAAA | Clean Air Act Amendment |
| Carb | carbureted |
| CaRFG | California Reformulated Gasoline |
| CO | carbon monoxide |
| CRC | Coordinating Research Council, Inc. |
| ETOH | Ethanol |
| EPA | (United States) Environmental Protection Agency |
| FHWA | Federal Highway Administration |
| g/day | grams per day |
| HC | hydrocarbon |
| HDGV | heavy-duty gasoline vehicle |
| HDV | heavy-duty vehicle |
| HDPE | high-density polyethylene |
| I/M | Inspection and Maintenance |
| LDGV | light-duty gasoline vehicle |
| LDV | light-duty vehicle |
| LDT | light-duty truck |
| LEV | low-emission vehicle |
| MDV | medium-duty vehicle |
| MTBE | methyl tertiary butyl ether |
| NLEV | national low emission vehicle |
| NOx | oxides of nitrogen |
| ORVR | onboard vapor recovery |
| PFI | ported fuel-injected |
| PZEV | partial zero emission vehicle |
| RFG | reformulated gasoline |
| RVP | Reid vapor pressure or fuel volatility |
| SAE | Society of Automotive Engineers |
| SIP | state implementation plan |
| SUV | sport utility vehicle |
| TBI | throttle body injected |
| TCF | temperature correction factor |
| tpd | tons per day |
| VMT | vehicle miles traveled |
| VOC | volatile organic compound |

**Effects of Gasoline Ethanol Blends on Permeation Emissions Contribution to VOC Inventory From On-Road and Off-Road Sources**

# 1.0 Executive Summary

The Clean Air Act Amendments of 1990 require that reformulated gasoline (RFG) contain 2% minimum oxygen content by weight. In the 1990s, the preferred oxygenate was methyl-tertiary-butyl-ether (MTBE) due to its high octane, low volatility, ability to be blended at the refinery, and resistance to phase separation with water. However, concerns over groundwater contamination have led several states to enact a ban on MTBE, and others are also studying a ban. Many RFG areas have moved toward using ethanol in place of MTBE. California's Phase 3 RFG standards banned MTBE. Over 95% of gasoline sold in California now contains ethanol.

It has been determined that ethanol blends increase permeation of volatile organic compound (VOC) emissions through fuel system components. Permeation emissions are the result of gasoline (either oxygenated or non-oxygenated) "transpiration" or movement from the inside of automotive plastic tanks and hoses to the outside surface of these materials. This transport results in evaporative emissions that contribute to the increase of total VOC emissions. The California Air Resources Board (ARB) was concerned about this issue, and assisted in funding a comprehensive vehicle-testing program through the Coordinating Research Council (CRC), known as the E-65 program. A final report was issued on this program in September 2004, and a later report was issued in December 2006 that covered further testing conducted on newer technology vehicles.

The American Petroleum Institute (API) contracted with Air Improvement Resource, Inc. (AIR) to estimate the change in the mobile source VOC inventory resulting from the impacts of ethanol on permeation emissions of fuel components. A first report was prepared and released on March 3, 2005. This second report updates the March 2005 report with new data from the CRC, and new temperature and population inputs. The estimates were made for ethanol blends in California and for several areas outside of California using test data on gasoline blends containing 5.7% ethanol by volume. AIR relied upon the CRC E-65 program data for on-road vehicles and drew upon data from the literature for estimating permeation inventories for off-road equipment and portable containers. The study focused on California and on three other areas in the United States – Atlanta, Houston, and the New York City/New Jersey/Connecticut ozone nonattainment areas. All of these areas have reformulated gasoline with ethanol, and most started with RFG with MTBE.

AIR reviewed the E-65 report and data and found that: (a) pre-1991 cars and light trucks experience about a 2 gram per day increase in permeation emissions from gasoline containing ethanol compared to MTBE, (b) mid-1990s vehicles experience about a 1.1 gram per day increase, and (c) vehicles which meet the enhanced evaporative standards experience about a 0.8 gram per day increase in permeation VOC emissions. In the later new technology testing, a vehicle certified to the Near Zero evaporative standard experienced a 0.1 g/day increase, and a partial zero emission vehicle (PZEV) experienced a very small 0.014 g/day increase. These increases are at test temperatures that are quite high even compared with normal summer temperatures, so temperature correction factors were also developed from the E-65 data. These temperature correction factors indicate that permeation emissions increase by a factor of 2 for each increase in 10ºC. These temperature correction factors are consistent with other experimental data.

AIR drew upon test data collected by the ARB to estimate the effect of ethanol blends on permeation emissions for off-road equipment. In addition, AIR found some data, also developed by the ARB, on the ethanol-blend impacts on permeation emissions from portable fuel containers.

Our examination of the impact of ethanol on permeation emissions from off-road equipment indicated an increase of about 0.4 gram per day for lawnmowers, the largest off-road equipment source in terms of population. No data were available on other off-road equipment types, so the 0.4 gram per day was assumed for all off-road equipment and vehicles not subject to evaporative hydrocarbon (HC) control. ARB had also tested gasoline with ethanol in some lawnmowers with permeation and vapor emission controls, and these data indicated that the ethanol permeation increase was reduced by about 70% to 0.12 gram per day. Lacking data on other equipment types with controls, we also assumed other equipment types with evaporative controls would experience a 0.12 gram per day increase with the use of gasoline containing ethanol.

Examination of data on portable containers showed that these sources, when filled with gasoline fuel blended with ethanol, had increased permeation emissions by almost 2 grams per day. In 2001, portable containers sold in California were required to have permeation and spillage controls. No data were available on the increase in permeation emissions from using gasoline blended with ethanol in controlled portable containers, so we assumed that the 2 gram per day impact would be reduced by the same percentage estimated for lawnmowers with permeation controls, or 70%. The controlled level was an increase of about 0.6 gram per day. As with the on-road vehicle data, all of these increases were measured under very hot test conditions, and needed to be corrected to more reasonable summertime temperature levels.

The inventory impacts were estimated by using the product of vehicle populations (on-road vehicle, off-road equipment, or off-road vehicle, and portable containers), impacts of gasoline blended with ethanol on permeation emissions for each population, and temperature correction factors. The modeling used local area temperatures, vehicle populations, and local vehicles, equipment and container turnover rates. Market penetration of ethanol was assumed to be 100% in the areas studied. All populations in California were obtained from the California regulatory emissions models. Vehicle populations outside of California were developed from registration data obtained from the Federal Highway Administration and state Department of Motor Vehicle agencies, along with estimates of annual growth based on human population projections and per capita vehicle ownership trends. All off-road equipment populations outside of California were taken from EPA's NONROAD model. Container populations were available in

California but not in other areas, therefore, a ratio method was applied – where the ratio of container populations to off-road equipment populations for California was calculated – to estimate container populations outside of California. Estimated populations for these three categories of sources for each of the areas for 2005-2020 are shown in Figure ES-1.

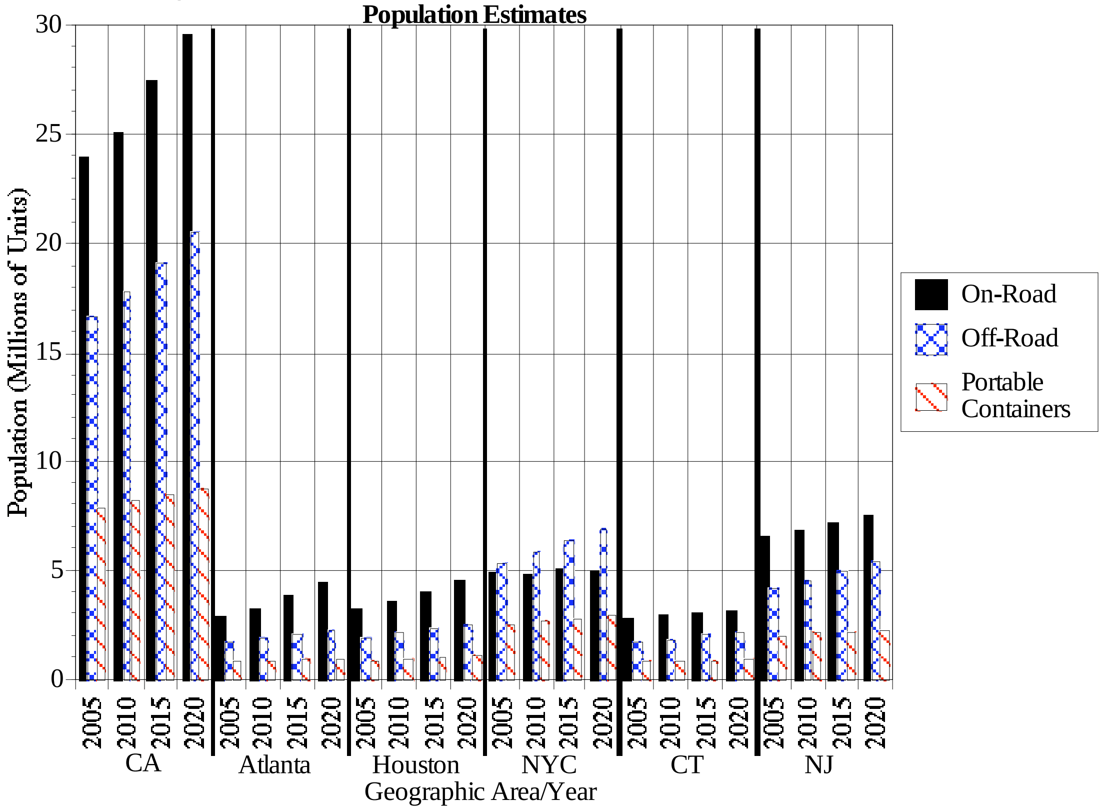


**Figure ES-1. On-Road, Off-Road and Portable Container Population Estimates**

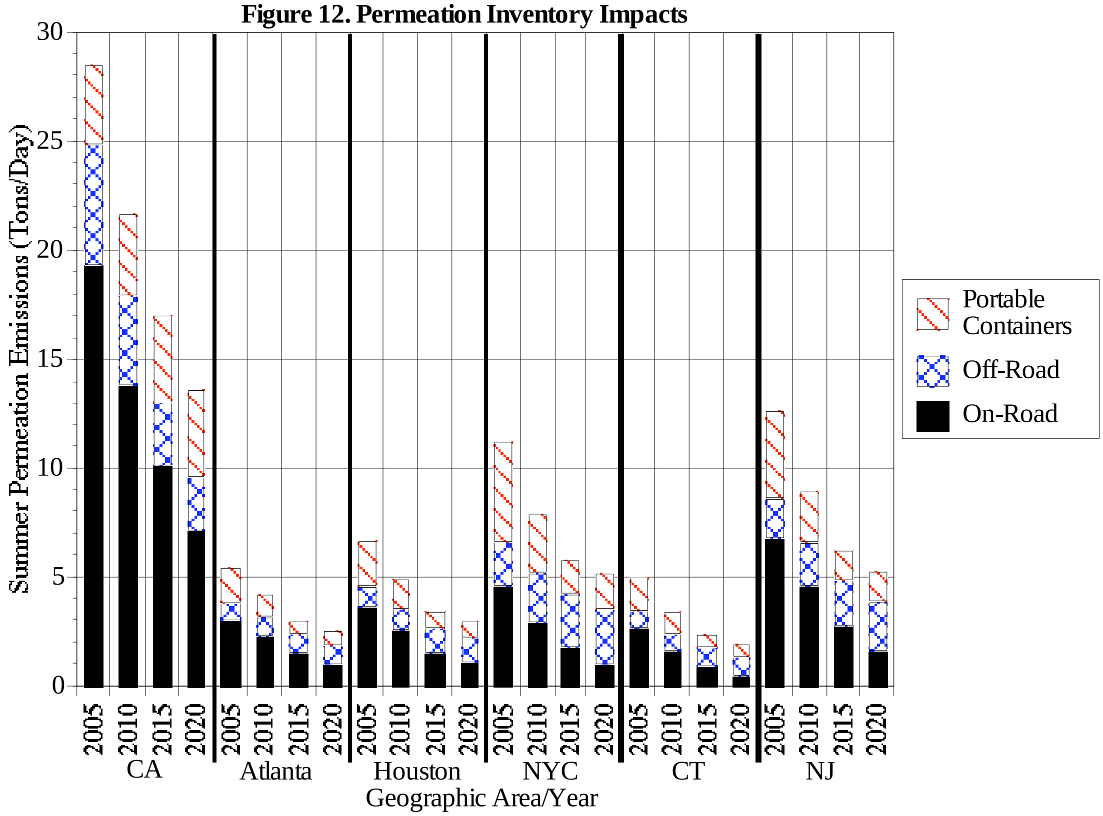
This study did not examine the impact of ethanol in gasoline on exhaust emissions, nor was it necessary to do this at this time. The impact of ethanol in gasoline on exhaust emissions is contained in the current California and Federal emissions models utilized by the states. The ethanol permeation impact, however, is not, and California is revising their Predictive Model for reformulated gasoline to include not only the permeation effect, but an update of the exhaust effects as well (based on newer exhaust emissions data from other testing programs).

Results of the summer inventory analysis showed that in California, ethanol in gasoline increases VOC permeation emissions by 29 tons per day in 2005, dropping to about 14 tons per day in 2020. The decrease in the ethanol impact is due to fleet turnover of vehicles, equipment, and portable containers with permeation controls. Corresponding summertime increases in the additional areas are as follows:

- Atlanta: 5.4 tons per day in 2005, 2.5 tons per day in 2020
- Houston: 6.6 tons per day in 2005, 3.0 tons per day in 2020
- New York/NJ/Connecticut area: 28.7 tons per day in 2005, 12.3 tons per day in 2020

The above results are shown in graphical form in Figure ES-2.

**Figure 12. Permeation Inventory Impacts**




California has performed their own estimate of the increases in permeation VOC emissions for on-road vehicles. Their estimates are ~50% higher than the on-road estimates developed in this study. There are significant differences in methodology. California postponed their assessment of the impacts on off-road sources until more data are obtained.

In California, permeation emissions are reduced from 2005 to 2020 due to the permeation controls on all sources. In the non-California areas, permeation emissions due to ethanol decrease with time for on-road sources and portable containers, but increase for off-road sources. This increase is due to the fact that these sources, with the exception of recreational vehicles and recreational marine, have no permeation controls in place yet. However, EPA is working on a proposal to reduce permeation emissions from these sources, which should be released later this year. Permeation emissions from portable fuel containers are controlled by EPA in its recent Mobile Source Air Toxics Rule, starting in 2009.

Regardless of when permeation controls are implemented, the permeation emissions increases due to ethanol reduce the estimated benefits of reformulated gasoline containing ethanol. This effect is not yet included in the models used by the states to estimate on-highway emissions and the benefits of RFG.

Over all the regions, the on-road ethanol increase averages about 3% of the total VOC inventories in 2005 from on-road sources.

We examined sources of uncertainty in our inventory estimates and reached the following conclusions:

- Differences in ethanol concentration in the non-California areas do not affect the estimates. The second phase of the CR E-65 testing data indicated that permeation rates are about the same at ethanol concentrations of 6% and 10% by volume

- This analysis assumed the market penetration of gasoline/ethanol blends was 100% in the areas evaluated. It could be less.

- The analysis assumes that the increase in permeation emissions during vehicle operation and during "hot soak" periods is the same as the permeation increase when the vehicle is resting. Operation of vehicles and equipment is known to increase fuel temperatures, which could increase the permeation effect due to ethanol. The amount of increase in permeation emissions during engine operation is not known, and would require further analysis and test data.

- The on-road ethanol impacts could be a little low, due to the fact that we used passenger car and light-duty truck data to represent the ethanol increase from heavy-duty gasoline vehicles with larger fuel tanks, and the fact that we did not include motorcycles.

- The population of portable containers is also an issue. This analysis uses the portable container populations for California from the OFFROAD model. A recent survey conducted by the ARB, however, indicates that plastic portable container populations could be much lower.

- The off-road equipment ethanol impacts are also probably low, inasmuch as we estimated the ethanol impact from lawnmowers, and many equipment types have larger fuel tanks and longer fuel hoses than lawnmowers.

- The ethanol permeation estimates could be impacted by future regulations all three sources

A comparison of permeation impacts of the state of California under summer conditions between the previous AIR study and this study is shown in Table ES-1. This comparison includes on-road vehicles, off-road equipment and vehicles, and portable containers.

Generally, the new permeation estimates are higher than the previous estimates. This is due primarily to population changes and to temperature changes. In 2015, however, the differences are much less than they are for the 2005 calendar year.

**Table ES-1. California Population and VOC Summer Ethanol Inventory Impact (tpd)**

| Analysis | Calendar Year | On-Road | Off-Road | Containers | Total |
|---|---|---|---|---|---|
| March 3, 2005 Report | 2005 | 16.3 | 4.3 | 2.9 | 23.6 |
| | 2010 | 13.4 | 3.3 | 3.0 | 19.7 |
| | 2015 | 11.1 | 2.4 | 3.1 | 16.6 |
| This Report | 2005 | 19.5 | 5.4 | 3.6 | 28.5 |
| | 2010 | 13.9 | 4.1 | 3.7 | 21.7 |
| | 2015 | 10.1 | 3.1 | 3.9 | 17.0 |

Overall the estimates of the inventory impacts of ethanol in this study are conservative, but could be higher or lower if more data were available.

## 2.0 Introduction

The Clean Air Act Amendments (CAAA) of 1990 required reformulated gasoline (RFG) to be provided to the nine metropolitan areas with the most severe summertime ozone problems. These requirements were implemented in two stages, with Phase 1 in 1995 and Phase 2 in 2000. In addition to specific emissions performance requirements implemented for RFG, the 1990 CAAAs required RFG to contain a minimum of 2% oxygen by weight. [1]

In addition to the federal reformulated gasoline required by the Clean Air Act, California adopted its own RFG requirements. The Phase 1 requirements were implemented in 1992, Phase 2 requirements were implemented in 1996, and Phase 3 requirements in 2003. While California has its own gasoline specifications, its RFG is also required by the 1990 CAAAs to have a minimum of 2% oxygen by weight.

The primary oxygenates used in RFG in the 1990s were ethanol and methyl tertiary butyl ether (MTBE). MTBE was the primary oxygenate used in California for meeting the Phase 2 rule for a number of reasons. However, in California's Phase 3 RFG rule, MTBE was phased out due to concerns over ground water contamination from leaking underground storage tanks. As a result of the oxygen content requirement in the 1990 CAAAs, ethanol replaced MTBE as the oxygenate used in California; 95% of the gasoline sold in California now contains ethanol. [2]

On two separate occasions, the state of California requested a waiver from the federal oxygen content mandate. The first request, submitted by California in May 2001, was denied by the United States Environmental Protection Agency (EPA) in June 2001. The primary basis of that request was that ethanol increased oxides of nitrogen (NOx) emissions from the on-road gasoline fleet, particularly so-called "Tech 4" and "Tech 5" vehicles (1988-1995, and 1996+ model year vehicles, respectively). EPA's evaluation of this waiver request concluded that the available data on 1996 and later vehicles was inconclusive with respect to the impact of ethanol on NOx. [3] California submitted a second waiver request on January 28, 2004 that is currently being evaluated by EPA. Other areas have also submitted requests for waivers from either the RFG requirements or the oxygen content mandate. For example, New York State requested an exemption from the oxygen content requirement in January 2003. [4]

One of the issues raised during the adoption of California Phase 3 RFG was the possibility of increased permeation emissions from a gasoline blended with ethanol.[1] The Board (ARB) directed the Staff to study this issue and report back to the Board. The Coordinating Research Council (CRC) initiated Project E-65 to develop test data to address the permeation issue, with funding from CRC and the ARB. Ten vehicles covering a wide range of model years were tested on three fuels meeting the ARB Phase 2 and Phase 3 RFG fuel specifications – one containing MTBE, one containing ethanol (with 2% oxygen), and one non-oxygenated fuel. A final report on the testing was

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[1] The permeation issue has also been raised by California and New York in their waiver requests.

released on September 10, 2004 (hereinafter referred to as the E-65 report). [5] Following this testing program, CRC initiated follow-on testing and additional two 3 vehicles – one vehicle meeting the California Near Zero evaporative requiremnts, one meeting the PZEV Zero evaporative requirements, and a flexible fuel vehicle (FFV). [6]

The E-65 reports describes how the permeation testing was conducted and the results of that testing. API contracted with AIR to further study the impact of gasoline with 5.7 volume % ethanol on permeation emission inventories in California and elsewhere in the U.S. using the CRC E-65 test results and other available data. The original impetus for evaluating ethanol's effect on permeation emissions started with California. However, other areas of the U.S. with or without RFG have either banned MTBE or are considering an MTBE ban, so there was interest in evaluating the impact on permeation emissions in some of these areas as well.

Off-road equipment such as lawnmowers, lawn and garden tractors, and the portable fuel containers that refuel this equipment also have permeation emissions that may be increased by the use of ethanol-blended gasoline. Although no extensive testing program such as the E-65 program has been conducted on these sources, some test data has been collected by the ARB that can be evaluated to develop permeation emission impacts for these sources.

This study therefore analyzes the CRC-65 data for on-road vehicles, analyzes other data sources to evaluate impacts for off-road gasoline sources such as lawn and garden equipment and portable fuel containers, and develops the ethanol permeation emission inventory impacts for four areas of the U.S.:

- California
- Atlanta
- Houston
- New York/New Jersey/Connecticut area

California was chosen for the reasons mentioned earlier. Atlanta, which was re-designated as a severe 1-hour ozone standard area in 2003, is required to implement reformulated gasoline by January 1, 2005. It is likely that most, if not all, RFG in Atlanta will contain ethanol. Houston currently is an RFG area that utilizes MTBE. New York and Connecticut banned MTBE at the end of 2003 and are using ethanol. New Jersey is still evaluating the MTBE ban issue.

As mentioned earlier, ethanol impacts exhaust emissions, and under certain circumstances can influence non-permeation related evaporative emissions, such as diurnal emissions, hot soak emissions, and running losses.[2] These effects can vary by emission source (on-road versus off-road), model year group and technology type. This

[2] Ethanol increases the volatility of gasoline, thereby increasing the emissions of these other evaporative components. Some areas grant ethanol a 1 psi volatility waiver, and in those areas, the volatility of ethanol blends is higher than the non-ethanol blends. A volatility waiver is not allowed in RFG areas or in California.

study does not address these other impacts, because (1) many of them are estimated by the available emissions models, and (2) they are the subject of ongoing testing. For example, the CRC E-67 program evaluated the impact of ethanol fuels on the exhaust emissions from late model vehicles. [7]

This report therefore evaluates the *change* in permeation volatile organic compound (VOC) emissions resulting from the use of ethanol-blended gasoline relative to gasoline not containing any oxygenate, or gasoline containing MTBE, since this change in permeation emissions is not addressed by any of the current on-road and off-road emission models. The *net* effects of ethanol on overall exhaust and evaporative emissions could be evaluated with the available emissions models *and* the information presented in this report.

The report is organized as follows: Section 3 (Background) discusses the existing on-road and off-road inventory models in California and the U.S., and generally outlines how they estimate permeation emissions and ethanol effects. It also contains a brief discussion of the inventory modeling method. Section 4 discusses the CRC E-65 results, and develops the emission impacts by vehicle class, model year group, and technology for the on-road fleet. Section 5 summarizes and discusses the available data for off-road equipment and portable containers. Section 6 explains how the inventory impacts were developed for the different geographical areas. Section 7 presents the emission inventory results by geographical region, and also places these results in the context of the on-road and off-road VOC inventory in these areas. Finally, Section 8 discusses uncertainties in the overall emission inventories.

# 3.0 Background

The first section of the Background discusses how permeation emissions are estimated in the current EPA and California models. The differences in evaporative definitions between the various models in part guided the method chosen to estimate the impacts of ethanol-blends on permeation inventories, so the second section discusses the implications of the models on the method chosen to evaluate inventories.

## 3.1 Review of the Models

The primary goal of this project is to estimate the impact of ethanol in gasoline on permeation for both on-road and off-road vehicles, in California and several non-California states. A basic requirement was to make these analyses consistent with the various models for on- and off-road vehicles in California and non-California areas. There are four such models:

- ARB EMFAC2007 (on-road, California)
- ARB OFFROAD (off-road, California, recreational vehicles, recreational marine, and portable containers)
- EPA MOBILE6.2 (on-road, remainder of U.S.)
- EPA NONROAD (off-road equipment and recreational vehicles, remainder of U.S.)

Generally, these models do not use the same definitions for different evaporative processes, nor do they estimate evaporative emissions consistently. However, there is consistency between the two California models and between the two U.S. models. These models differ primarily in their treatment of permeation emissions, the very type of emissions this study is focused on.

### 3.1.1 Definitions of Evaporative Emissions - California Models

Evaporative emissions in the EMFAC and OFFROAD models are divided into four components - diurnal emissions, hot soak emissions, running loss emissions, and resting emissions. In the California models, the evaporative process depends both on (1) the ambient temperature and (2) how the vehicle or engine is (or has recently been) operated.

- Diurnal emissions – In the California models, these are emissions which occur when the ambient temperature is rising and the engine is not operating or has not operated for at least 45 minutes (35 minutes for on-road vehicles). Mechanisms that produce these emissions are breathing losses in the fuel tank due to the ambient and fuel temperature rise, and permeation of both fuel vapor and liquid fuel through permeable fuel components. [8]

- Resting emissions – These are emissions which occur when the temperature is steady or falling, and the vehicle or engine is not operating or has not operated in the last 45 minutes (35 minutes for on-road vehicles). Resting emissions are primarily permeation emissions. [9]

- Running losses - running losses are those evaporative emissions which occur while either the vehicle or engine is being operated. Running loss emissions can consist of both permeation emissions and breathing losses from the fuel tank, but breathing losses from recent model year vehicles with running loss controls are essentially zero. [8]

- Hot soak emissions - hot soak emissions are those that occur within 45 minutes of engine shut-down (35 minutes for on-road vehicles). These consist of both permeation emissions and any vapor generation again from the fuel tank or fuel system (in the case of engines equipped with carburetors, from the float bowl). [10]

Finally, leaks of liquid fuel at fuel and vapor connections can also add to evaporative emissions, and leaks can affect the emissions of all four processes.

Evaporative control systems are present on most on-road vehicles to control all four components, and these requirements and emissions standards have been continually updated by California. Additional detail on these standards is presented in Section 4. Controls on permeation emissions and spillage emissions were adopted for portable containers starting in 2001, and controls for permeation and vapor emissions for off-road equipment start in 2006. [11,12] Additional details on these requirements are in Section 5.

Both the EMFAC and OFFROAD models incorporate most of the emissions effects of the Cleaner Burning Gasoline regulations that have been implemented in California since the early 1990s and measured in vehicle and engine testing programs. For example, both models contain correction factors for Phase 1 reformulated gasoline (RFG) implemented in 1992, Phase 2 RFG implemented in 1996 and Phase 3 RFG implemented in 2003/2004. The model accounts for these effects by adjusting exhaust emissions, or by adjusting evaporative emissions for the fuel volatility changes that have occurred.EMFAC2007, released in November of 2006, now includes ethanol permeation effects. [13] Appendix A compares the methods used by ARB to develop these effects with the effects developed in this report. The OFFROAD model, however, does not currently include the effects of ethanol on permeation emissions. The ARB plans to conduct an extensive testing program on offroad equipment to determine the effects for these sources.

### 3.1.2 Definitions of Evaporative Emissions – EPA Models

The current version of NONROAD only includes diurnal evaporative emissions and crankcase emissions. The diurnal emissions are estimated by multiplying equipment tank size in gallons by an emission rate of 1 g/gallon/day. The emission factor of 1 g/gallon/day was developed from limited test data of several equipment types tested on gasoline not containing ethanol fuel. Diurnal emissions in the NONROAD model are corrected for temperature and fuel volatility (RVP). [14]

EPA updated the NONROAD model to include hot soak emissions, permeation emissions, and running losses, in addition to the diurnal and crankcase emissions. Some of these emissions may be based on test data used by the ARB to develop the emissions for the OFFROAD model. The most recent version of the NONROAD model was released in December, 2005. [15]

Evaporative emissions in the MOBILE6.2 model and new NONROAD model consist of the same four components as the California models, but in the NONROAD model, the resting emissions are referred to as permeation emissions.

- Diurnal emissions - In both EPA models, these are breathing losses only. In MOBILE6.2, they are estimated by first estimating the permeation emissions from 24-hour diurnal tests, and then subtracting these permeation emissions from the total 24-hour emissions test. [16] In the new NONROAD model, diurnal emissions are estimated from theoretical calculations utilizing average tank size, fuel volatility and temperature. There is also an adjustment factor applied that was developed from a comparison of the theoretical calculations to actual data.

- Hot Soak emissions – In both models, hot soak emissions are the evaporative emissions following engine shut-off. They include both permeation and breathing losses. [17]

- Running loss emissions – In both models, running loss emissions are any evaporative emissions that occur during engine operation, and these include both permeation and breathing losses. [18]

- Resting emissions – In the MOBILE6.2 model, these emissions are estimated as the emissions between the $19^{th}$ and $24^{th}$ hours of a 24-hour diurnal test, and are designed to be only permeation emissions. In the NONROAD model, the resting loss emissions are called permeation emissions, and are theoretically estimated from experimentally determined permeation rates of the various components. [16]

MOBILE6.2 allows the user to select ethanol market fraction and average ethanol concentration. The user also inputs whether the ethanol fuel receives a volatility waiver. The model uses the waiver input to determine in-use fuel volatility, and corrects the in-use evaporative emissions as needed. The model also determines the extent of in-use commingling effect [3] and makes a correction for this effect as well. Finally, the model also estimates the impact of ethanol fuel on exhaust emissions, and these effects vary by model year and technology type.

The above discussion of ethanol effects also carries over to how MOBILE6.2 estimates the influence of reformulated gasoline on emissions. The model currently estimates the

[3] Commingling effect is a phenomenon in which a vehicle containing gasoline with MTBE at a given volatility can be filled with gasoline containing ethanol at the same volatility, and the resulting mixture has a higher volatility than either of the starting fuels.

emissions benefits from the basic performance requirements of RFG. When the federal RFG program was first implemented, many refiners complied with the oxygen content requirement by blending MTBE into gasoline. MTBE, however, has been phased-out in many RFG areas, and replaced with ethanol. The MOBILE6.2 model does not currently account for the changes in permeation emissions.

NONROAD also allows the user to select ethanol market fractions and average ethanol concentration. However, this model only accounts for the effects of differences in ethanol usage through an adjustment of exhaust emissions; evaporative emissions are unaffected.

## 3.2 Implications of the Model Evaporative Definitions

It is clear from the above discussion that the models currently are not designed to evaluate the permeation impacts of ethanol blends. Revisions to these emission models should be initiated as soon as possible to correct this deficiency, since the models are used extensively to evaluate the emission benefits of reformulated gasolines.

Normally in a study of this type, it is usually easiest to modify the existing models for the effect (in this case, the "ethanol" permeation effect), and then run the models in their baseline and modified conditions to estimate the inventory changes. However, this modeling approach is not easy to use in this study, primarily due to the fact that the evaporative emissions as defined include more than just permeation emissions. For example, hot soak emissions in both the California and EPA models include both permeation and breathing losses. If we were to find a percentage change in emissions due to ethanol relative to either MTBE or non-oxygenated gasoline, we would first have to subtract out any vapor emissions in order to limit the adjustment to only the permeation fraction. [4] The same is true for running losses, and for diurnal emissions in the California models (the EPA models define diurnal as vapor only). We are not aware of test data that allows permeation emissions to be separated from vapor emissions, particularly for all the vehicle classes and model year groups. To solve these problems, a modeling approach was conceived that would not directly use the existing models, and would also be consistent in Federal areas as well as California. This approach is introduced below, and described in more detail in Section 6.

## 3.3 Modeling Approach

The CRC E-65 tests, which will be described in more detail in Section 4, utilize a 24-hour diurnal test for the various fuels. This means that permeation emissions are reported in grams per day (g/day). The same 24-hour test has been used by the ARB in testing portable containers and off-road equipment. The modeling approach used in this study is to estimate the ethanol impact in g/day for on-road vehicles, off-road equipment, and portable containers. Next, this effect is temperature corrected, again using the CRC E-65

[4] This is the approach California used. See Appendix A and the ARB documentation on permeation emissions for further details.

data. Finally, the temperature-corrected ethanol effects can be multiplied by populations of on-road vehicles, off-road equipment, and portable containers in the various regions.

The inputs needed for the above approach are the (1) emission differences due to ethanol for the various sources, (2) temperature correction factors, and (3) source populations. The emission differences are discussed in Sections 4 and 5, and other inputs are discussed in Section 6.

As noted above, the underlying measurements are based on a 24-hour diurnal test, in which the vehicle (or engine) is not operated. The 24-hour testing conducted by CRC required removal of the fuel system from the vehicle in order to eliminate any confounding effects of the vehicle on permeation emissions (for example, emissions from the tires or upholstery).

The approach above assumes that the change in emissions due to ethanol is the same when a vehicle (or piece of equipment) is operating as when it is at rest. It is possible that the effect during engine operation or during hot soak could be different than during the 24-hour diurnal test. For example, during engine operation, fuel temperatures in the entire fuel system rise. This increase in temperature could increase the permeation from nearby fuel components to a rate higher than occurs during the diurnal procedure. However, the existing test data do not allow one to determine the influence of vehicle and equipment operation on permeation emissions and the resulting change in permeation emissions due to ethanol. Moreover, if a vehicle experiences 2 hours of operation and hot soak in a day, and its permeation emissions are higher during those 2 hours than they would have been at rest, our failure to account for this may not have a significant impact because our methodology is probably estimating the appropriate permeation emissions for the other 22 hours (90%) of the day.

Therefore, we believe the approach being used here is a reasonable way to use the existing data, and a reasonable way to ensure that the adjustments are being done consistently in different parts of the country, recognizing the differences among the available emission models.

# 4.0 On-Road Vehicle Emissions

This section first discusses the results of the CRC E-65 testing program. It then utilizes these results and other information to develop changes in total hydrocarbon (THC) permeation emissions due to ethanol use for all gasoline-fueled on-road vehicles, both in the past and in the future.

## 4.1 CRC E-65 Program and Data

In the CRC E-65 program, permeation evaporative testing was conducted on three different fuels – a Phase 2 California RFG containing MTBE, a Phase 3 California RFG containing 5.5% ethanol by volume, and a gasoline meeting the California Phase 3 RFG specifications containing no oxygenate.[5] The testing was conducted by Automotive Testing Laboratory, and Harold Haskew and Associates. The next three sections summarize the test fleet, the testing procedures, and the results.

### 4.1.1 Test Fleet

The original test fleet was chosen to represent the calendar year 2001 California fleet of on-road gasoline-fueled vehicles, and consisted of six passenger cars and four light-duty trucks (LDTs). The odometer mileages on the test vehicles ranged from 15,000 miles for the newest vehicle to 143,000 miles. Four vehicles were equipped with non-metallic fuel tanks, and the remainder equipped with metal fuel tanks. To provide for a reasonable spread in model years, the California fleet was divided into 10 model year groups with equal populations, and one vehicle was selected from each model year group. The model years of the test vehicles ranged from 1978 to 2001. Vehicles with very high sales were selected.

Phase 3 of the E-65 testing added three additional vehicles, a vehicle meeting the California Near Zero evaporative standards, a vehicle meeting the Zero Evaporative standards, and one flexible fuel vehicles (FFV). Only the first two vehicles can be used in this analysis. Details of all the test vehicles are shown in Table 1.

[5] In Phase 3 of this testing, only the non-oxy fuel and ethanol fuel were tested on the Near Zero evap and PZEV vehicles.

| Table 1. CRC E-65 Test Fleet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Model Year | Make | Model | Class | Fuel System* | Odom. | Tank Size (gal) | Plastic/ Metal | Evap Tech |
| 2004 | Chrysler | Sebring | PC | PFI | 6,434 | 16 | Metal | PZEV |
| 2004 | Ford | Taurus | PC | PFI | 29,973 | 18 | Metal | Near Zero |
| 2001 | Toyota | Tacoma | LDT | PFI | 15,460 | 15.8 | Metal | Enhanced |
| 2000 | Honda | Odyssey | LDT | PFI | 119,495 | 20.0 | Plastic | Enhanced |
| 1999 | Toyota | Corolla | Car | PFI | 77,788 | 13.2 | Metal | Enh/ORVR |
| 1997 | Chrysler | Town and Country | LDT | PFI | 71,181 | 20.0 | Plastic | Pre-enhanced |
| 1995 | Ford | Ranger | LDT | PFI | 113.077 | 16.5 | Plastic | Pre-enhanced |
| 1993 | Chevrolet | Caprice | Car | TBI | 100,836 | 23.0 | Plastic | Pre-enhanced |
| 1991 | Honda | Accord LX | Car | PFI | 136,561 | 17.0 | Metal | Pre-enhanced |
| 1989 | Ford | Taurus GL | Car | PFI | 110,623 | 16.0 | Metal | Pre-enhanced |
| 1985 | Nissan | Sentra | Car | Carb | 142,987 | 13.2 | Metal | Pre-enhanced |
| 1978 | Olds | Cutlass | Car | Carb | 58,324 | 18.1 | Metal | Pre-enhanced |

* PFI = ported fuel injected, TBI=throttle body injected, carb=carbureted
LDT = light duty truck, ORVR = onboard vapor recovery

Digital pictures of the fuel systems from the test vehicles are available on the data CDs for this testing program. AIR examined all of the pictures, and also inquired concerning other evaporative system specifics. The following is a summary of our evaluation.

- The 1995 Ford Ranger's plastic tank was untreated, that is, it did not have a permeation barrier treatment process such as flourination or sulfonation
- The 1993 Caprice's plastic tank was flourinated
- The 1997 and 2000 model year plastic tanks were either treated, or were multi-layer technology
- The 1997 Town and Country had advanced hardware fitted in anticipation of the enhanced evaporative regulations, but the vehicle was not certified as an enhanced evaporative vehicle

Examination of the pictures revealed that the earlier evaporative and fuel system systems (1978-1989 vehicles) were characterized by metal tanks and both metal and plastic (or rubber) fuel lines. All vehicles had a charcoal canister to store fuel vapor from the fuel tank and carburetor vent bowl. Relative to the mid-1990s and later vehicles, the earlier systems were simple. Metal lines usually had several rubber-type connectors, to allow for movement between the fuel system and vehicle chassis (this movement is needed to prevent fuel from leaking in the event of a crash). In these systems, most of the permeation would occur through the rubber fuel connectors, fuel vapor lines, and the canisters, which were also plastic.

The mid-1990s systems and the enhanced evaporative systems were more complicated, in that there were more fuel and vapor lines, purge valves, etc. All vehicles also had carbon canisters.

The 1999, 2000, and 2001 model year vehicles were equipped with enhanced evaporative systems. These systems are designed to meet low emission standards of 2 g/day on a 24-hour diurnal test (sum of diurnal and hot soak emissions). The charcoal canisters were larger than the pre-enhanced evaporative systems to accommodate fuel vapor over a longer period (24-hour real-time diurnal tests). They must also meet running loss emissions test standards. The Corolla was also equipped with an onboard vapor recovery system, which is designed to capture fuel vapor during vehicle refueling.

The 2004 Ford Taurus was certified to meet the California Near Zero evaporative emission standard of 0.5 g/test, and the 2004 Sebring was certified to meet the PZEV zero evaporative standard (less than 0.05 g/test). Both vehicles are equipped with steel fuel tanks and onboard vapor recovery systems (ORVR).

Overall, we believe this test fleet captures most of the variety of the vehicles, fuel systems, and evaporative systems in California. In addition, the two 2004 vehicles represent the future California fleet. In later sections of this report, we divide this fleet into several model year groups in order to simplify the emissions modeling. The representativeness of these model year groups is discussed further in those sections of the report.

### 4.1.2 Summary of Testing Procedures

The vehicles above were procured in California and taken to Arizona for testing. At the lab in Arizona, the vehicles were carefully inspected to ensure that the original fuel system was present and in good repair. After passing this initial inspection, the entire fuel and evaporative emission system was removed intact from the vehicle (without making any disconnections in the fuel system). The fuel and evaporative system was placed on an aluminum rack or “rig” that held the components in the same relative positions as they were present on the vehicles.

Each rig was filled to 100% full with test fuel and stored in a test room at 105°F until the evaporative testing determined that stabilization of the permeation emissions was achieved. After stabilization at 105° F, the rig was tested at 85° F and then prepared for a California 2-day diurnal (65º to 105º to 65º F) emission test. For the two-day diurnal test, fresh test fuel was used with a 40% fill level in accordance with the California 2-day procedure. In addition to the two-day diurnal test, constant temperature tests were performed at 85º F and 105º F (only 105º F for the Phase 2 vehicles). These two steady-state tests were conducted with the tank at 100% full.

The fuel tanks and the canisters were vented to the outside of the testing enclosure to eliminate the possibility of the tank venting emissions being counted as permeation. Emission rates were calculated using the 2001 California certification procedure.

All rigs except the two 2004 vehicles were tested on three fuels in the order listed below (the two 2004 vehicles were not tested on gasoline containing MTBE):

- The ARB “Phase 2” fuel containing 2 wt % MTBE (9.88 vol % MTBE)
- The ARB “Phase 3” fuel containing 2 wt % Ethanol (5.46 vol % ethanol)
- The ARB “Phase 2” fuel containing no oxygenate

The two 2004 vehicles were also tested on an E10 fuel, and a separate E6 fuel with higher aromatics content (E6HI).

Other than the type of oxygenate used, the fuels were very similar to each other. For example, the fuel volatilities were about 7.0 psi, aromatics ranged from 23-27 volume % (except for E6HI, where aromatics was 38.5%), and olefins ranged from 5-6 volume %.

In the core testing program, fuel systems were stabilized with the tanks at 100% full, and steady state temperature tests were performed with tanks 100% full and diurnal tests were performed at 40% full after stabilization at 100% full. Additional tests were performed on the rigs with plastic tanks to test the effect of preconditioning fill level on emissions. In these tests, the fuel systems were first stabilized with the tanks at 100% full, and then, when they were sufficiently stabilized, additional stabilization was performed with the tank at 20% full. The steady state tests at 85ºF and 105ºF were run at 20%, full, and the diurnal test was repeated with a fill level of 40%.

In addition to mass emission measurements for the diurnal and steady-state tests, the testing program measured individual hydrocarbon species. This enabled an estimate of overall reactivity of the permeation emissions for each fuel to be made.

#### 4.1.3 Correction of MTBE Results for FID Response

Hydrocarbon emissions are measured in the E-65 program using a Flame Ionization Detector, or FID. The permeation emissions for fuels containing either ethanol or MTBE contain ethanol or MTBE in vapor form, and the FID response to oxygenates is lower for these compounds than for straight gasoline. Consequently, the emissions as measured by the FID for tests involving oxygen must be corrected.

The ethanol results presented in the Final E-65 report are corrected for FID response, but the MTBE results are not. The ARB developed MTBE response correction factors for each of the vehicles in the E-65 program; these vary by vehicle (or rig) from 1.04 to 1.1, and the derivation of these are explained in more detail in Appendix B. We have utilized the ARB MTBE correction factors for all MTBE values in the remainder of this report.

.1.4 Primary Results and Conclusions from the CRC-E-65 Program

This section summarizes the primary results and conclusions of the E-65 program. A later section poses issues that need to be resolved in order to conduct this modeling study, and these issues are discussed in turn.

Figure 1 shows average diurnal emissions of the twelve vehicles on each of the three fuels. In this plot, Days 1 and 2 of the 2-day diurnal test have been averaged (the Taurus and Sebring are tested on only two fuels). The MTBE fuel referred to in this figure and subsequent figures refers to the ARB Phase 2 fuel containing 2.0 wt % oxygen as MTBE. The Ethanol fuel referred to in this figure and subsequent figures refers to the ARB Phase 3 fuel with 2.0 wt % oxygen as ethanol (low aromatics). Finally, the non-oxygenated fuel referred to in this figure and subsequent figures refers to the ARB Phase 3 fuel without any oxygenate.

**Figure 1. Diurnal Permeation Emissions**

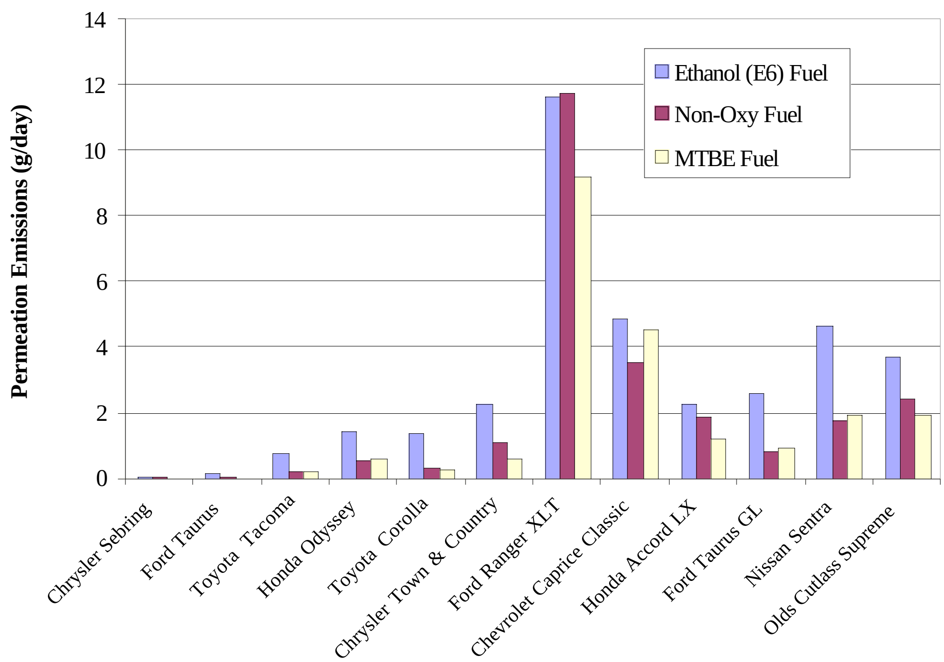



Figure 1 shows the following:

- In all cases except for the test with non-oxygenated fuel on the Ford Ranger, the permeation emissions from gasoline with ethanol fuel were higher than the permeation emissions on either gasoline with MTBE or non-oxy fuel.

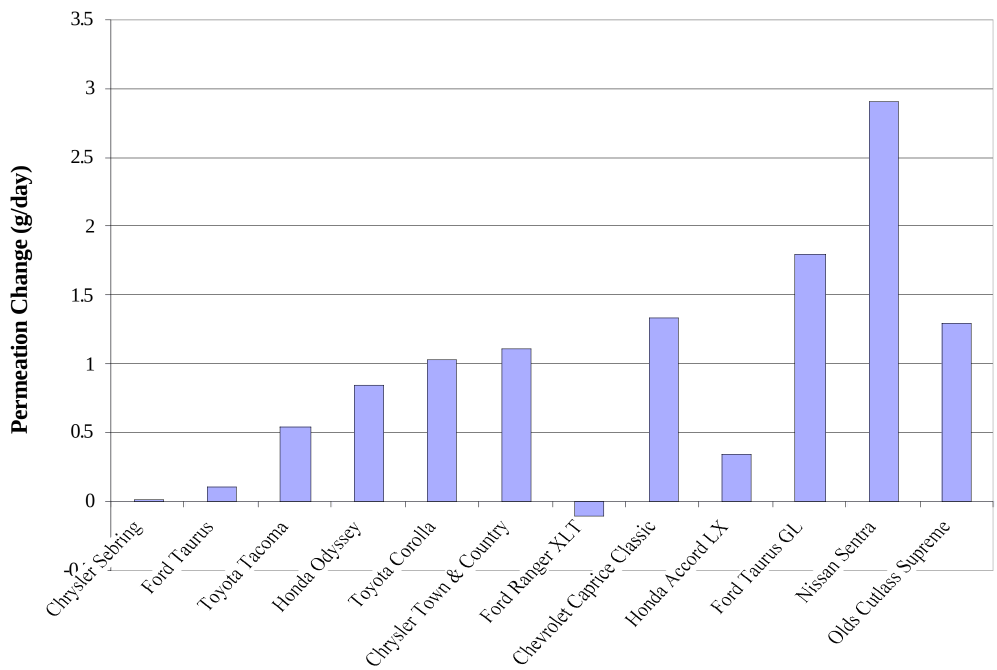
- The Ford Ranger and the Caprice, both with early plastic tanks, had the highest permeation emissions (the Caprice had a fluorinated tank and the Ranger's tank was untreated).

- The 3 vehicles with enhanced evaporative systems (Tacoma, Odyssey and Corolla) had lower permeation emissions compared to the older vehicles.

- The Ford Taurus and Chrysler Sebring (far left) had extremely low permeation emissions on any fuel.

Figure 2 shows the absolute change in diurnal permeation emissions from the non-oxygenated fuel to the ethanol fuel for each vehicle (the change relative to MTBE is not shown in this plot because the two 2004 vehicles were not tested on MTBE).

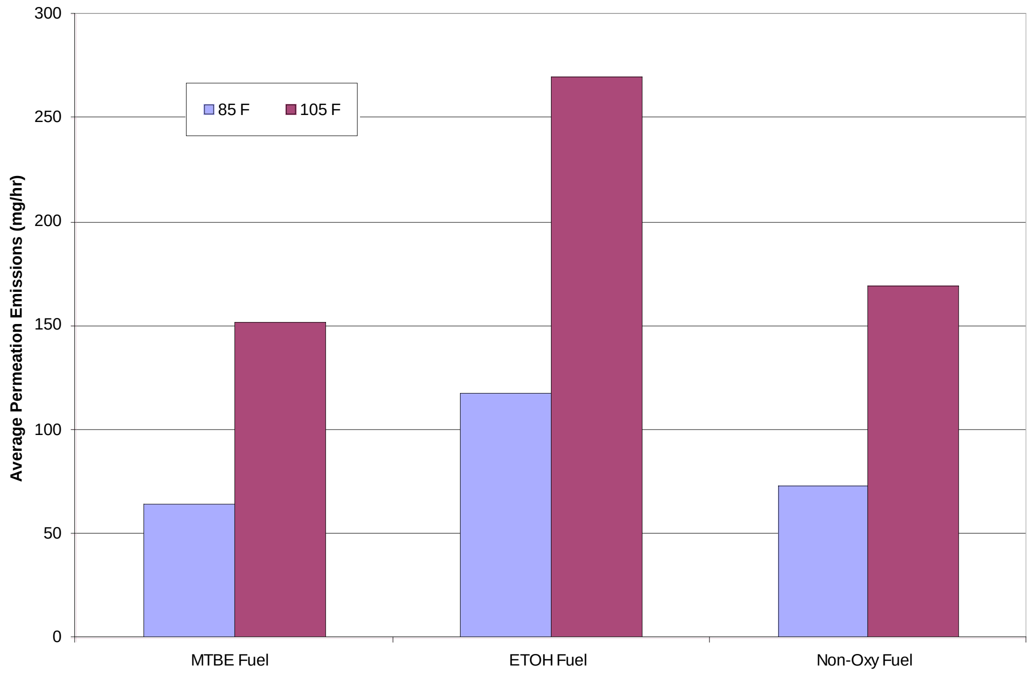
**Figure 2. Change in Diurnal Permeation Emissions Due to Ethanol (from Non-Oxygenated fuel)**




Generally, we see increasing emissions on ethanol as we move from the newer vehicles on the left to the older vehicles on the right. There are several exceptions to that – the Ford Ranger XLT, the Honda Accord LX, and the Olds Cutlass. The emission increases range from near zero for the Sebring to almost 3 g/day for the older Nissan Sentra.

Figure 3 shows the average steady-state permeation emissions for ten of the vehicles in Phase 1 (all but the two 2004 vehicles, which were not tested on the steady state test at 85 F) measured at both 85º F and 105º F for the three different fuels.

**Figure 3. Average Steady-State Permeation Emissions (Excludes the Near Zero and PZEV)**




This figure shows the temperature sensitivity of the permeation increase on the gasoline/ethanol blend – the increase at 85º F is much less than the increase at 105º F.

The two 2004 vehicles were tested at the steady state temperature of 105º F on both ethanol (E6) and non-oxygenated gasoline. The steady state permeation rates of these vehicles were extremely low on the non-oxygenated fuel – on the order of 3 mg/hr. On ethanol fuel, the Taurus (Near Zero Evap) increased to 11.2 mg/hr, and the Sebring (PZEV) increased to 3.4 mg/hr.

These are a few of the findings in the CRC E-65 study; others from the Executive Summary of Phase 1 of the CRC report are listed below.

- Non-ethanol hydrocarbon permeation emissions generally increased when the ethanol containing fuel was tested.

- The average specific reactivity of the permeate (i.e., the permeation emissions) from the three test fuels were similar. The specific reactivity of the permeate of the MTBE and ethanol fuels were not statistically different on average. The non-oxy fuel permeate was higher than the other two with a statistically significant difference.

- Permeation rates measured at different temperatures followed the relationship predicted in the literature, nominally doubling for a 10°C rise in temperature.

- Vehicles certified to the newer “enhanced” evaporative emission standards had lower permeation emissions, including those with non-metallic tanks.

- Permeation emissions generally approached a stabilized level within 1-2 weeks when switching from one fuel to another.

A few of the findings from Phase 2 of the E-65 study were:

- The low level ethanol blends (E6, E6Hi, E10 and E20) increased permeation in all the vehicle systems and technologies tested, compared to non-ethanol fuel (E0)

- The advanced technology LEV II and PZEV systems had much lower permeation emissions than the model year 2000-2001 systems. The PZEV system had the smallest increase due to ethanol of all vehicles tested

The CRC E-65 data clearly show that ethanol increases permeation emissions from on-road vehicles across a wide range of model years and evaporative and fuel system technologies. The testing raises a number of modeling issues that need to be addressed in order to make predictions of the increase in on-road inventories due to ethanol use. These issues are:

1. What is the appropriate fuel to compare to the ethanol blend? Is it the gasoline/MTBE fuel, the non-oxygenated fuel, or both? Should a different baseline fuel be used for the California versus the non-California modeling?

2. What are the effects of higher aromatics on permeation and should they be accounted for?

3. What are the ethanol permeation effects for different model year groups and vehicle classes? How does permeation vary with ethanol content?

4. Is there an effect of fill level on permeation that should be taken into account, and if so, how?

5. How can the effects of temperature be taken into account?

These issues are discussed in more detail in the next few sections.

## 4.2 What Fuel Should Be Compared to the Gasoline/Ethanol Blend?

In the original E-65 testing (Phase 1), fuels tested were an MTBE blend, an ethanol blend (nominally, E6), and a non-oxygenated gasoline meeting Phase 2 specifications. In Phase 3 of the E-65 program, the MTBE blend was eliminated, and two extra ethanol blends were used – E10 and E20.

All areas of the country with RFG have transitioned from RFG with MTBE to RFG with ethanol. So, a case could be made that the base fuel to compare to ethanol is the MTBE-containing fuel. ARB's analysis always assumes the base fuel contains MTBE. However, as noted above, the Phase 3 E-65 testing eliminated the MTBE test, so the only fuel to compare with ethanol is the non-oxygenated fuel. The Phase 1 E-65 testing can be examined to determine whether the non-oxygenated values for vehicles 11 and 12 should be readjusted to an MTBE level.

Table 2 shows the average diurnal emissions for both days for the original 10 vehicles in the E-65 testing program, for both MTBE and non-oxygenated gasoline. Vehicles are shown in order of the newest to oldest. The MTBE emissions have been corrected for FID response. Also shown is the ratio of non-oxygenated permeation emissions to MTBE permeation for each vehicle, and the average ratio for all vehicles, and also the ratio of the total emissions of all 10 vehicles.

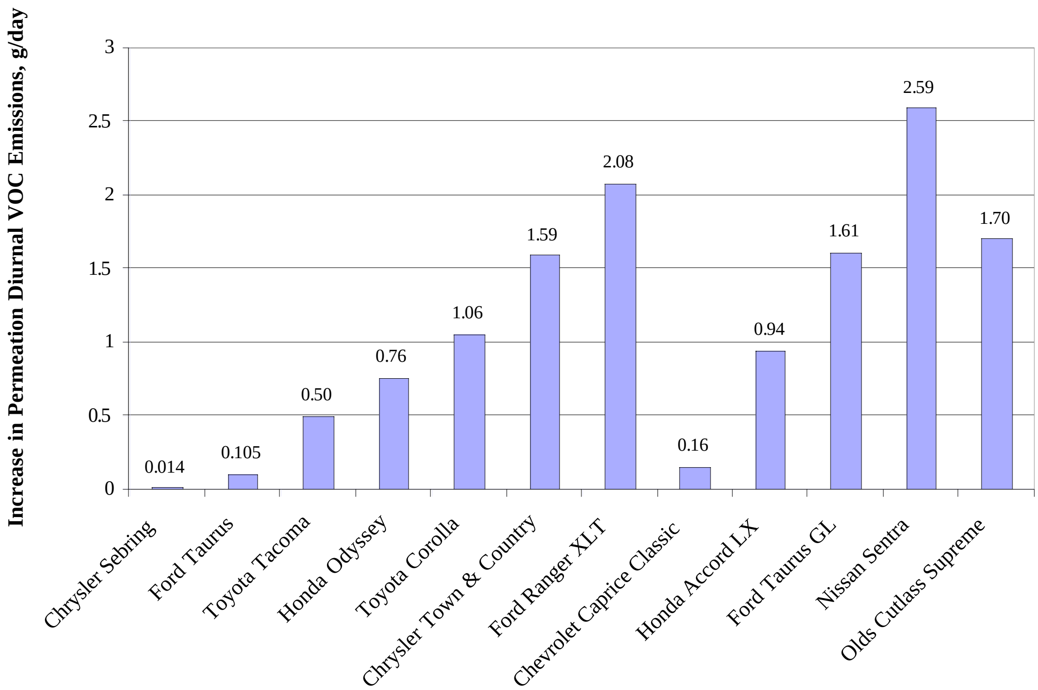
**Table 2. Emissions on MTBE ad Non-Oxygenated Gasoline**

| Rig | Vehicle | MTBE | Non-oxygenated | Ratio, Non-oxy/MTBE |
|---|---|---|---|---|
| 1 | Toyota Tacoma | 0.24 | 0.22 | 1.19 |
| 2 | Honda Odyssey | 0.64 | 0.58 | 1.17 |
| 3 | Toyota Corolla | 0.29 | 0.33 | 0.94 |
| 4 | Chrysler Town and Country | 0.63 | 1.13 | 0.58 |
| 5 | Ford Ranger XLT | 9.20 | 11.75 | 0.81 |
| 6 | Chevrolet Caprice Classic | 4.55 | 3.55 | 1.33 |
| 7 | Honda Accord LX | 1.24 | 1.91 | 0.69 |
| 8 | Ford Taurus GL | 0.96 | 0.82 | 1.24 |
| 9 | Nissan Sentra | 1.96 | 1.77 | 1.18 |
| 10 | Olds Cutlass Supreme | 1.92 | 2.44 | 0.83 |
| | Total emissions | 22.60 | 24.50 | Average ratio = 1.0 |
| | Ratio/Non-oxy total/MTBE total | | 1.08 | |

The results show that the average ratio of emissions on non-oxygenated gasoline to MTBE gasoline is 1.0. If the emissions are totaled and then divided, this shows that the non-oxy emissions are a little higher than the MTBE, but this is driven primarily by one vehicle – the Ford Ranger XLT. We conclude that there is little difference in the MTBE emission and non-oxy emissions overall, so for the Phase 3 test results we further conclude that (1) the MTBE results should be used for Rigs 1-10, and that the non-oxy results should be used for Rigs 11 and 12, with no adjustment. This is a change from the March 2005 report, where we estimated the increase in permeation as the difference between the ethanol results and the average of the MTBE and no-oxy results.

The increase in emissions for each vehicle on E6 as compared to the MTBE results for the original 10 vehicles, and as compared to the non-oxygenated results for vehicles 11 and 12, are shown in Figure 4. The increases range from 0.014 g/day for the PZEV Sebring to 2.59 g/day for the older Nissan Sentra. These diurnal emission increases are for the 65º-105º F test temperature, which would be considered an extreme diurnal temperature day.

**Figure 4. Increase in Permeation Emissions Due to Ethanol**




Many areas outside of California have RFG or conventional gasoline with 10% ethanol. Table 3 examines the diurnal permeation emissions of four of the vehicles in Phase 3 of E-65 on both E6 and E10. Three of the vehicles experienced lower diurnal permeation emissions on E10 than on E6, and one experienced higher emissions on E10. The average ratio of E10/E6 diurnal permeation emissions is 0.93-1.01 depending on how this average is estimated, therefore, this analysis will assume that the diurnal permeation emissions on E10 is the same as on E6.

**Table 3. E6 vs E10 Diurnal Permeation Comparison**

| Vehicle (Rig) | E6, mg/day | E10, mg/ day | Ratio, E10/E6 |
|---|---|---|---|
| Tacoma (1) | 475 | 468 | 0.985 |
| Odyssey (2) | 1426 | 1301 | 0.912 |
| Taurus (11) | 144 | 123 | 0.854 |
| Sebring (12) | 50 | 64 | 1.280 |
| Total | 2095 | 1956 | 0.93 |
| Average Ratio | | | 1.008 |

## 4.3 Effect of Aromatics

Phase 3 of the E-65 program tested 2 of the vehicle from Phase 1 and the Near Zero and PZEV vehicle on a higher aromatics fuel (E6HI) to determine the influence of aromatics and ethanol on permeation emissions. The aromatics level of the E6HI fuel was 38.5%.

Aromatics levels in California are limited by the reformulated gasoline regulations to no more than about 25%. However, in other parts of the country, aromatics levels are not specifically limited.

Examination of the permeation emissions data on the four vehicles shows that at higher aromatics levels, permeation is reduced on average of about 21% for the fuel with 38.5% aromatics. But this is with an E6 fuel, and most of the reformulated gasoline in the other areas modeled in this study is E10. We do not know if there would be the same effect of aromatics on E10 as on E6. Therefore, in this study we are not adjusting the permeation rates for potentially higher aromatics levels outside of California.

## 4.4 Estimating the Ethanol Effect for Different Model Years and Vehicle Classes

In order to determine ethanol's impact on permeation emissions of the fleet, the increase in permeation emissions must be determined for different vehicle classes such as cars, LDTs, SUVs, and even HDGVs, (motorcycles have been omitted from the analysis, but would likely have increases in permeation emissions due to ethanol also). In addition, for each vehicle class, ethanol impacts should be estimated for different model year groups to reflect the different technologies, for example, enhanced evaporative and Tier 2 emission controls.

The first part of this section contains a review of the evaporative emission standards in both California and Federal areas. The second part of this section develops emission rates for the different vehicle classes for these areas. The third part of this section develops emission rates for future evaporative standards for all the areas.

### 4.4.1 Evaporative Emission Standards

#### 4.4.1.1 Federal Standards

For model years from 1980 to 1995, federal cars and LDTs were certified to a 2.0 gram hot soak + diurnal emission standard. The test required the vehicle's fuel tank to be heated through a 60º to 84ºF heat cycle in 1 hour. The certification fuel volatility was 9.0 psi.

The enhanced evaporative standards were phased in starting in 1996, on a 20/40/90/100% schedule for light-duty vehicles (LDVs) and LDTs. The hot soak + diurnal standard was 2.0 grams, but the diurnal test was a 24-hour test from 72º to 96ºF and back to 72º, and the hot soak test is at 95ºF. The enhanced evaporative emission standards also include a running loss test where the emission standard is 0.05 g/mi. LDTs with tank sizes greater than 30 gallons have a diurnal + hot soak emission standard of 2.5 g instead of 2.0 g. The enhanced evaporative standards applied to heavy-duty gasoline vehicles as well on the same phase-in schedule. [19]

The Tier II rule lowered the diurnal + hot soak standard of 2.0 g to 0.95 g/day for cars and LDTs, and to 1.2 g/day for heavy light duty trucks. The Tier II evaporative requirements for cars and LDTs start with model year 2004, with a four-year phase-in schedule of 25/50/75/100. [20]. The phase-in schedule for heavy light-duty trucks is 50/100 starting in 2008 (as shown in Appendix C).

4.4.1.2 California Standards

For model year 1980-1994 cars, LDTs, and heavy-duty gasoline vehicles, the diurnal + hot soak standard was the same as the federal standard.

The enhanced evaporative standards started one year earlier (1995) in California than in Federal areas, and phased-in with a 10/30/50/100% schedule. The diurnal + hot soak and running loss standards are the same as for Federal vehicles, but the volatility of test fuel is lower (7.0 RVP), and the test temperatures are higher (65-105-65º F for the diurnal test, 105º F for the hot soak, and 105º F for the running loss test). [21]

The LEV II regulations introduced two new evaporative standards – a Near Zero evaporative standard, and the Zero evaporative standard which is required for partial zero emission vehicles (PZEVs). The Near Zero evaporative standard is 0.5 g/day (hot soak + diurnal) for passenger cars and LDTs less than 3,750 lbs, is 0.65 g/day for LDTs between 3,750 and 6,000 lbs, and is 0.9 g/day for LDTs between 6,000 and 8,500 lbs. The standard is 1.0 for medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs). The Near Zero standards are phased-in starting in 2004 on a 40/80/100% schedule. There is a separate Zero evaporative emission standard for PZEVs. Current rules stipulate that in order for a vehicle to be certified to the PZEV standard, it must have no more than 0.054 g/day of hot soak + diurnal fuel emissions. The California standards are summarized in Table 4.

**Table 4. Evaporative Standards for Passenger Cars**

| Standard | 3-day Diurnal + Hot Soak (g/day) | Running Loss (g/mi) |
|---|---|---|
| Enhanced | 2.0 | 0.05 |
| Near-zero | 0.5 | 0.05 |
| Zero (PZEV) | 0.35 total (0 grams fuel, defined as <54 mg) | 0.05 |

4.4.1.3 Emission Standards Assumed for the Various Regions

Atlanta and Houston are assumed to comply with the Federal standards. New York opted into the California standards for vehicles in 1994. New Jersey also opted into the California standards, starting with the 2009 model year. Connecticut vehicles are subject to the Federal standards, but many of its vehicles are California-certified because of the California standards implemented by surrounding states. This analysis assumes that vehicles in California, New Jersey, and New York comply with the California standards, and that in Connecticut 75% of the vehicles are certified to the California standards, and 25% are certified to the Federal standards.[6]

### 4.4.2 Development of Emission Rates for Current Vehicles

The CRC permeation tests were performed on fuel systems from twelve vehicles, four of which are classified as light duty trucks (LDTs). There are not enough data to separate the cars and LDTs and make separate estimates. In addition, the evaporative standards of most on-road gasoline vehicles are identical, so combining cars and LDTs is appropriate.

The twelve-vehicle fleet has been divided into five groups as shown in Table 5.

**Table 5. Mapping of Test Vehicles to Evaporative Technologies**

| Technology Group | Test Vehicle |
|---|---|
| PZEVs | 2004 Sebring |
| California LEVII and Federal Tier II Evap | 2004 Taurus |
| Enhanced Evap | Tacoma, Odyssey, Corolla |
| Pre-enhanced evap, mid 1990s | Town and Country, Ranger, Caprice, Accord |
| Pre-1991 Vehilcles | Taurus GL, Sentra, Cutlass Supreme |

The 1997 Town and Country could perhaps have been included with the enhanced evaporative vehicles because it had hardware in advance of the standards, but it was not certified as an enhanced evaporative vehicle, so it was included with the mid-1990s vehicles.

One issue with the four mid-1990s vehicles is that three have non-metallic tanks (Town and Country, Ford Ranger, Chevrolet Caprice). In addition, these vehicles have higher ethanol impacts than the one metal tank vehicle. AIR contacted industry representatives to determine if this is a reasonable fraction of non-metallic tanks for this period, and the consensus was that in this time period, the percent of plastic tanks was unlikely to be above 50%, and in fact was probably in the 30-45% range. Therefore, to estimate the emissions increase for this group, it is necessary to re-weight the ethanol impact for the appropriate fraction of non-metallic tanks.

Figure 5 shows the average emission impacts for the five groups of vehicles. For the mid-1990s vehicles the permeation increase has been estimated for plastic and metal tank impacts separately, and the assumed fraction of plastic tanks is 40%. The non-metallic tank average impact is 1.28 g/day, the metal tank impact is 0.94 g/day, so the weighted average is 1.07 g/day.

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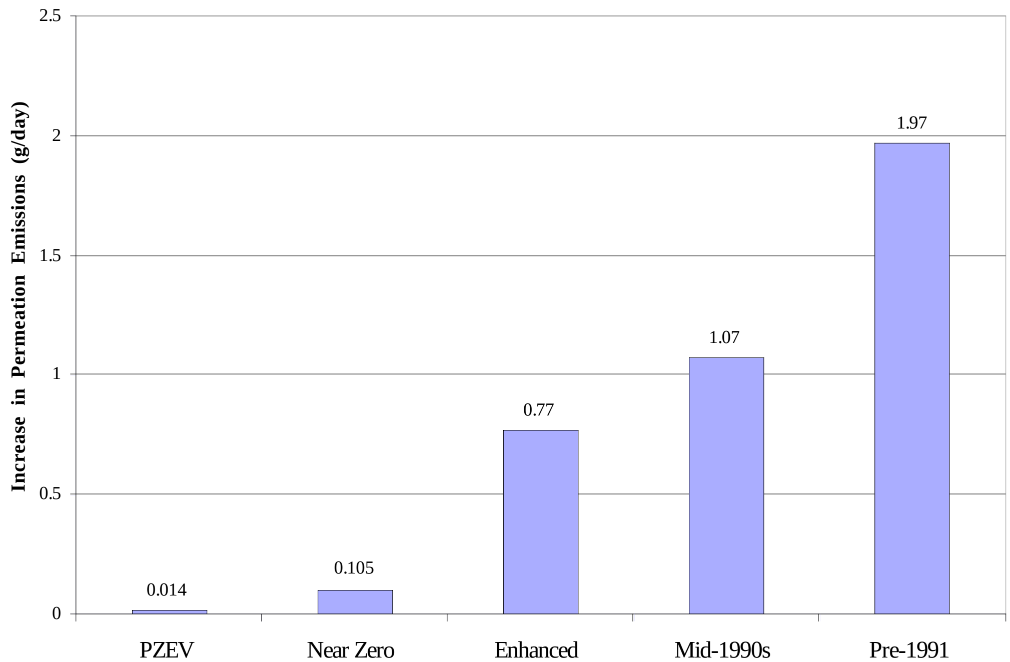
[6] The percentage of Connecticut fleet meeting California standards is based on a communication with the Connecticut Department of Motor Vehicles.

**Figure 5. Increase in Emissions Due to Ethanol**



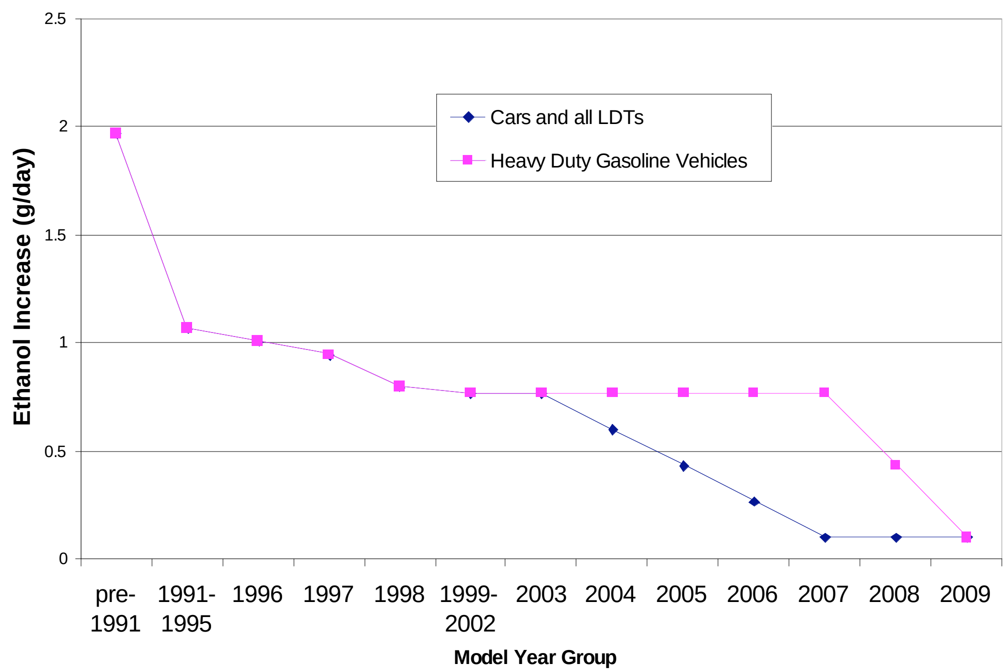

For federal areas, this analysis assumes that the impact of ethanol on permeation emissions is the same for cars, all LDTs, and heavy-duty gasoline vehicles (HDGVs). The analysis also accounts for the phase-in schedule of the enhanced evaporative standards. For California, the analysis assumes that the impact of ethanol on permeation emissions is the same for cars, LDTs, and HDGVs. The California analysis also accounts for the phase-in of the enhanced evaporative emission standards. The Federal and California technology schedules are shown in Appendix C.

It is possible that HDGVs with larger tanks could have higher permeation emissions, and these were not tested in the CRC program. However, tank size is not the only criteria – the Caprice with a 23-gallon tank experienced one of the lower permeation impacts associated with ethanol. Until data are developed for HDGVs with large tank sizes, we think the assumption that the increase in permeation emissions due to ethanol is the same for all vehicle types is appropriate. Also, HDGVs account for only 4% of the total on-road gasoline vehicle fleet, so even if this assumption is erroneous, it would probably not have a large effect on the final permeation inventory impacts.

4.4.3 Summary of Emission Factors by Model Year

Using the emissions factors in Figure 5 and the phase-in schedules of both the enhanced evaporative and Tier II evaporative standards (Appendix C), the model year-specific permeation emission increases from the use of gasoline/ethanol blends for various on-road vehicles types are shown in Figure 6 for Federal areas (Houston, Atlanta, and 25% of Connecticut).

**Figure 6. Ethanol Increase by Model Year - Federal Areas**




As noted in Figure 6, the model year-specific permeation effect of ethanol for cars and LDTs drops sharply starting in 2004 four years before the same effect occurs for heavy-duty gasoline vehicles. This is because the Near Zero standards for passenger cars and LDTs are implemented starting in 2004, whereas the Near Zero standards for HDGVs are implemented starting in 2008.

Figure 7 shows the permeation impacts from the use of gasoline/ethanol blends by model year in California. These estimates use the phase-in of enhanced evaporative standards in California, the phase-in of the Near-Zero evaporative standards that were a part of the LEV II program, and the fractions of PZEVs as estimated by the ARB in the recent modification of the ZEV mandate. [22]

**Figure 7. Increase in Emissions Due to Ethanol - California**

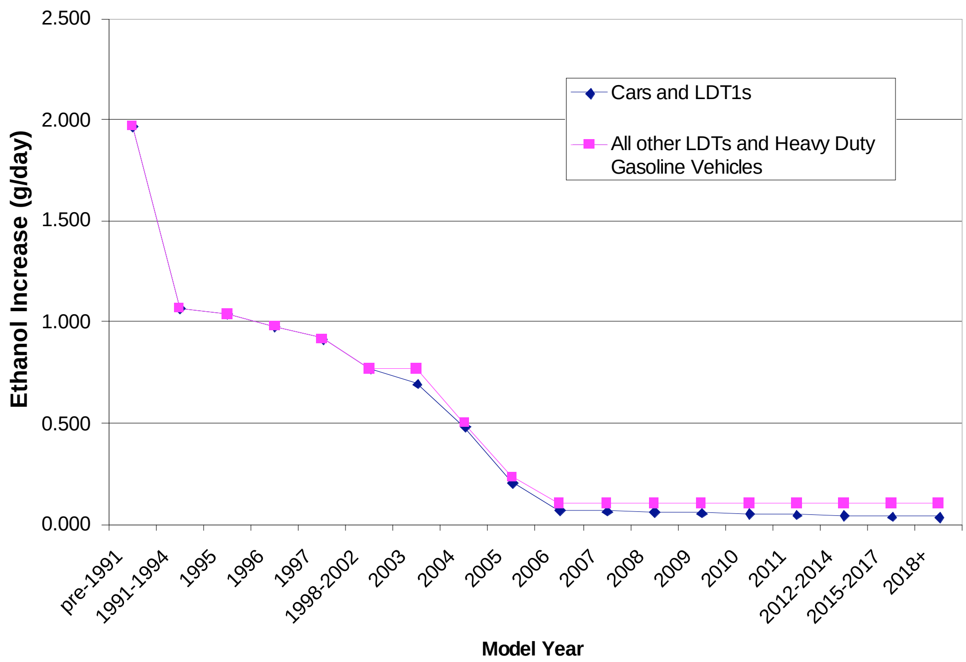



Figure 7 shows that the the impact of ethanol on the permeation increase for cars and LDT1s is lower than for the other vehicles starting in model year 2003. This is due to the fact that the near zero evaporative standards, PZEVs, and ZEVs start to penetrate in this year.

## 4.5 Ethanol Permeation Temperature Correction Factors

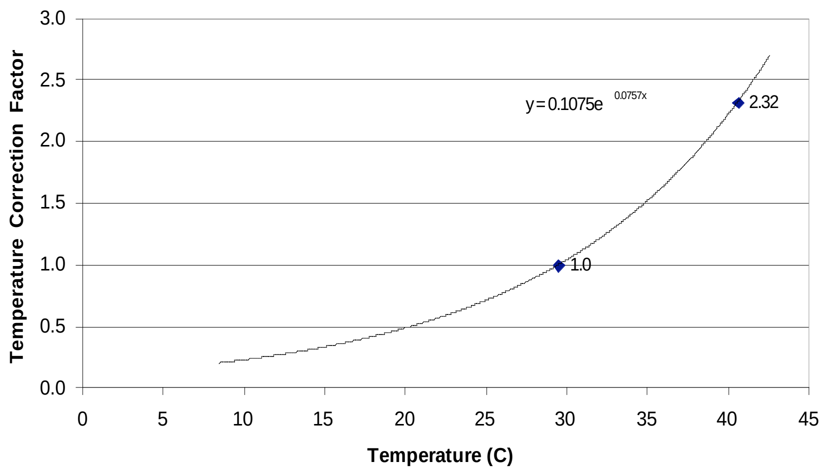
Figure 3 presented earlier illustrated the sensitivity of permeation emissions on all three fuels to temperature. The E-65 test procedure used the California certification procedure, which requires the fuel tank and fuel system to be heated through a 65-105-65º F heating cycle. This is a worse case temperature cycle in the summer in California; typical temperatures on summer days are much lower, particularly in coastal areas. The EMFAC and OFFROAD models contain diurnal temperatures that vary by county and month. These models correct the evaporative emissions at the conditions of the test procedure to the local and seasonal summer temperatures.

It is clear from Figure 3 that the increase in emissions due to ethanol must be corrected for ambient temperature. Other research indicates that permeation emissions increase by about a factor of 2 for every 10° C increase. [23] Table 6 shows the average permeation emissions in mg/hr of the 10 vehicles in E-65 Phase 1 at 85º F and 105º F for each fuel. It also shows the ratio of emissions at 105º F to 85º F. All three fuels show about the same temperature sensitivity.

| Table 6. Average Permeation Emissions (mg/hr) at 85ºF and 105ºF | | | |
|---|---|---|---|
| Temperature | MTBE Fuel | Ethanol Fuel | Non-oxy Fuel |
| 85ºF | 64 | 118 | 73 |
| 105ºF | 152 | 270 | 170 |
| Ratio, 105 to 85ºF | 2.36 | 2.29 | 2.31 |

To develop temperature correction factors (TCFs), the ratios of emissions at 105º F to 85º F were estimated for each vehicle and fuel. The average ratio was then computed for all vehicles and fuels at 2.32. The temperatures were then converted to C, and an exponential curve was fitted through the two points. The result is shown in Figure 8. The curve shown in Figure 11 results in a TCF that is 2.13 times higher for each 10ºC increase in temperature.

**Figure 8. Temperature Correction Factors**



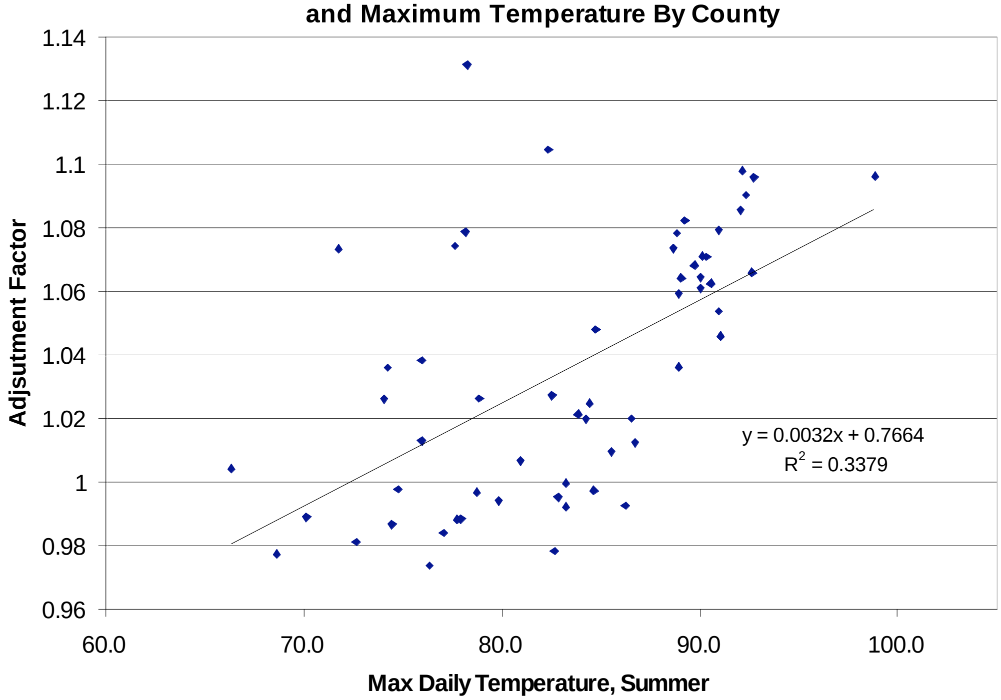

This analysis will use the TCFs shown in Figure 8 to correct permeation emissions for temperature, for both on-road vehicles and off-road equipment and portable containers. One issue, however, is that the above TCFs were developed on steady-state temperature tests, and yet temperatures vary continually throughout the day. The California emission models, for example, contain temperatures for every hour of the day for each of the California counties.

One solution is to use the above TCFs on an hourly basis to correct permeation emissions. This would be overly complicated, however, and does not solve the problem that it is probably difficult to obtain the hourly temperatures for other areas of the country. Another solution is to use the daily minimum and maximum temperatures for each county in California to create an average temperature at the midpoint, and use this temperature to correct permeation emissions on a daily average basis. The test temperature minimum and maximum are 65ºF {18.3ºC} and 105ºF {40.6ºC}, making the midpoint temperature 85ºF {29.4ºC}, corresponding to a TCF for the testing of 1.0. If, for example, the daily diurnal temperatures are 70º {21.1ºC} and 90ºF {32.2ºC}, the mid point of these two temperatures is 80ºF {26.7ºC}, which would correspond to a TCF of about 0.81. This may be an oversimplification, however, because the average temperature during the day is not always the midpoint of the minimum and maximum temperatures

To test the second method, hourly temperatures for each of the 69 areas or counties in California were used to estimate hourly temperature correction factors for all of the areas. Then, average daily TCFs were estimated from the hourly temperatures for each area. Next, the midpoint temperatures were estimated from the daily minimum and maximum temperatures, and a TCF was estimated for each area based on this midpoint. When the two TCFs were compared to each other for each of the 69 areas, it was found that the TCFs estimated from the hourly temperature data were slightly higher than from the midpoints. Over the whole state, these hourly TCFs were 4% higher than the TCFs for the midpoint temperatures.

Figure 9 shows a regression of the ratio of the hourly TCFs to the midpoint TCFs, to the maximum temperatures in the summer for all 69 areas. The adjustment does increase somewhat at higher maximum temperatures, but the overall adjustment is not large.

**Figure 9. Relationship Between TCF Adjustment Factors and Maximum Temperature By County**




Thus, in this analysis, the midpoints will be used to estimate the temperature correction factors, but these will be corrected upward by 4% to account for the difference in hourly and midpoint temperatures.

## 4.6 Effect of Fill Level on Emissions

The CRC program also tested for the effect of preconditioning fill level on emissions. Those results are briefly reviewed here to determine if it is necessary to correct for fill level in the modeling performed in this study.

A 2001 SAE paper by Nulman, et.al, indicates that fill level should not have much effect on total permeation emissions. Nulman and his associates performed permeation measurements on slabs of polymers exposed to both liquid fuel and its vapor. The paper indicates “there is little difference between the fluxes obtained when the slabs are in contact with the vapor and those obtained when the slabs are in contact with the vapor...” [24]

The percent fill level testing was performed on the four vehicles with non-metallic tanks.[7] Vehicles were stabilized at 100% full, preconditioned at 20% full, steady-state tested at 20%, and diurnal tested at 40% full. Only the non-oxygenated fuel was used in this testing. Results are shown in Table 7.

**Table 7. Fill Level Effect Results in E-65 Phase 1**

| Test | Vehicle | 100% Fill Preconditioning | 20% Fill Preconditioning | % Change |
|---|---|---|---|---|
| 105 F, g/hr | 2000 Odyssey | 0.044 | 0.033 | -25 |
| | 1997 T & C | 0.072 | 0.056 | -22 |
| | 1995 Ranger | 0.820 | 0.750 | -9 |
| | 1993 Caprice | 0.298 | 0.277 | -7 |
| | Average | 0.308 | 0.279 | -9 |
| 85 F, g/hr | 2000 Odyssey | 0.019 | 0.013 | -32 |
| | 1997 T & C | 0.041 | 0.021 | -49 |
| | 1995 Ranger | 0.349 | 0.350 | 0 |
| | 1993 Caprice | 0.094 | 0.095 | +1 |
| | Average | 0.126 | 0.120 | -5 |
| Diurnal (average, Day 1 and 2), g/day | 2000 Odyssey | 0.583 | 0.428 | -27 |
| | 1997 T & C | 1.131 | 0.732 | -35 |
| | 1995 Ranger | 11.079 | 11.919 | +8 |
| | 1993 Caprice | 3.547 | 4.049 | +14 |
| | Average | 4.085 | 4.282 | +5 |

The results show that the two enhanced evaporative vehicles have lower emissions at 20% fill than at 100% fill, but the other two non-metallic tank vehicles have higher emissions at 20% fill than at 100% fill. The averages of the four vehicles do not show much change in emissions due to fill level.

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[7] There is no reason to test systems with metal tanks for fill level, due to the fact that fuel does not permeate through metal, and any change in fill level would not affect the permeation of fuel through other vehicle components such as liquid fuel and fuel vapor lines.

A case could perhaps be made for adjusting the enhanced evaporative vehicles for fill level. This would also involve predicting in-use fill levels, which are probably closer to 40% than 20%, which would mitigate the effect. However, perhaps an opposite adjustment would also be necessary for pre-enhanced vehicles. Also, the testing was only performed on non-oxygenated fuel, and not on an ethanol fuel, so it is not known whether the same percent fill adjustment can be applied to the ethanol increases as developed earlier. Given these uncertainties, this analysis does not adjust the permeation emissions for fill level effects.

# 5.0 Off-Road Source Data Analysis

This section reviews the basic data on ethanol impacts on permeation emissions from off-road equipment and portable fuel containers. The first section reviews data on off-road equipment and develops the ethanol effects for off-road equipment. The second section reviews data on portable containers and develops ethanol effects for these sources. The third and final section summarizes the changes in daily emissions due to ethanol for both sources.

## 5.1 Off-Road Equipment

Current off-road gasoline equipment consists of handheld equipment, non-handheld equipment, and industrial and commercial off-road equipment like forklifts, construction equipment, and airport baggage handling equipment. Examples of handheld equipment include chainsaws and lawn trimmers. Non-handheld equipment includes lawnmowers, lawn and garden tractors, and many other types. There are dozens of different types of off-road equipment fueled by gasoline.

Most non-handheld offroad equipment with engines under 25 hp are equipped with fuel tanks made from high density polyethylene (HDPE), but many types of handheld equipment have tanks made from nylon. Some commercial equipment is equipped with metal tanks, but even those pieces equipped with metal tanks usually have non-metallic fuel lines that permeate and may experience an increase in emissions due to ethanol.

In 2003, the California adopted regulations for off-road equipment that reduce evaporative emissions from off-road equipment. Starting in 2006, all off-road equipment is to be equipped with low permeation fuel hoses. Total equipment evaporative standards are implemented starting with the 2007 model year, and are phased in over several years.

The EPA adopted evaporative standards for recreational marine and recreational vehicles in 2002. The EPA will be proposing greatly expanded evaporative standards for small off-road engines, off-road recreational vehicles, and recreational marine in early 2007.

The next section summarizes permeation data from the ARB on uncontrolled equipment. The following section summarizes permeation data from the ARB on equipment with evaporative controls.

### 5.1.1 Uncontrolled off-road equipment

Three ARB testing programs have evaluated both gasoline/MTBE fuels and gasoline/ethanol blends used in uncontrolled equipment. Two focused on walk-behind mowers, and the third tested equipment fuel tanks. These are discussed below.

5.1.1.1 Lawnmower Testing Programs

In an effort to gauge the emissions from fuel containing ethanol, hot soak and diurnal evaporative tests were performed on eight walk-behind mowers (only 5 of the 8 received ethanol tests). [25] Prior to testing, the fuel systems of the mowers were drained and refilled with fuel containing ethanol. They were then soaked for thirty days to stabilize the tanks. After the soak period, the aged fuel was drained, and the mowers were filled to 50% capacity with fresh test fuel. The hot soak and diurnal tests were performed immediately after refueling. The hot soak test consists of a 3-hour soak after engine operation. The diurnal test was a 24-hour test over the ARB test temperatures of 65-105-65. Commercial pump fuel with MTBE had a fuel volatility of 6.9 psi, while the commercial pump fuel containing ethanol had a fuel volatility of 7.3 psi. Results are shown in Table 8, which is from Table 4 of the ARB's report.

**Table 8. ARB Test Ethanol Results on Eight Lawnmowers**

| | Commercial Pump Fuel Containing MTBE | | Commercial Pump Fuel Containing Ethanol | |
|---|---|---|---|---|
| Mower | Hot Soak (g/test) | Diurnal (g/test) | Hot Soak (g/test) | Diurnal (g/test) |
| Honda | 0.475 | 2.495 | | |
| Toro | 0.699 | 5.746 | 0.769 | 7.274 |
| Lawn Boy | 0.412 | 2.068 | | |
| Yard Machine 1 | 0.406 | 2.289 | 0.573 | 3.207 |
| Yard Machine 2 | 0.614 | 2.446 | | |
| Yard Machine 3 | 0.632 | 2.450 | 1.163 | 3.356 |
| Craftsman 1 | 0.580 | 2.181 | 0.858 | 3.266 |
| Craftsman 2 | 0.546 | 2.256 | 0.677 | 3.287 |
| Average | 0.546 | 2.741 | 0.808 | 4.078 |
| Average emissions increase on ethanol | | | 48% | 49% |

The results show a significant increase in both hot soak and diurnal emissions with ethanol fuel, however, some of the increase could be due to the differences in volatilities of the two fuels. Also, the samples are not matched, since some of the lawnmowers were tested on the MTBE fuel but not tested on the ethanol fuel.

Table 9 shows the emission results from the ARB testing on lawnmowers just for engines that were tested on both fuels.

| Table 9. ARB Lawnmower Data with Tests on Both Fuels (g/test) | | | | | | |
|---|---|---|---|---|---|---|
| | Pump Fuel w/MTBE | | Pump Fuel w/ETOH | | Difference | |
| Mower | Hot Soak | Diurnal | Hot Soak | Diurnal | Hot Soak | Diurnal |
| Toro | 0.699 | 5.746 | 0.769 | 7.274 | 0.07 | 1.528 |
| Yard Machine #1 | 0.406 | 2.289 | 0.573 | 3.207 | 0.167 | 0.918 |
| Yard Machine #3 | 0.632 | 2.45 | 1.163 | 3.356 | 0.531 | 0.906 |
| Craftsman #1 | 0.58 | 2.181 | 0.858 | 3.266 | 0.278 | 1.085 |
| Craftsman #2 | 0.546 | 2.256 | 0.677 | 3.287 | 0.131 | 1.031 |
| Average | 0.57 | 2.98 | 0.81 | 4.08 | 0.23 | 1.09 |

The data show an increase in diurnal emissions of about 1.09 g/day, and an increase in hot soak emissions of about 0.23 g. These increases, however, could be influenced by the difference in fuel volatility. If the volatilities were matched, the diurnal differences would be all permeation differences.

To examine how much of the diurnal emissions could be due to the fuel volatility difference, we utilized Reddy's equation of the estimate of emissions increase for a 65-105-65ºF diurnal with 6.9 psi fuel versus 7.3 psi. [26] The equation predicts a 10% decrease in emissions on 6.9 psi fuel. Therefore, if the average diurnal results on ethanol are lowered by 10%, then the average would be 3.68, and the difference in diurnal emissions would be 0.7/day.

We are not sure how much of the hot soak emissions are due to permeation versus vapor generation from either the fuel tank or carburetor float bowl. However, the above corrected diurnal difference is 0.7 g/day, or about 0.03 g/hr. Since the hot soak test is 3 hours, this translates to about 0.09 g. That is less than 0.23 g shown in the table above, but some of the 0.23 g hot soak difference could be due to fuel volatility differences and not permeation differences. Therefore, the 0.7 g diurnal difference appears to be a reasonable estimate of the difference in emissions, whether the engines are operated or not. To determine conclusively whether the permeation differences would be greater during vehicle operation and hot soak, additional test data would need to be collected.

The ARB conducted a second program on lawnmowers on both MTBE and ethanol fuels. These lawnmowers were later equipped with permeation and vapor controls to evaluate the effect of these controls. The 24-hour diurnal test results for these lawnmowers without the evaporative controls are shown in Table 10 (the next section presents the MTBE vs ethanol results with controls). [27] The MTBE blend volatility was 6.7 psi, and the ethanol volatility was 6.9 psi.

| Table 10. 2nd ARB Fuel Program on Lawnmowers | | | |
|---|---|---|---|
| Mower | MTBE (g/day) | Ethanol (g/day) | Increase (g/day) |
| B&S 1 | 2.849 | 2.969 | 0.120 |
| B&S 2 | 2.578 | 3.374 | 0.796 |
| Tecumseh 1 | 3.255 | 3.414 | 0.159 |
| Tecumseh 2 | 3.537 | 3.149 | -0.388 |
| Honda 1 | 2.538 | 2.963 | 0.425 |
| Honda 2 | 2.506 | 3.777 | 1.271 |
| Average | 2.877 | 3.274 | 0.397 |

The results show a range of changes from a decrease of about 0.4 g/day to an increase of 1.3 g/day. Five out of six lawnmowers show an increase due to ethanol. The average increase is about 0.4 g/day.

5.1.1.2 Offroad Equipment Fuel Tanks - Untreated

Tests on offroad tanks are helpful, but these tests alone cannot estimate the permeation impact for equipment because equipment includes tanks and fuel lines, and fuel lines are known sources of permeation.

ARB tested a number of untreated equipment fuel tanks for permeation emissions on both certification fuel (with MTBE) and a gasoline-ethanol mix. [28] In each case, ARB had two identical tanks, where one was tested on fuel containing MTBE, and the other was tested on the gasoline-ethanol blend. Tanks were filled to the full condition with test fuel and stored at room temperature for a minimum of 30 days. After the 30-day soak period, the fuel was drained and fresh fuel was added to the full condition, each tank's fuel opening was sealed with a HDPE coupon that was welded to the tank. The purpose of this was to ensure that when tested, all emissions would be attributable to permeation and none would be due to vapor expansion within the tank. After being stored for 30 days, the tanks were tested in a variable temperature SHED over a 5-day period using the standard ARB temperature profile of 65-105-65ºF. Emissions were measured by evaluating the weight losses of the tanks.

The ARB data on permeation emissions from off-road equipment fuel tanks are shown in Table 11. VOC emissions are reported in g/day. In some cases there were two identical tanks tested on the same fuels.

The test results show that when tested on fuels containing ethanol, the daily emissions increase for these untreated tanks increased between 0% and 84%.  The mass changes in permeation ranged from 0 g/day to 0.44 g/day. The last line shows average increases. The average percent increase of 17.2% was estimated from the average emissions on certification versus ethanol fuel (1.17 g/day and 1.38 g/day). The average emissions were estimated from the individual tanks if only one tank was tested, and from the average if more than one tank was tested

| Table 11. ARB Permeation Testing on Fuel Tanks from Equipment | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mfg | Equipment | Tank Size (gal) | Tank # | Cert Fuel G/day | Ethanol g/day | % Increase | Increase g/day |
| | | | | | | | |
| Toro | Tractor | 3.9 | 1 | 3.00 | Not tested | | |
| | | 3.9 | 2 | 3.43 | 3.39 | -1.1% | -0.039 |
| | | | Avg | 3.22 | 3.39 | 5.5% | 0.18 |
| Toro (Briggs and Stratton Quantum engine) | Mower | 0.5 | 1 | 1.22 | 1.66 | 35.7% | 0.44 |
| | | 0.5 | 1 | 2.78 | 2.94 | 5.8% | 0.16 |
| | | 0.5 | 2 | 2.59 | 2.86 | 10.4% | 0.27 |
| | | | Avg | 2.68 | 2.90 | 8.2% | 0.22 |
| Tecumseh | Unknown | 0.25 | 1 | 0.63 | 0.74 | 17.5% | 0.11 |
| | | 0.25 | 2 | 0.63 | 0.86 | 36.5% | 0.22 |
| | | | Avg | 0.63 | 0.80 | 26.9% | 0.16 |
| FHP-1 | Unknown | 0.07 | 1 | 0.21 | 0.36 | 71.4% | 0.15 |
| FHP-2 | Unknown | 0.09 | 1 | 0.19 | 0.35 | 84.2% | 0.16 |
| FHP-3 | Unknown | 0.06 | 1 | 0.18 | 0.33 | 83.3% | 0.15 |
| Yard Machine | Mower | 0.25 | 1 | 0.69 | 0.95 | 37.6% | 0.26 |
| Yard Machine | Mower | 0.25 | 1 | 1.02 | 1.07 | 5% | 0.05 |
| Average, all | | | | 1.17 | 1.38 | 17.2% | 0.20 |
| Standard Deviation | | | | 1.17 | 1.19 | | 0.11 |

The increase in permeation emissions for the mowers and tractors appears to be on the order of zero to 0.44 g/day. There is some relationship with tank size between the smallest tanks and the 0.25 and 0.5 gallon tanks, but the increase on the 3.9 gallon tank is effectively zero. The three FHP tanks are used for handheld equipment.

The increase in permeation emissions exhibited by these tank data is less than the 0.4-0.7 g/day estimated from lawnmowers, but these data are only for the fuel tanks, and do not include the fuel lines like the lawnmower data.

Overall, the lawnmower data seem to suggest an impact of ethanol on permeation emissions of 0.4-0.7 g/day for current lawnmowers. The data on fuel tanks from handheld equipment seem to show a smaller increase (0.15 g/day), but these data are only for the fuel tank and not the fuel lines. There are no test data on the ethanol increase on equipment with larger fuel tanks. For this analysis, we will assume that all off-road equipment not subject to evaporative controls experience a 0.4 g/day increase in permeation emissions due to ethanol. The handheld equipment increase may be smaller than this, but it is likely that the larger nonhandheld equipment would have a greater increase. This estimate is based on the data presented in Table 11. Further, the estimate is based on the California test temperatures, and must be corrected for ambient temperature conditions.

### 5.1.2 Off-road Equipment with Evaporative Controls

ARB also tested 6 lawnmowers that were equipped with permeation and vapor controls on both gasoline with MTBE and gasoline with ethanol. [27] ARB used low permeation fuel lines, and carefully flourinated the HDPE tanks. In addition, tank vapors were controlled by a pressure system that was activated when the lawnmower engine was turned off. The results of these tests are shown in Table 12.

**Table 12. Diurnal Results on Six Lawnmowers with Evaporative Controls**

| Lawnmower | MTBE Fuel (g/day) | ETOH Fuel (g/day) | Difference (g/day) |
|---|---|---|---|
| B&S #1 | 0.643 | 0.809 | 0.166 |
| B&S #2 | 0.810 | 0.814 | 0.004 |
| Tecumseh #1 | 1.023 | 1.251 | 0.228 |
| Tecumseh #2 | 0.944 | 1.356 | 0.412 |
| Honda #1 | 0.836 | 0.782 | -0.054 |
| Honda #2 | 0.877 | 0.861 | -0.016 |
| Average | 0.856 | 0.979 | 0.123 |

Four out of 6 lawnmowers experienced an increase in emissions on ethanol. The average increase was 14%, or 0.123 g/day.

The ARB treated a number of fuel tanks with sulfonation and fluorination, and tested them on ethanol fuels. Equipment and tank manufacturers are expected to use treated tanks when the offroad evaporative requirements take place starting in 2006. Unfortunately, the ARB did not test any identically treated tanks on both certification fuel and ethanol, so little is known about the increase in emissions due to ethanol. The tests are summarized in Table 13.

**Table 13. ARB Tests of Treated Tanks on Certification and Ethanol Fuels**

| Equipment Type | Treatment | Test Fuel | Emissions (g/day) |
|---|---|---|---|
| Toro Mower | Untreated | Certification | 2.44 |
| | Flourinated | Ethanol | 0.56 |
| Craftsman Mower | Untreated | Certification | 4.40 |
| | Flourinated | Ethanol | 0.51 |
| Craftsman Mower | Untreated | Certification | 2.32 |
| | Flourinated | Ethanol | 1.14 |
| B&S Quantum Tank | Sulfonated | Certification | 2.94 |
| | Sulfonated | Ethanol | 2.91 |

The first three pieces of equipment were tested in the untreated condition with certification fuel, and in the treated condition with ethanol fuel. In all three cases, emissions were reduced with the treatment. However, since the treated tanks were not tested on certification fuel, the data cannot indicate what the change in emissions for a treated tank would be between certification fuel and ethanol fuel. The last tank was tested in the treated condition on both certification and ethanol fuel, and there was no difference in emissions. However, the treatment did not appear to be working, or the emissions of this tank would have been much lower. Therefore, this test data is inconclusive.

This analysis assumes an increase of 0.123 g/day for all 2007 and later equipment subject to evaporative controls in California, and for recreational marine and recreational vehicles in Federal areas. For other off-road equipment in Federal areas, the analysis assumes only the 0.4 g/day increase, due to the fact that evaporative controls have not yet been adopted for these areas, except for marine and recreational vehicles.

Overall, we believe that these lawnmower-based impacts of ethanol on permeation emissions for off-road equipment are very conservative. We would not be surprised if the actual increases are higher, when more data becomes available. For example, the average tank size of all off-road gasoline powered equipment and recreational vehicles (and marine) in is 1.4 gallons, and the average tank size of equipment under 25 hp is about 0.8 gallons. These are larger than the 0.3 gallon size of the lawnmower fuel tanks on which the above impacts are based.

## 5.2 Portable Fuel Containers

Portable containers are used to transport gasoline used in a multitude of applications. Not all portable containers are plastic and subject to permeation. ARB estimates in its OFFROAD model that about 76% of portable containers are plastic, the rest are metal containers. Metal containers do not have permeation emissions, so only non-metallic container populations are adjusted for permeation emissions in this study.

### 5.2.1 Uncontrolled Containers

The ARB also tested a number of portable containers on both certification fuel (containing MTBE) and ethanol fuel. The containers were tested in a similar manner to the tanks above, in that the containers were soaked for 30 days, refueled, and a HDPE coupon was welded to the container. The containers were tested over a 65-105-65℉ test cycle and weighed at intervals. Eight tanks were tested on ethanol fuel, and thirteen containers were tested with certification fuel. Some of the containers were tested on both fuels.  For example, Wedco 6.6 gallon tanks were tested on both ethanol fuel and certification fuel.  Results are shown in Table 14. Container sizes range from 1 to 7 gallons.

| Table 14. ARB Permeation Testing of Portable Fuel Containers | | | | | | |
|---|---|---|---|---|---|---|
| Fuel | Number | Mfg | Vol | ID | Loss (g/gal/day) | g/day |
| Ethanol | 1 | Wedco | 6.6 | EC.6W1 | 1.44 | 9.50 |
| | 2 | Wedco | 6.6 | ERC6W1 | 1.77 | 11.68 |
| | 3 | Wedco | 5 | ERCW3 | 2.17 | 10.85 |
| | 4 | B&S | 2.5 | ECSF1 | 1.27 | 3.18 |
| | 5 | Blitz | 2.06 | ECB1 | 2.29 | 4.72 |
| | 6 | Blitz | 2.06 | ECB2 | 2.52 | 5.19 |
| | 7 | Vemco | 1.25 | ECV1 | 3.44 | 4.30 |
| | 8 | Wedco | 1 | ECV2 | 3.34 | 3.34 |
| CERT | 1 | Wedco | 6.6 | C6W1 | 1.09 | 7.19 |
| | 2 | Wedco | 5 | CW1 | 1.39 | 6.95 |
| | 3 | Wedco | 5 | CW2 | 1.46 | 7.30 |
| | 4 | Wedco | 5 | CW3 | 1.41 | 7.05 |
| | 5 | Wedco | 5 | CW4 | 1.47 | 7.35 |
| | 6 | B&S | 2.5 | CSF1 | 1.46 | 3.65 |
| | 7 | B&S | 2.5 | CSF2 | 1.09 | 2.73 |
| | 8 | Blitz | 2.06 | CB1 | 1.88 | 3.87 |
| | 9 | Blitz | 2.06 | CB2 | 1.95 | 4.02 |
| | 10 | Blitz | 2.06 | CB3 | 1.91 | 3.93 |
| | 11 | Blitz | 2.06 | CB4 | 1.78 | 3.67 |
| | 12 | Vemco | 1.25 | CV1 | 1.51 | 1.89 |
| | 13 | Vemco | 1.25 | CV2 | 1.52 | 1.90 |
| Average, Ethanol | | | 3.38 | | 2.28 | 6.59 |
| Standard Deviation | | | | | 0.8 | 3.49 |
| Average, CERT | | | 3.26 | | 1.53 | 4.73 |
| Standard Deviation | | | | | 0.28 | 2.12 |
| Ethanol Percent Amount Higher | | | | | 49% | 39% |
| Ethanol Amount Higher (g/day) | | | | | | 1.86 |

The results show that on average, ethanol increases emissions from these containers by about 39% on a g/day basis. The increase in emissions is about 1.9 g/day per container with the change in test temperature from 65ºF to 105ºF. Typical California temperatures are lower than this, so the increase will be smaller when temperature-corrected.

### 5.2.2 Containers with Treatments

Starting in 2001 in California, containers were required to have a spill-proof design and to be treated with a permeation barrier. The emissions changes for containers with barrier treatments are likely to be different than the untreated tanks shown above. However, ARB has no data on the emissions from treated containers filled with certification fuel versus ethanol. Similar rules for portable containers in federal areas were recently finalized in EPA’s Mobile Source Air Toxics rule, with an implementation date of 2009.

One method for estimating the ethanol increase for portable containers with permeation controls is to estimate the percent reduction in the ethanol increase for lawnmowers, and apply it to portable containers as well. In the previous section, it was determined that the increase for uncontrolled lawnmowers is 0.4 g/day, and for controlled lawnmowers is 0.123 g/day. This is a 70% reduction in the increase. The increase from uncontrolled portable tanks is estimated at 1.86 g/day, so a 70% reduction from this level is 0.56 g/day.

### 5.3 Summary of Ethanol Changes for Offroad Equipment and Portable Containers

The estimated increases in VOC emissions for off-road equipment and portable containers in California and non-California areas are summarized in Table 15.

**Table 15. Permeation Increases for Off-road Sources and Portable Containers**

| Region | Source | Model Year Group | Permeation Increase (g/day) |
|---|---|---|---|
| California | All off-road Sources | Pre-2007 | 0.4 |
| | | 2007+ | 0.123 |
| | Portable Containers | Pre-2001 | 1.86 |
| | | 2001+ | 0.56 |
| Non-California | Off-road sources except recreational marine, and recreational vehicles | All | 0.4 |
| | Recreational vehicles and recreational marine | Pre-2008 | 0.4 |
| | | 2008+ | 0.123 |
| | Portable containers | Pre-2009 | 1.86 |
| | | 2009+ | 0.56 |

# 6.0 Inventory Method

## 6.1 Overview of Method

As indicated in Section 3.3, the basic method used to estimate the inventory impacts of ethanol was to: (a) determine the increases in VOC permeation emissions due to ethanol for on-road vehicles, off-road equipment, and portable containers, (b) correct the increases for ambient temperature, and (c) multiply the increases by the various populations of the sources. This is shown below.

$$\text{Ethanol Effect on Permeation} = \Sigma_{myrs} [\text{Population}_{myr} * \text{g/day}_{myr,\ 65\text{-}105} * \text{TCF} * \text{CF}]$$

Where:

| | |
|---|---|
| $\Sigma_{myrs}$ | = sum of increased permeation emission for all equipment types by model year over the range of model years considered for the calendar year of consideration |
| Population | = population of each model year group |
| $\text{g/day}_{myr,\ 65\text{-}105}$ | = the permeation ethanol effect of a particular model year group, utilizing the 65-105-65 diurnal test |
| TCF | = temperature correction factor from average temperature of 65-105 diurnal to average temperature of inventory day (generated from CRC steady-state temperature data) |
| CF | = correction factor from grams per day to tons per day |

Inventories are estimated for California, Houston, Atlanta, and the New York City/New Jersey Connecticut areas. The calendar years selected for evaluation are 2003, 2005, 2010, and 2015. The ethanol increases for the various sources were determined in Sections 4 and 5. The temperature correction factors were also developed in Section 4. The following items are discussed in this section:

- Ethanol market share and concentration
- On-road vehicle, off-road equipment, and portable container populations
- Ambient temperatures
- Detailed inventory method

## 6.2 Ethanol Market Share and Concentration

Ninety-five percent of the gasoline sold in California currently contains ethanol. Houston is an RFG area, so 100% of its gasoline contains ethanol. Atlanta is not yet an RFG area, but is required to implement RFG, so its market share of oxygenate will eventually be 100%. New York and Connecticut are RFG areas that have banned MTBE and have ethanol in all gasoline. New Jersey is an RFG area, and currently uses MTBE.

While most of the permeation testing to date has been developed with ethanol at 6%, the E-65 Phase 3 testing showed that permeation is no higher at E10 than E6, at least for on-highway vehicles. In this study, we will assume permeation remains constant at ethanol levels above E6, and that the ethanol content in areas modeled will not exceed E10.

### 6.3 On-Road Vehicle Populations

On-road gasoline vehicle populations included gasoline passenger cars, all light duty gasoline trucks (including SUVs, etc.), and heavy-duty gasoline vehicles. Motorcycles were omitted from the analysis.

#### 6.3.1 California

On-road vehicle populations (all gasoline vehicles except for motorcycles) for California were determined directly from the most recent version of the EMFAC model, EMFAC2007. [8] These are shown in Table 16.

**Table 16. California On-Road Vehicle Populations**

| Year | On-road gasoline vehicle population |
|---|---|
| 2005 | 23,958,616 |
| 2010 | 25,118,477 |
| 2015 | 27,482,109 |
| 2020 | 29,558,692 |

#### 6.3.2 Non-California Areas

The on-highway vehicle populations were identified for the following regions.

- Downstate New York RFG Area – 12 counties contained in the two non-attainment regions of New York-New New Jersey-Long Island and Poughkeepsie
- Connecticut – statewide
- New Jersey – statewide
- Houston Non-Attainment Area – 8 counties
- Atlanta Non-Attainment Area – 13 counties

The base year populations were identified for each region using the latest available vehicle registration data. The base year populations are summarized in Table 17. Connecticut and New Jersey vehicle populations are based on State total registrations as published by FHWA. [29] New York and Atlanta county-level registration data were obtained from on-line databases maintained by the respective state agencies. [30, 31] Houston vehicle populations are based on a count of Inspection and Maintenance (I/M)-subject vehicles in the 8-county non-attainment area adjusted to account for the portion of the fleet not covered by the I/M program. [32, 33]

[8] ARB estimates the increases in permeation emissions for motorcycles, so their populations are slightly higher. Awe ignored this source because there was no data to make this estimate.

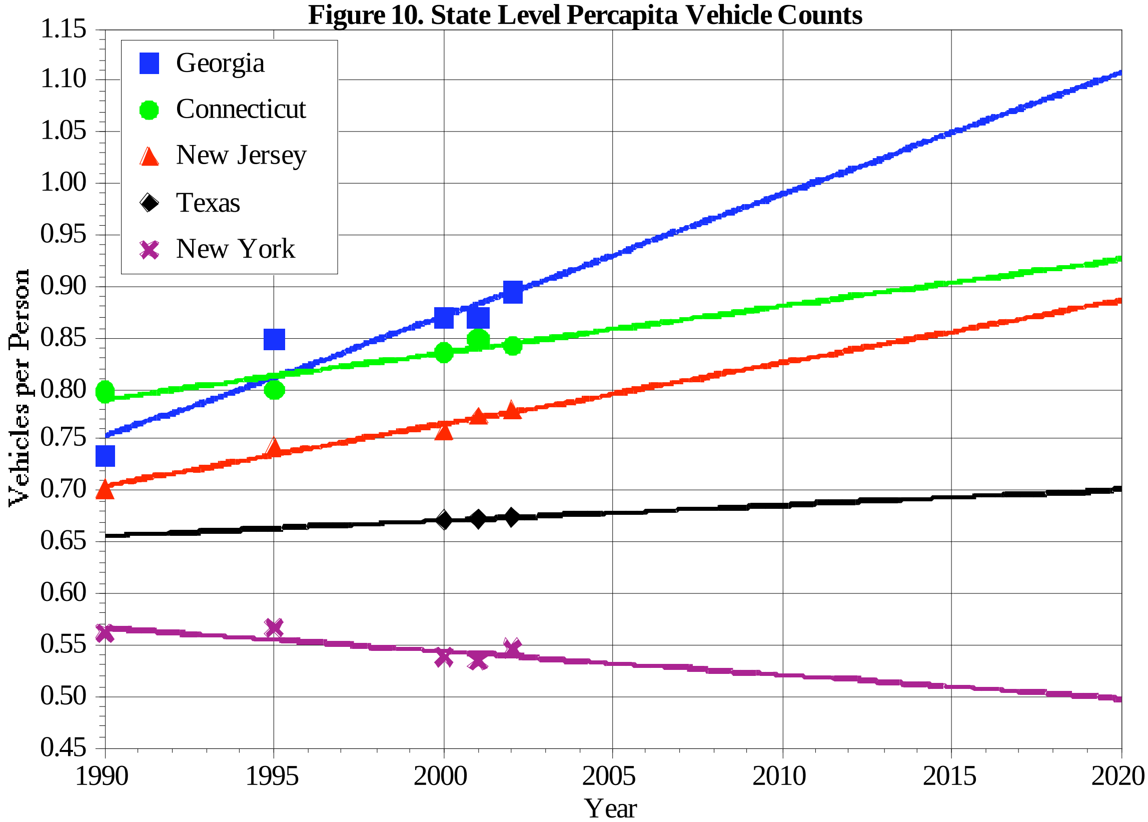
| Table 17. Base Year Total On-Highway Vehicle Population | | |
|---|---|---|
| Region | Base Year | Population |
| Downstate New York | 2003 | 5,466,122 |
| Connecticut | 2002 | 2,920,377 |
| New Jersey | 2002 | 6,695,061 |
| Houston | 2000 | 3,167,854 |
| Atlanta | 2004 | 2,962,278 |

Two factors were used to project estimated total vehicle populations, human population projections and per capita vehicle ownership trends. These data were used to project total vehicle populations to the evaluation years of 2003, 2005, 2010 and 2015. Per capita vehicle ownership trends were factored into the analysis since the number of vehicles per person and their trend is distinctly different for the regions of study.

Changes in human population to 2020 were obtained from the latest available metropolitan planning agency estimates using linear interpolation, when necessary, to evaluate years not documented by the planning agency. Downstate New York, Connecticut and New Jersey population growth factors are based on estimates prepared by New York Metropolitan Transportation Council. [34] Houston and Atlanta population growth factors are based on estimates prepared by the Houston-Galveston Area Council and the Atlanta Regional Commission, respectively. [35, 36]

Per capita vehicle ownership trends were estimated at the state-level using total human population reported by the US Census and total vehicle population reported by the Federal Highway Administration. [37, 38] Data were obtained for the years 1990, 1995, 2000, 2001 and 2002 and the state-level number of vehicles per person is summarized in Figure 10. The linear trend estimated from the 1990 to 2002 data was used to project per capita vehicle ownership for Connecticut, New Jersey, New York and Georgia to 2015. The linear trend estimated from 2000 to 2002 data was used to project vehicle ownership for Texas to 2015. It was assumed for Texas that the decline in per capita vehicle ownership observed in the 1990s would not continue into the future.

**Figure 10. State Level Percapita Vehicle Counts**




The human population and per capita vehicle ownership data were converted into multiplicative adjustment factors, which were used to project vehicle populations from the base year to the year of evaluation. These data are summarized in Table 18. The "total adjustment" shown in Table 18 represents the combined human population and per capita vehicle ownership adjustment factors and was used to project base year vehicle population estimates. These data demonstrate the regional variation in estimated vehicle population projections. For example for the period of 2010 to 2015, vehicle population changes are estimated to range from -1.1% for downstate New York to +17.4% for Atlanta.

| Table 18. Multiplicative Adjustment Factors Used to Project Total Vehicle Population | | | | |
|---|---|---|---|---|
| Region | Adjustment Basis | Human Population Adjustment | Per Capita Vehicle Ownership Adjustment | Total Adjustment (Human Population × Per Capita Vehicle Ownership) |
| Downstate New York | Base year to 2003 | 1.0000 | 1.0000 | 1.0000 |
| | 2003 to 2005 | 1.0041 | 0.9915 | 0.9956 |
| | 2005 to 2010 | 1.0103 | 0.9786 | 0.9887 |
| | 2010 to 2015 | 1.0115 | 0.9781 | 0.9894 |
| | 2015 to 2020 | 1.0156 | 0.9777 | 0.9929 |
| Connecticut | Base year to 2003 | 1.0021 | 1.0085 | 1.0106 |
| | 2003 to 2005 | 1.0041 | 1.0107 | 1.0148 |
| | 2005 to 2010 | 1.0103 | 1.0264 | 1.0369 |
| | 2010 to 2015 | 1.0115 | 1.0257 | 1.0375 |
| | 2015 to 2020 | 1.0156 | 1.0250 | 1.0410 |
| New Jersey | Base year to 2003 | 1.0021 | 1.0054 | 1.0075 |
| | 2003 to 2005 | 1.0041 | 1.0155 | 1.0197 |
| | 2005 to 2010 | 1.0103 | 1.0381 | 1.0488 |
| | 2010 to 2015 | 1.0115 | 1.0367 | 1.0486 |
| | 2015 to 2020 | 1.0156 | 1.0354 | 1.0515 |
| Houston | Base year to 2003 | 1.0582 | 1.0066 | 1.0652 |
| | 2003 to 2005 | 1.0367 | 1.0044 | 1.0413 |
| | 2005 to 2010 | 1.0885 | 1.0111 | 1.1005 |
| | 2010 to 2015 | 1.1091 | 1.0109 | 1.1212 |
| | 2015 to 2020 | 1.1148 | 0.9342 | 1.0414 |
| Atlanta | Base year to 2003 | 0.9872 | 0.9871 | 0.9744 |
| | 2003 to 2005 | 1.0260 | 1.0261 | 1.0528 |
| | 2005 to 2010 | 1.0633 | 1.0637 | 1.1310 |
| | 2010 to 2015 | 1.1071 | 1.0599 | 1.1735 |
| | 2015 to 2020 | 1.0968 | 1.0565 | 1.1587 |

Applying the data of Table 18 to the base year population estimates (Table 17) results in the total vehicle populations shown in Table 19 for each calendar year of study. The total vehicle population estimates were converted into a gasoline vehicle total (excluding motorcycles) using national data on vehicle populations by fuel type and vehicle class developed for EPA's MOBILE6 model shown in Table 20. [39] The gasoline vehicle populations by region and year are also shown in Table 19.

Lastly, for inventory calculations the gasoline fleet was distributed into population estimates by model year using region-specific age distribution data obtained by state environmental planning agencies. [33-39, 40, 41, 42, 43] These data capture the rate at which the fleet turns over. The average age of the fleet for each region is shown in Table 21.

**Table 19. Estimated Vehicle Populations by Region by Year**

| Region | Year | Estimated Total Vehicle Population | Estimated Gasoline Vehicle Population, Excluding Motorcycles |
|---|---|---|---|
| Downstate New York | 2003 | 5,466,122 | 5,163,496 |
| | 2005 | 5,442,159 | 5,135,796 |
| | 2015 | 5,380,574 | 5,078,768 |
| | 2020 | 5,323,642 | 5,021,861 |
| | 2020 | 5,285,718 | 4,985,064 |
| Connecticut | 2003 | 2,951,378 | 2,787,978 |
| | 2005 | 2,995,170 | 2,826,558 |
| | 2010 | 3,105,788 | 2,931,578 |
| | 2015 | 3,222,298 | 3,039,636 |
| | 2020 | 3,354,432 | 3,163,630 |
| New Jersey | 2003 | 6,745,066 | 6,371,632 |
| | 2005 | 6,877,755 | 6,490,576 |
| | 2010 | 7,213,253 | 6,808,649 |
| | 2015 | 7,564,161 | 7,135,372 |
| | 2020 | 7,953,853 | 7,501,434 |
| Houston | 2003 | 3,295,145 | 3,112,713 |
| | 2005 | 3,431,180 | 3,238,024 |
| | 2010 | 3,775,965 | 3,564,164 |
| | 2015 | 4,233,669 | 3,993,675 |
| | 2020 | 4,770,533 | 4,499,182 |
| Atlanta | 2003 | 2,886,560 | 2,726,748 |
| | 2005 | 3,038,977 | 2,867,899 |
| | 2010 | 3,437,174 | 3,244,377 |
| | 2015 | 4,033,356 | 3,804,717 |
| | 2020 | 4,673,650 | 4,407,810 |

| Table 20. Percent of Total Fleet Population from Gasoline Vehicles (Excluding Motorcycles) | |
|---|---|
| Year | Percent of Total Fleet |
| 2003 | 94.5% |
| 2005 | 94.4% |
| 2010 | 94.4% |
| 2015 | 94.3% |
| 2020 | 94.3% |

| Table 21. Average Age of Gasoline Fleet by Region. | |
|---|---|
| **Region** | **Average Age (Years)** |
| Downstate New York | 7.1 |
| New Jersey | 7.1 |
| Connecticut | 7.1 |
| Houston | 6.5 |
| Atlanta | 7.6 |

### 6.4 Off-Road Equipment and Portable Container Populations

The OFFROAD model indicates that the weighted average percent of plastic containers (commercial and residential) is 75.8%. The projections shown in the table below include only plastic containers. Metal containers will be assumed to have no permeation emissions. [9]

#### 6.4.1 California

The off-road gasoline equipment and portable container populations were determined from the ARB's OFFROAD2002 model, and are shown in Table 22.[10] Also shown in Table 22 is ARB's more recent estimate of portable container populations that show a significant decline from 2005 through 2020. [44] This downward trend is attributed to a decline in the number of households with containers. ARB has not yet drafted a technical report of these findings, and portable container populations and inventories are not present in the OFFROAD2007 model. The direction in containers (metal and nonmetal) runs the opposite to the populations of portable equipment. For this analysis, we will use the OFFROAD2002 populations, but the ethanol emission impact would be significantly smaller if the new populations were used.

[9] Tests by ARB indicate very low permeation emissions from metal portable containers.
[10] Portable containers were removed from the OFFROAD2007 model.

| Table 22. California Vehicle, Equipment, and Container Stock Estimates | | | |
|---|---|---|---|
| Year | Off-road gasoline equipment (handheld and non-handheld) | Non-metallic portable containers, OFFROAD2002 | Non-metallic portable containers, new ARB analysis |
| 2005 | 16,671,135 | 7,884,690 | 5,678,981 |
| 2010 | 17,803,550 | 8,172,746 | 4,435,248 |
| 2015 | 19,120,024 | 8,461,178 | 3,513,434 |
| 2020 | 20,551,478 | 8,749,415 | 2,845,548 |

### 6.4.2 Non-California Areas

Once the counties are identified, the off-road equipment populations can be determined directly from EPA's NONROAD model. The NONROAD model, however, does not contain portable container populations. To determine portable container populations outside of California, the California OFFROAD model was examined to determine an off-road gasoline equipment to container ratio. This ratio was then multiplied by the non-California gasoline equipment to estimate portable container populations in non-California areas.

The counties included in the inventory analysis are as follows:

- New York/New Jersey/Connecticut
  - All of New Jersey
  - All of Connecticut
  - New York downstate area: Bronx, Kings, Nassau, New York, Orange, Queens, Richmond, Rockland, Suffolk, Westchester, Duchess, Orange, and Putnam counties
- Houston-Galveston-Brazoria
  - Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, Waller counties
- Atlanta
  - Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinett, Henry, Paulding, and Rockdale counties

The OFFROAD model was examined to determine the ratio of equipment to container populations. The results for the large urban areas and statewide are shown in Table 23.

| Table 23. Ratio of Equipment to Non-Metallic Containers (Calendar Year 2003) in ARB OFFROAD Model | | | | |
|---|---|---|---|---|
| Area | 2005 | 2010 | 2015 | 2020 |
| Los Angeles | 2.11 | 2.18 | 2.28 | 2.41 |
| Sacramento | 2.14 | 2.19 | 2.24 | 2.27 |
| San Diego | 2.36 | 2.49 | 2.58 | 2.68 |
| San Francisco | 1.83 | 1.87 | 1.92 | 1.97 |
| All of California | 2.11 | 2.18 | 2.26 | 2.35 |

Examination of large urban areas in California shows that the ratio of equipment to non-metallic containers varies from 1.8 to 2.3. In this analysis, the ratio for the state of California was used for all areas outside of California for each calendar year.

The off-road equipment and container populations for the various areas outside of California are shown in Table 24.

| Table 24. Offroad Equipment and Estimated Portable Container Populations | | | |
|---|---|---|---|
| Area | Year | Off-road equipment | Non-metallic portable Containers |
| Atlanta | 2005 | 1,703,004 | 805,444 |
| | 2010 | 1,892,384 | 868,701 |
| | 2015 | 2,072,184 | 917,003 |
| | 2020 | 2,243,422 | 955,096 |
| Houston | 2005 | 1,912,221 | 904,393 |
| | 2010 | 2,114,190 | 970,522 |
| | 2015 | 2,309,831 | 1,022,169 |
| | 2020 | 2,499,222 | 1,063,998 |
| New York City | 2005 | 5,304,534 | 2,508,804 |
| | 2010 | 5,855,462 | 2,687,959 |
| | 2015 | 6,397,561 | 2,831,111 |
| | 2020 | 6,928,745 | 2,949,786 |
| New Jersey | 2005 | 4,142,981 | 1,959,442 |
| | 2010 | 4,575,169 | 2,100,238 |
| | 2015 | 4,985,686 | 2,206,314 |
| | 2020 | 5,376,306 | 2,288,864 |
| Connecticut | 2005 | 1,700,872 | 804,435 |
| | 2010 | 1,877,152 | 861,709 |
| | 2015 | 2,044,010 | 904,535 |
| | 2020 | 2,202,294 | 937,586 |

## 6.5 Ambient Temperatures

For California, this analysis used summer State Implementation Plan (SIP) ozone planning temperatures by county that are found in both the OFFROAD and EMFAC2007 models on a county basis to correct the ethanol increases. For the non-California areas, temperatures used come from the various SIPs.

Using the temperature correction factor methodology discussed earlier and the various state minimum and maximum temperatures, the overall temperature correction factors for 2005? were developed as shown in Table 25 (California temperature correction factors are estimated from population-weighting the individual county temperature correction factors).

| Table 25. Temperature Correction Factors | | |
|---|---|---|
| Area | Summer | Annual |
| California – statewide | 0.755 | 0.595 |
| Atlanta | 0.976 | 0.479 |
| Houston | 1.100 | 0.576 |
| New York | 0.879 | 0.396 |
| Connecticut | 0.957 | 0.397 |
| New Jersey | 0.980 | 0.408 |

The temperature correction factors in Table 25 are different than in the March 2005 report because the new temperature correction factors are based on new temperatures developed by the ARB for EMFASAC2007.

## 6.6 Further Details on the Inventory Method

The method used to estimate the increase in permeation emissions requires the development of populations by model year group for the various regions. As mentioned earlier, for all areas, populations of on-road vehicles, off-road equipment, and portable containers were split into the appropriate model year group populations by calendar year using region-specific age distribution data obtained by state environmental planning agencies.

## 7.0 Results

This section presents the results of the inventory analysis expressed as the increase in VOC permeation emissions due to the use of gasoline/ethanol blends. The results are presented by geographical area, and they are compared to other VOC inventories in each region in order to provide a context.

Figure 11 shows the population estimates for 2005 and 2020 for the various areas, and Figure 12 shows the ethanol permeation impacts for summer temperatures for 2005 and 2020 for the various areas. These are discussed further in the sections below.

**Figure 11. On-Road, Off-Road and Portable Container Population Estimates**

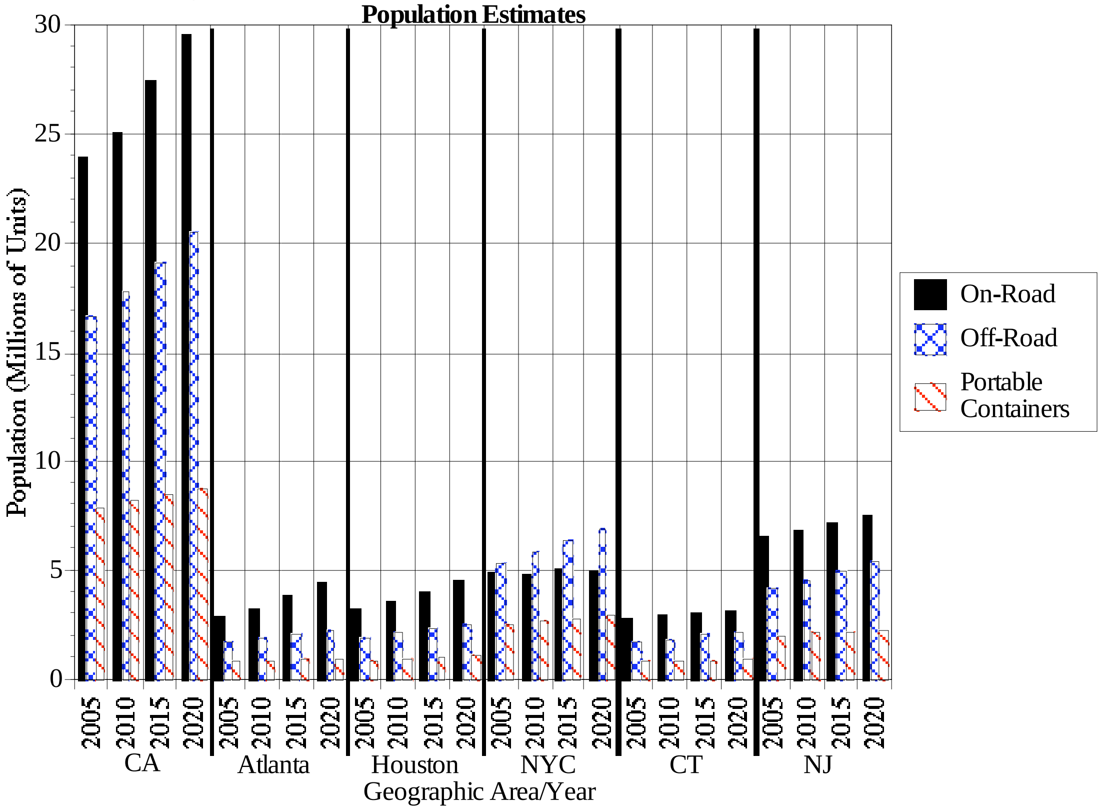
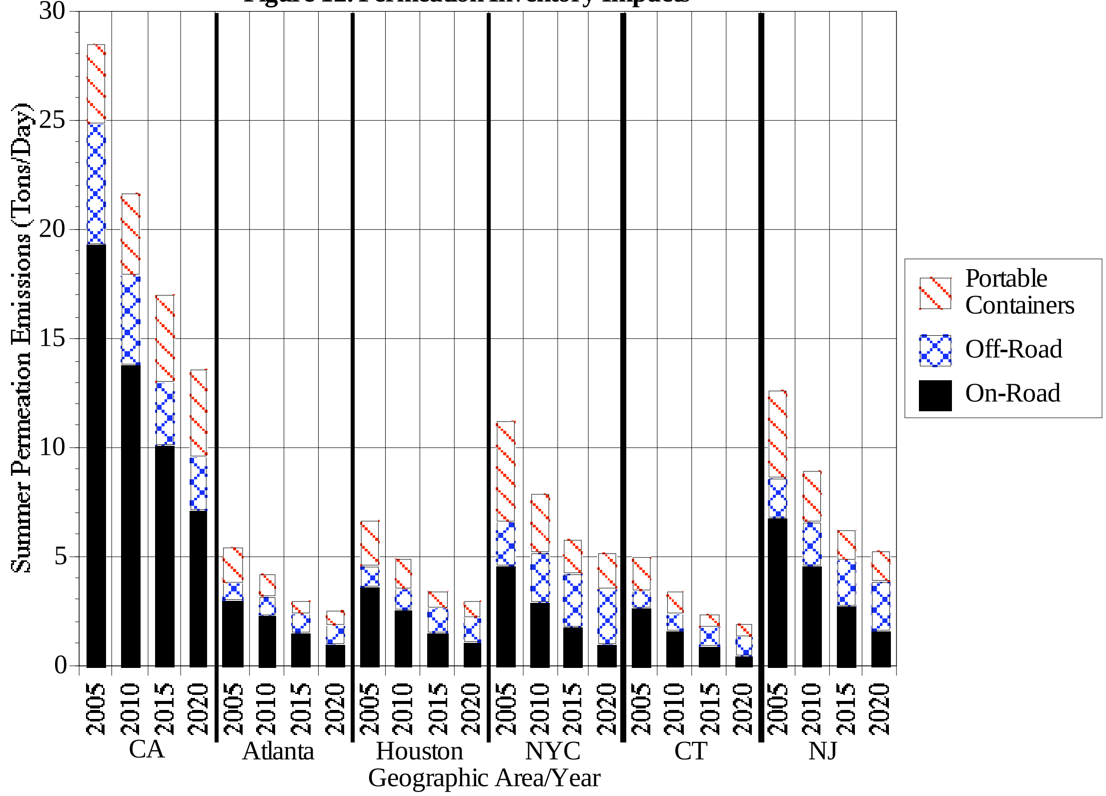


Figure 12. Permeation Inventory Impacts




## 7.1 California

### 7.1.1 Statewide

The increase in VOC permeation emissions in California due to ethanol is shown in Table 26. These results are for a typical ozone season day in the summer. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 19.5 tons per day (tpd), off-road equipment by 5.4 tpd, and containers by 3.6 tpd. The total impact in 2005 is 28.5 tpd.

| Table 26. California Population and VOC Summer Ethanol Inventory Impact (tpd) | | | | | |
|---|---|---|---|---|---|
| Year | Parameter | On-Road | Off-Road | Containers | Total |
| 2005 | Population | 23,958,616 | 16,671,135 | 7,884,690 | |
| | Emissions | 19.5 | 5.4 | 3.6 | 28.5 |
| 2010 | Population | 25,118,477 | 17,803,550 | 8,172,746 | |
| | Emissions | 13.9 | 4.1 | 3.7 | 21.7 |
| 2015 | Population | 27,482,109 | 19,120,024 | 8,461,178 | |
| | Emissions | 10.1 | 3.1 | 3.9 | 17.0 |
| 2020 | Population | 29,558,692 | 20,551,478 | 8,749,415 | |
| | Emissions | 7.1 | 2.5 | 4.0 | 13.7 |

For on-road vehicles, the ethanol impact starts at 19.5 tpd in 2005, and drops to 7.1 tpd in 2020. The reason for the decline is due to the projected increase in the on-road fleet penetration of Near Zero evaporative vehicles and PZEVs that we are estimating to have substantially lower per vehicle ethanol impacts than for enhanced evaporative and earlier vehicles.

For off-road equipment, the analysis predicts that the impact declines from 5.4 tpd in 2005 to 2.5 tpd in 2020. The reduction is due to newer off-road equipment with permeation controls experiencing less of an increase for ethanol than the earlier equipment. For portable containers, the ethanol impact starts at 3.6 tpd in 2005, and increases to 4.0 tpd in 2020. Permeation controls are introduced on portable containers in 2001, and the EMFAC model has a fast turnover rate for containers, so most of the reduction in the ethanol increase has occurred by 2005, and the increase from 2005 to 2010 is due to growth in the number of portable containers.

The increase in permeation emissions in California due to ethanol on an annual average basis is shown in Table 27. These increases are smaller than the summer increases because the temperatures are lower.

| Table 27. California VOC Annual Ethanol Inventory Impact (tpd) | | | | |
|---|---|---|---|---|
| Year | On-Road | Off-Road | Containers | Total |
| 2005 | 15.3 | 3.1 | 2.0 | 20.4 |
| 2010 | 10.9 | 2.3 | 2.1 | 15.3 |
| 2015 | 7.9 | 1.7 | 2.2 | 11.8 |
| 2020 | 5.6 | 1.4 | 2.2 | 9.2 |

### 7.1.2 Air Basin Impacts – Onroad Vehicles and Offroad Equipment

The summer inventory analysis was also conducted at the Air Basin level in California. The results are shown in Table 28.

| Table 28. California By-Basin Permeation Emissions Due to Ethanol (tpd) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | | | | 2010 | | | | 2015 | | | | 2020 | | | |
| Basin | On Road | Off-Road | Cont. | Total | On-Road | Off-Road | Cont. | Total | On-Road | Off-Road | Cont. | Total | On-Road | Off-Road | Cont. | Total |
| Great Basin Valley | 0.03 | 0.01 | 0.00 | 0.04 | 0.02 | 0.01 | 0.00 | 0.03 | 0.02 | 0.01 | 0.00 | 0.03 | 0.01 | 0.00 | 0.00 | 0.01 |
| Lake County | 0.06 | 0.02 | 0.01 | 0.09 | 0.05 | 0.02 | 0.01 | 0.08 | 0.04 | 0.01 | 0.01 | 0.06 | 0.03 | 0.01 | 0.01 | 0.05 |
| Lake Tahoe | 0.02 | 0.01 | 0.00 | 0.03 | 0.02 | 0.01 | 0.00 | 0.03 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.00 | 0.01 | 0.02 |
| Mountain Counties | 0.39 | 0.13 | 0.05 | 0.57 | 0.31 | 0.1 | 0.06 | 0.47 | 0.24 | 0.08 | 0.06 | 0.38 | 0.18 | 0.07 | 0.06 | 0.31 |
| Mojave Desert | 0.71 | 0.15 | 0.09 | 0.95 | 0.52 | 0.12 | 0.1 | 0.74 | 0.38 | 0.10 | 0.1 | 0.58 | 0.27 | 0.08 | 0.1 | 0.45 |
| North Coast | 0.18 | 0.05 | 0.03 | 0.26 | 0.15 | 0.04 | 0.03 | 0.22 | 0.12 | 0.03 | 0.03 | 0.18 | 0.09 | 0.02 | 0.04 | 0.15 |
| North Central Coast | 0.37 | 0.09 | 0.07 | 0.53 | 0.29 | 0.07 | 0.07 | 0.43 | 0.21 | 0.05 | 0.07 | 0.33 | 0.14 | 0.04 | 0.07 | 0.25 |
| Northeast Plateau | 0.05 | 0.02 | 0.01 | 0.08 | 0.05 | 0.01 | 0.01 | 0.07 | 0.04 | 0.01 | 0.09 | 0.14 | 0.03 | 0.01 | 0.01 | 0.05 |
| South Coast | 7.00 | 2.07 | 1.38 | 10.45 | 4.53 | 1.53 | 1.40 | 7.46 | 3.28 | 1.14 | 1.44 | 5.86 | 2.32 | 0.95 | 1.48 | 4.75 |
| South Central Coast | 0.69 | 0.2 | 0.12 | 1.01 | 0.52 | 0.15 | 0.12 | 0.79 | 0.38 | 0.11 | 0.12 | 0.61 | 0.27 | 0.09 | 0.13 | 0.49 |
| San Diego | 1.46 | 0.47 | 0.28 | 2.21 | 1.07 | 0.36 | 0.29 | 1.72 | 0.77 | 0.27 | 0.30 | 1.34 | 0.54 | 0.22 | 0.31 | 1.07 |
| San Francisco | 3.86 | 1.03 | 0.79 | 5.68 | 2.85 | 0.75 | 0.81 | 4.41 | 2.03 | 0.55 | 0.83 | 3.41 | 1.41 | 0.45 | 0.86 | 2.72 |
| San Joaquin Valley | 2.35 | 0.58 | 0.41 | 3.34 | 1.80 | 0.44 | 0.44 | 2.68 | 1.31 | 0.33 | 0.46 | 2.1 | 0.92 | 0.27 | 0.49 | 1.68 |
| Salton Sea | 0.46 | 0.12 | 0.06 | 0.64 | 0.33 | 0.09 | 0.07 | 0.49 | 0.25 | 0.08 | 0.07 | 0.4 | 0.18 | 0.07 | 0.08 | 0.33 |
| Sacramento Valley | 1.84 | 0.50 | 0.33 | 2.67 | 1.37 | 0.38 | 0.35 | 2.1 | 1.00 | 0.29 | 0.36 | 1.65 | 0.71 | 0.24 | 0.38 | 1.33 |
| Total | 19.45 | 5.44 | 3.64 | 28.53 | 13.89 | 4.08 | 3.74 | 21.71 | 10.08 | 3.05 | 3.88 | 17.01 | 7.09 | 2.54 | 4.02 | 13.65 |

### 7.1.3 Comparison with California Overall Inventories

Summer VOC inventories from on-road vehicles and off-road gasoline equipment in California are shown in Table 29. Total summer inventories from these sources start at 1036 tpd in 2005, and decline to 550 tpd in 2020.

The summer ethanol permeation impact is estimated at 28.53 tpd in 2003 and 13.65 tpd in 2015. These are about 2% of the VOC inventory in both years.

| Table 29. Reactive Organic Gas (ROG) Inventories From Gasoline Vehicles and Equipment in California (Statewide annual average tons per day) | | | | | |
|---|---|---|---|---|---|
| Year | On-Road Vehicles | | Off-road gasoline equipment | | Total |
| | Exhaust | Evap | Exhaust | Evap | |
| 2005 | 398.4 | 275.5 | 237.4 | 124.6 | 1035.9 |
| 2010 | 232.9 | 208.1 | 207.5 | 112.1 | 760.5 |
| 2015 | 144.8 | 179.0 | 193.1 | 104.6 | 621.6 |
| 2020 | 93.2 | 161.7 | 190.9 | 104.6 | 550.3 |

## 7.2 Atlanta

The increase in summer VOC permeation emissions in Atlanta due to ethanol is shown in Table 30. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 3 tpd, off-road equipment by 0.7 tpd, and containers by 1.6 tpd. The total impact in 2005 is 5.4 tpd.

| Table 30. Atlanta Population and Summer VOC Ethanol Inventory Impact (tpd) | | | | | |
|---|---|---|---|---|---|
| CY | Parameter | On-Road | Off-Road | Containers | Total |
| 2005 | Population | 2,867,899 | 1,703,004 | 805,444 | |
| | Emissions | 3.0 | 0.7 | 1.6 | 5.4 |
| 2010 | Population | 3,244,377 | 1,892,384 | 868,701 | |
| | Emissions | 2.3 | 0.8 | 1.0 | 4.1 |
| 2015 | Population | 3,804,717 | 2,072,184 | 917,003 | |
| | Emissions | 1.6 | 0.9 | 0.6 | 3.0 |
| 2020 | Population | 4,407,810 | 2,243,422 | 955,097 | |
| | Emissions | 1.0 | 0.9 | 0.6 | 2.5 |

The on-road inventory declines with time because Tier 2 evaporative vehicles replace earlier models. The off-road inventories do not decline, because with the exception of recreational marine and recreational vehicles, evaporative controls have not been adopted for off-road equipment.[11]

The increase in annual average VOC emissions in Atlanta due to ethanol is shown in Table 31. The increases are lower for the annual average case than for the summer case because the temperatures are lower.

[11] EPA will soon propose control of permeation emissions from small off-road engines and further controls from off-road recreational vehicles and marine. When these are adopted, these controls will reduce the off-road permeation increase.

| Table 31. Atlanta VOC Annual Ethanol Inventory Impact (tpd) | | | | |
|---|---|---|---|---|
| Year | On-Road | Off-Road | Containers | Total |
| 2005 | 1.5 | 0.4 | 0.8 | 2.6 |
| 2010 | 1.1 | 0.4 | 0.5 | 2.0 |
| 2015 | 0.8 | 0.5 | 0.3 | 1.5 |
| 2020 | 0.5 | 0.5 | 0.3 | 1.2 |

## 7.3 Houston

The increase in VOC permeation emissions in Houston due to ethanol is shown in Table 32. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 3.7 tpd, off-road equipment by 0.9 tpd, and containers by 2.0 tpd. The total impact in 2005 is 6.6 tpd.

| Table 32. Houston Population and VOC Ethanol Inventory Impact (tpd) | | | | | |
|---|---|---|---|---|---|
| CY | Parameter | On-Road | Off-Road | Containers | Total |
| 2005 | Population | 3,238,024 | 1,912,221 | 904,393 | |
| | Emissions | 3.7 | 0.9 | 2.0 | 6.6 |
| 2010 | Population | 3,564,164 | 2,114,190 | 970,522 | |
| | Emissions | 2.6 | 1.0 | 1.2 | 4.8 |
| 2015 | Population | 3,993,675 | 2,309,831 | 1,022,169 | |
| | Emissions | 1.6 | 1.1 | 0.7 | 3.4 |
| 2020 | Population | 4,499,182 | 2,499,222 | 1,063,998 | |
| | Emissions | 1.1 | 1.2 | 0.7 | 3.0 |

The increase in annual average VOC emissions in Houston due to ethanol is shown in Table 33. The increases are lower for the annual average case than for the summer case because the temperatures are lower.

| Table 33. Houston VOC Annual Ethanol Inventory Impact (tpd) | | | | |
|---|---|---|---|---|
| Year | On-Road | Off-Road | Containers | Total |
| 2005 | 1.9 | 0.5 | 1.1 | 3.5 |
| 2010 | 1.3 | 0.5 | 0.6 | 2.5 |
| 2015 | 0.8 | 0.6 | 0.4 | 1.8 |
| 2020 | 0.6 | 0.6 | 0.4 | 1.5 |

## 7.4 New York, New Jersey, and Connecticut

### 7.4.1 Permeation VOC Inventory Increase

The increase in VOC permeation emissions in New York City due to ethanol is shown in Table 34. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 4.6 tpd, off-road equipment by 2.1 tpd, and containers by 4.5 tpd. The total impact in 2005 is 11.1 tpd.

**Table 34. New York City Population and VOC Ethanol Inventory Impact (tpd)**

| CY | Parameter | On-Road | Off-Road | Containers | Total |
|---|---|---|---|---|---|
| 2005 | Population | 4,913,701 | 5,304,534 | 2,508,804 | |
| | Emissions | 4.6 | 2.1 | 4.5 | 11.1 |
| 2010 | Population | 4,859,139 | 5,855,462 | 2,687,959 | |
| | Emissions | 2.9 | 2.3 | 2.7 | 7.9 |
| 2015 | Population | 5,021,861 | 6,397,561 | 2,831,111 | |
| | Emissions | 1.8 | 2.4 | 1.5 | 5.7 |
| 2020 | Population | 4,985,064 | 6,928,745 | 2,949,789 | |
| | Emissions | 1.0 | 2.6 | 1.6 | 5.2 |

The increase in VOC permeation emissions in New Jersey due to ethanol is shown in Table 35. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 6.8 tpd, off-road equipment by 1.8 tpd, and containers by 3.9 tpd. The total impact in 2005 is 12.5 tpd.

**Table 35. New Jersey Population and VOC Ethanol Inventory Impact (tpd)**

| CY | Parameter | On-Road | Off-Road | Containers | Total |
|---|---|---|---|---|---|
| 2005 | Population | 6,490,576 | 4,142,981 | 1,959,442 | |
| | Emissions | 6.8 | 1.8 | 3.9 | 12.5 |
| 2010 | Population | 6,808,649 | 4,575,169 | 2,100,238 | |
| | Emissions | 4.6 | 2.0 | 2.4 | 9.0 |
| 2015 | Population | 7,135,372 | 4,985,686 | 2,206,314 | |
| | Emissions | 2.8 | 2.1 | 1.3 | 6.2 |
| 2020 | Population | 7,501,434 | 5,376,306 | 2,288,866 | |
| | Emissions | 1.7 | 2.2 | 1.4 | 5.2 |

The increase in VOC permeation emissions in Connecticut due to ethanol is shown in Table 36. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 2.7 tpd, off-road equipment by 0.7 tpd, and containers by 1.6 tpd. The total impact in 2005 is 5.0 tpd.

| Table 36. Connecticut Population and VOC Ethanol Inventory Impact (tpd) | | | | | |
|---|---|---|---|---|---|
| CY | Parameter | On-Road | Off-Road | Containers | Total |
| 2005 | Population | 2,826,558 | 1,700,872 | 804,435 | |
| | Emissions | 2.7 | 0.7 | 1.6 | 5.0 |
| 2010 | Population | 2,931,578 | 1,877,152 | 861,709 | |
| | Emissions | 1.7 | 0.8 | 1.0 | 3.4 |
| 2015 | Population | 3,039,636 | 2,044,010 | 904,535 | |
| | Emissions | 1.0 | 0.8 | 0.5 | 2.3 |
| 2020 | Population | 3,163,630 | 2,202,294 | 937,587 | |
| | Emissions | 0.5 | 0.9 | 0.6 | 1.9 |

The increase in VOC permeation emissions in the combined NY/NJ/Ct area due to ethanol is shown in Table 37. In 2005 for example, this analysis predicts that ethanol increases VOC emissions from on-road vehicles by 14.1 tpd, off-road equipment by 4.6 tpd, and containers by 10.0 tpd. The total impact in 2005 is 28.7 tpd.

| Table 37. NYC/NJ/Ct Population and VOC Ethanol Inventory Impact (tpd) | | | | | |
|---|---|---|---|---|---|
| CY | Parameter | On-Road | Off-Road | Containers | Total |
| 2005 | Population | 14,230,835 | 11,148,388 | 5,272,681 | |
| | Emissions | 14.1 | 4.6 | 10.0 | 28.7 |
| 2010 | Population | 14,599,366 | 12,307,784 | 5,649,906 | |
| | Emissions | 9.2 | 5.0 | 6.1 | 20.2 |
| 2015 | Population | 15,196,869 | 13,427,257 | 5,941,960 | |
| | Emissions | 5.5 | 5.3 | 3.4 | 14.2 |
| 2020 | Population | 15,650,127 | 14,507,346 | 6,176,242 | |
| | Emissions | 3.1 | 5.7 | 3.5 | 12.3 |

The increase in annual average VOC emissions in the New York/New Jersey/Connecticut area due to ethanol is shown in Table 38. The increases are lower for the annual average case than for the summer case because the temperatures are lower.

| Table 38. New York/New Jersey/Connecticut Area VOC Annual Ethanol Inventory Impact (tpd) | | | | |
|---|---|---|---|---|
| Year | On-Road | Off-Road | Containers | Total |
| 2005 | 6.0 | 2.0 | 4.3 | 12.3 |
| 2010 | 3.9 | 2.2 | 2.6 | 8.7 |
| 2015 | 2.3 | 2.3 | 1.5 | 6.1 |
| 2020 | 1.3 | 2.4 | 1.5 | 5.3 |

### 7.4.2 Comparison with SIP Inventories

Connecticut, New Jersey and Atlanta have developed regulatory ozone SIP inventories and conformity budgets using the MOBILE6 model (or later version). Houston and New York have submitted revised ozone SIP inventories developed with MOBILE6. (The Houston-Galveston area mobile source inventory has been evaluated using MOBILE6 for an 11-day ozone episode, which is being used for modeling ozone attainment.) The VOC SIP inventory estimates for each of the aforementioned geographic areas are shown in Table 39.

**Table 39. Ozone Season VOC Inventories**

| Geographic Area | Sector, Year | Inventory Description | VOC Inventory (tons/day) |
|---|---|---|---|
| New York City, NY Nonattainment Area [45] | Off-highway, 2005 | Ozone inventory as documented in oxygenate waiver request | 172.2 |
| New York City, NY Nonattainment Area [45] | On-highway, 2005 | Ozone inventory as documented in oxygenate waiver request | 192.9 |
| New Jersey [46] | On-highway, 2005 | Ozone SIP transportation conformity budget using MOBILE6 | 213.4 |
| Connecticut [47] | On-highway, 2007 | Ozone SIP transportation conformity budget using MOBILE6 | 68.3 |
| Atlanta Nonattainment Area [48] | Off-highway, 2004 | Ozone SIP ROP inventory | 74.5 |
| Atlanta Nonattainment Area [48] | On-highway, 2004 | Ozone SIP ROP inventory using MOBILE6 | 160.6 |
| Houston-Galveston Nonattainment Area [49] | On-highway, 2000 | 11-day episode average used in ozone attainment demonstration using MOBILE6 | 139.0 |
| Houston-Galveston Nonattainment Area [50] | On-highway, 2007 | 11-day episode average used in ozone attainment demonstration using MOBILE6 | 77.2 |

Table 39 includes only a partial list of off-highway VOC inventories for the geographic areas of interest, but it does provide the on-highway VOC inventories for all of the areas. Table 40 compares the increase in on-highway permeation emissions due to ethanol to the VOC inventory from just on-highway vehicles by geographic area. California is also included.

| Table 40. Comparison of On-Highway Permeation Increase for All Sources to On-Highway SIP VOC Inventories | | | |
|---|---|---|---|
| Area | On-Highway SIP VOC (tpd) | 2005 On-Highway Increase in Permeation (tpd) | % Increase |
| Atlanta | 161 (2004) | 3.0 | 1.8% |
| Houston | 77 (2007) | 3.7 | 4.8% |
| New York | 193 (2005) | 4.6 | 2.4% |
| New Jersey | 213 (2005) | 6.8 | 3.2% |
| Connecticut | 68 (2007) | 2.7 | 4.0% |
| California | 674 (2005) | 19.5 | 2.9% |
| Total | 1335 | 40.3 | 3.0% |

The on-highway increases in permeation as a percent of the on-highway inventories range from 1.8% in Atlanta to 4.8% in Houston. The average over the various regions is 3%. Reasons for the variation from place-to-place could be temperature differences, fleet turnover differences, and our prediction of vehicle, off-road equipment and container populations versus the SIPs use of vehicle miles traveled.

## 8.0 Discussion

We examined sources of uncertainty in our inventory estimates and reached the following conclusions:

- This analysis assumed the market penetration of gasoline/ethanol blends was 100% in the areas evaluated. It could be less.

- The analysis assumes that the increase in permeation emissions during vehicle operation and during "hot soak" periods is the same as the permeation increase when the vehicle is resting. Operation of vehicles and equipment is known to increase fuel temperatures, which could increase the permeation effect due to ethanol. The amount of increase in permeation emissions during engine operation is not known, and would require further analysis and test data.

- The on-road ethanol impacts could be a little low, due to the fact that we used passenger car and light-duty truck data to represent the ethanol increase from heavy-duty gasoline vehicles with larger fuel tanks, and the fact that we did not include motorcycles.

- The population of portable containers is also an issue. This analysis uses the portable container populations for California from the OFFROAD2002 model. A recent survey conducted by the ARB, however, indicates that plastic portable container populations could be much lower.

- The off-road equipment ethanol impacts are probably low, inasmuch as we estimated the ethanol impact from lawnmowers, and many equipment types have larger fuel tanks and longer fuel hoses than lawnmowers.

- The vehicle- or equipment-specific estimates of the impact of ethanol on permeation could be influenced by future regulations on on-road vehicles, off-road equipment, or portable containers.

Overall the estimates of the permeation VOC inventory impacts of ethanol in this study are conservative, but could be higher or lower if more data were available.

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**Appendix A**
**Comparison of California's Method for Estimating Ethanol's On-Road Permeation Impacts**

California EPA has also been developing its estimates of the impacts of ethanol on permeation VOC emissions from on-road vehicles. The impacts of ethanol permeation are slated to be included in a new version of the Predictive Model for reformulated gasoline. The ARB methodology is explained in numerous presentations available as a part of the Predictive Model Workshops available at www.arb.ca.gov/fuels/gasoline/meeting/2007/mtg2007.htm., and in a technical report. [x] AIR has reviewed the California methodology, and has had discussions with ARB staff concerning the differences in the AIR method and the ARB method. This section provides an overview of the differences in the two methods.

In the AIR approach, ethanol permeation impacts are developed from the E-65 data, and are temperature corrected and then added to the California evaporative emissions. The ethanol impacts vary by evaporative technology group, with the latest technologies having the smaller impacts. In the ARB method, the E-65 data is used to develop multiplicative correction factors called ethanol augmentation ratios that are then applied to the EMFAC evaporative inventories. The augmentation ratios are themselves not dependent on temperature, but since the based evaporative inventories change with temperature, ethanol's impacts increase as ambient temperature increases.

Table A-1 shows a comparison of ethanol's permeation VOC impacts statewide for on-road vehicles in 2020. Both inventories use the same ambient temperatures, and for the passenger car, LDT1 and LDT2 inventories, all inputs are the same in both methods, with the only difference being the methods used. The ARB impacts are ~50% higher than the AIR estimated impacts.

**Table A-1. Comparison of Ethanol Permeation Statewide Impacts for On-Road Vehicles in 2010**

| Vehicle Group | ARB (tons per day)* | AIR (tons per day) |
|---|---|---|
| Cars, LDT1s, LDT2s, LDT3s, and LDT4s (Predictive Model Classes) | 18.4 | 12.1 |
| All gasoline on-road vehicles | 21.0 | 13.9 (Excludes motorcycles) |

* Source of ARB Impacts: "Emissions Inventory Slides", Ben Hancock, PSTD MSAB Analysis Section, November 16, 2006.

ARB Method

ARB develops ethanol multiplicative correction factors, and uses these with the evaporative emissions inventories by process to estimate ethanol's impact. The basic equation is shown below.

$Emissions_{etoh}$ = $Evap_{mtbe}$ * Permeation Fraction * Augmentation $Ratio_{etoh}$

Where:

$Emissions_{etoh}$ = Evap emissions on ethanol by process and temperature
$Evap_{mtbe}$ = Evap emissions on MTBE by process and temperature
Permeation Fraction = Permeation fraction of emissions by process
Augmentation $Ratio_{etoh}$ = Ratio of ethanol emissions to MTBE emissions

Evaporative emissions by process and temperature (hot soak, diurnal , resting, and running losses) are available from the EMFAC model. The augmentation ratios are developed from the E-65 data, and are developed separately for normal and high emitters. However, the evaporative emissions for the different process are not just permeation emissions – they can contain breathing losses, and leaks. Therefore, ARB developed permeation fractions for the various evaporative processes. At the time these methods were developed, there was no data on which to base these permeation fractions by process, so ARB developed them from an assumption about the permeation fraction of resting losses, and from the evaporative inventories in EMFAC.

One of the apparent advantages to this expression is that it appears to be correcting not only vehicles that are parked all day for ethanol effects, it is also incorporating vehicles that are running (i.e., running losses) and vehicles in the hot soak condition.[12] However, as we shall see presently, this is not the case.

If the inputs to this equation are correct, then the ethanol emissions impacts should be correct. Each of the inputs is discussed in more detail below.

Evaporative Emissions on MTBE

The evaporative emissions on MTBE come from the EMFAC2007 model. These estimates have been developed from testing – the diurnal and resting losses come from real time 24-hour diurnal testing conducted in a SHED. Running loss and hot soak emission inventories also come from SHED testing of vehicles. Many of these testing programs have been conducted by the CRC, EPA and ARB. While there is a need for more data on vehicles equipped with enhanced evaporative and later emissions controls, we do not see any problems with these inventories, and in fact, are using these inventories as the base when we are adding our estimates due to ethanol.

[12] The AIR method assumes that the permeation emission increases for vehicles in running loss and hot soak mode would be the same as if they were parked.

Permeation Fraction

Since the E-65 data consists only of permeation emissions, this equation appears to require the need for permeation fraction of emissions by process. There was no testing data to base these on, so ARB assumed that 90% of resting losses were permeation emissions (for all vehicles, temperatures, and model year groups), then developed the permeation fraction by dividing the 90% times the resting losses by the hot soak, diurnal, and running loss emissions, separately.[13] All of this was performed over different temperatures, so that the permeation fractions for each process could vary by temperature.

We have three concerns with the permeation fractions: (1) the assumption that resting losses are 90% permeation emissions, (2) that the permeation fractions have to be developed from EMFAC inventories, and not from direct testing data, (3) due to other parts of the ARB equation, the permeation fractions are not needed anyway, and (4) ARB uses resting emissions analyzed during temperature declines to represent permeation emissions at all times.

ARB assumes that 90% of resting losses are permeation emissions. This figure could be 95%, 90%, 85%, or 80%, and could vary with vehicle technology or temperature. Resting losses should be mostly permeation, but there are circumstances when resting losses could include breathing losses, and this is probably more the case on older technology vehicles with less breathing control than it is on vehicles equipped with enhanced evaporative systems.

The resting loss period is that period when the ambient temperature is constant or declining. When the ambient temperature is rising, typically the fuel system temperatures, particularly in the fuel tank, lag the ambient temperature by a few degrees. When the ambient temperature levels out at its peak, the resting loss period as defined by the ARB begins. But the tank temperatures can still be rising at the onset of this resting period, at least until the tank temperature coincides with the ambient temperature. Thus, in older vehicles with less breathing loss control, there can be significant breathing losses right at the onset of the ARB resting loss period, and that could drive the permeation fraction to a low level. So we really do not know if the 90% assumption is a good one or not, and it is likely that it varies by technology, and also by ambient temperature (at higher ambient temperatures, there is a greater chance for higher breathing losses).

Secondly, the permeation fraction by process was not developed through direct test data, but from EMFAC emission inventories by technology group. While these inventories for each evaporative process are the best they can be based on the available data, using these inventories, along with all of their temperature correction factors to develop permeation fractions is questionable – small changes in the inventories can create large changes in permeation fraction.

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[13] The apparent need to develop permeation fraction by process without testing data was one of the primary reasons why AIR chose the additive approach.

Thirdly, we do not think the permeation fractions developed from the 90% assumption and from the inventories by process are even needed. The permeation fraction is the ratio of 90% times the resting losses, divided by the hot soak, running loss, or running loss emissions on MTBE (by temperature). However, the denominator of the fraction also occurs in the numerator of the ARB equation ($Evap_{mtbe}$), so this cancels out, and we are left with:

$Emissions_{etoh}$ = 90% * Resting Losses *Augmentation $Ratio_{etoh}$

The emissions on ethanol is simply a function of 90% times the resting losses, times the ethanol augmentation ratio, which is based on the vehicles (or rigs) that are parked all day. As a result, the ARB method is not correcting for potentially different permeation emissions during running and hot soak operation.

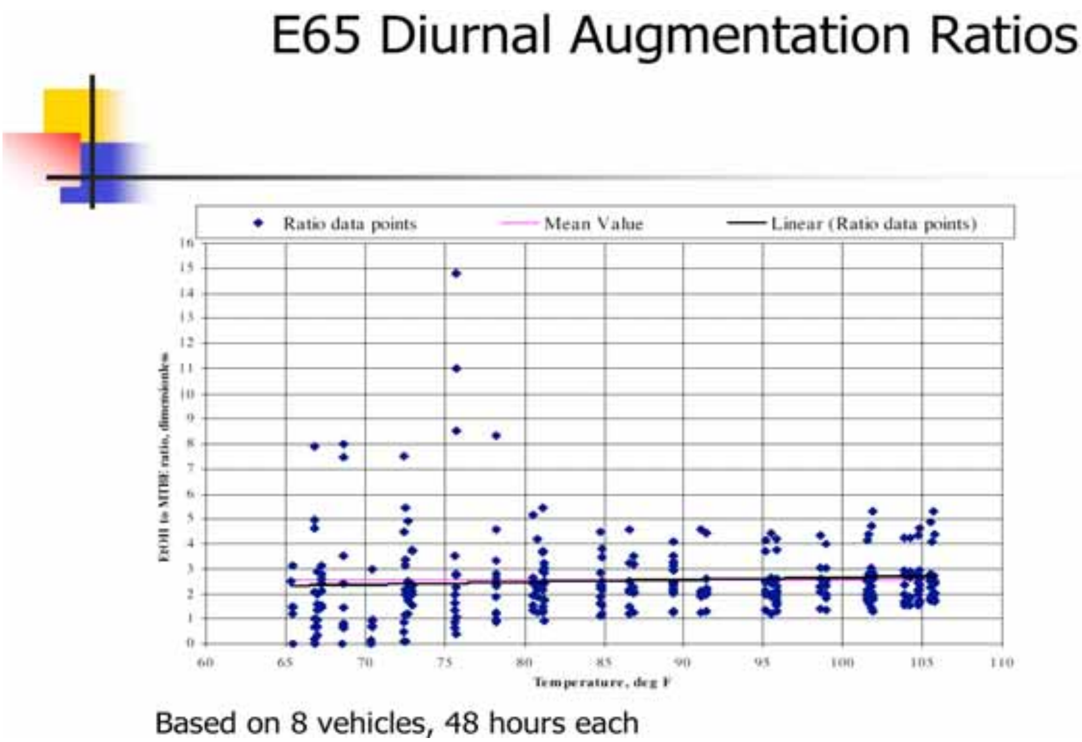
While the equation reduces to the one shown above, the equation in EMFAC2007 still uses permeation fractions as shown in the earlier equation. It is also unlikely that the $Evap_{mtbe}$ completely cancels out in the model as it should, since the permeation fractions versus temperature and process (i.e., the numerator of the permeation fractions) are in fact curve fits of the ratios of the various inventories versus temperature. Thus, the EMFAC2007 expression should be modified.

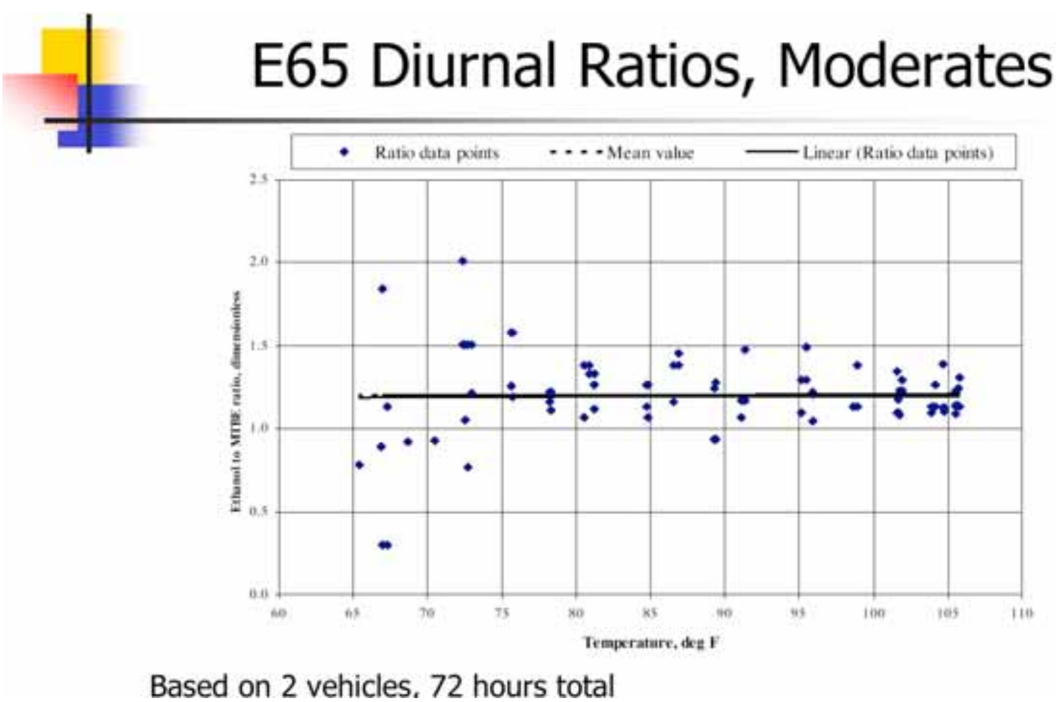
Lastly, we have concerns with using resting losses to represent permeation emissions during all parts of the day. The resting losses are estimated by ARB while the temperature in the SHED is declining – and during this period, the fuel system and tank temperature can be higher than ambient to the lead and lag between tank and ambient temperatures. During ambient temperature increases, the fuel and fuel system temperatures can be lower than ambient, possibly resulting in lower resting losses at a given temperature than during ambient temperature decreases. Thus, estimating resting losses only during temperature declines – as ARB does – could overstate daily permeation emissions.

Augmentation Ratios

The ethanol augmentation ratios were developed from the E-65 data, the same data used in this analysis. Separate ratios are developed for both “normal” and “moderate” emitting vehicles. The 1995 Ford Ranger XLT (Rig 5) and the 1994 Chevrolet Caprice Classic (Rig 4) were determined to be moderate emitting vehicles on the basis of their higher MTBE emissions, the remainder, include the newer Near Zero and PZEV vehicles, were assumed to be normal emitting vehicles. The augmentation ratios were developed versus temperature, but no temperature effect was found, as shown in the two figures from ARB shown below (from their November 11, 2005 presentation – these do not include the two new advanced technology vehicles).

The normal emitter augmentation ratio with the newer technology vehicles is now about 2.5 and the normal emitter augmentation is about 1.2. To develop the increase in evaporative inventories, ARB divides the EMFAC2007 inventories into those from normal and moderate emitters, and multiplies these inventories by their separate augmentation ratios. ARB also has a separate augmentation ratio for “leakers” or those that have very high emissions due to fuel leaks, which they estimate at 1.02.



Our concern with the augmentation ratios is that these ratios, especially for newer, lower emitting vehicles, are highly variable. A small change in mass emissions between MTBE on a vehicle with very low MTBE emissions can produce a large ratio, which then has a large influence on the augmentation ratio.

Summary

ARB's and AIR's methods represent a classic comparison of additive versus multiplicative approaches using essentially the same data, which result in two different answers, that unfortunately, are somewhat far apart (37-46%). Reasons for the differences in inventories probably are a combination of the following:

1. The AIR additive increase for heavier light duty trucks and for heavier duty vehicles (i.e., HDGVs above 8500 lbs), which are based on cars and LDTs, may be a little low. However, this is not a foregone conclusion, as many HDGVs are fitted with metal tanks that would have zero permeation on both MTBE and ethanol fuels.

2. The AIR additive increases were based on 12 vehicles, and if many more vehicles were tested, could have been higher (or lower) than found in E-65. However, if more vehicles were tested, this would not only change the AIR additive values, but also ARB's ethanol augmentation ratios. The two estimates could go in the same direction, or in opposite directions, with new data.

3. Near Zero and PZEV vehicles probably have a larger impact at reducing the increase in ethanol permeation in the AIR approach than the ARB approach. In the AIR approach, these are modeled separately, and they have a large impact because their ethanol increases are very small. In the ARB approach, they are included with the normals in estimating the overall augmentation ratios of nomrals.

4. The ARB assumption that 90% of resting losses are permeation emissions for all vehicles at all temperatures could be in error.

5. The ARB assumption that resting losses developed when temperature is declining are the same as when the temperature is rising, even though fuel system temperatures could be significantly lower. Resting losses during temperature increases could be lower than during temperature declines, thereby the ARB method may overstate the ethanol permeation emissions.

**Appendix B**

ARB's Derivation of MTBE Correction Factors

The HC SHED values for tests that use MTBE need to be corrected for the same basic reason that the ethanol values are corrected - that the FID responds to both MTBE and ethanol differently than for hydrocarbons that do not include oxygen. The basic process used to correct the total permeation emissions are as follows:

1. Start with the raw uncorrected permeation HC values
2. Determine the analyzer response to MTBE
3. Determine the vapor space weight percent MTBE
4. Using 2 and 3, split the raw HC values into adjusted MTBE and NMHC values
5. Add the adjusted MTBE and NMHC values to form a new corrected total permeation HC value
6. Divide the adjusted permeation by the uncorrected permeation to determine a correction factor for each vehicle.

Table B-1 shows the raw permeation values by rig, the adjusted MTBE and NMHC values, the corrected total emissions and the MTBE correction factors for each vehicle. ARB deteremined that the analyzer response factor to MTBE was 0.831 (each 1 mole of MTBE would be measured as 0.831 moles of HC).

**Table B-1. Development of Rig-Specific MTBE Response Factors**

| Rig | Vapor Space Wt% MTBE | Raw Permeation, g/day | MTBE g/day | NMHC g/day | Corrected Total g/day | MTBE Correction Factor |
|---|---|---|---|---|---|---|
| 1 | 13.8 | 0.24 | 0.04 | 0.23 | 0.26 | 1.09 |
| 2 | 9.1 | 0.65 | 0.06 | 0.62 | 0.68 | 1.06 |
| 3 | 12.5 | 0.29 | 0.04 | 0.27 | 0.31 | 1.08 |
| 4 | 8.9 | 0.63 | 0.06 | 0.60 | 0.66 | 1.05 |
| 5 | 6.2 | 9.25 | 0.60 | 8.99 | 9.59 | 1.04 |
| 6 | 7.0 | 3.82 | 0.28 | 3.7 | 3.98 | 1.04 |
| 7 | 9.3 | 1.21 | 0.12 | 1.16 | 1.28 | 1.06 |
| 8 | 9.3 | 0.96 | 0.09 | 0.92 | 1.01 | 1.06 |
| 9 | 9.2 | 1.97 | 0.19 | 1.89 | 2.08 | 1.06 |
| 10 | 10.2 | 1.92 | 0.21 | 1.83 | 2.04 | 1.06 |

The following page shows equations ARB used to develop the above factors.

$$THC_{raw} = RF \times EtOH + NEHC \qquad \text{Eqn 1}$$

$$RAT_{EtOH} = \frac{EtOH}{NEHC + EtOH} \qquad \text{Eqn 2}$$

Where $THC_{raw}$ is the raw FID reading in grams
$EtOH$ is the actual or real ethanol mass in grams
$RF$ is the FID response to ethanol, dimensionless
$NEHC$ is the actual or real non-ethanol hydrocarbon reading, grams
$RAT_{EtOH}$ is the ethanol fraction from chromatographic analysis

From (2)

$$NEHC = EtOH\left(\frac{1}{RAT_{EtOH}} - 1\right) \qquad \text{Eqn 3}$$

Substituting in (1)

$$THC_{raw} = RF \times EtOH + EtOH\left(\frac{1}{RAT_{EtOH}} - 1\right) \qquad \text{Eqn 4}$$

$$= EtOH\left(RF + \frac{1}{RAT_{EtOH}} - 1\right) \qquad \text{Eqn 5}$$

Thus

$$EtOH = \frac{THC_{raw}}{\left(RF + \frac{1}{RAT_{EtOH}} - 1\right)} \qquad \text{Eqn 6}$$

And, subbing into (3)

$$NEHC = \left(\frac{1}{RAT_{EtOH}} - 1\right)\frac{THC_{raw}}{\left(RF + \frac{1}{RAT_{EtOH}} - 1\right)} \qquad \text{Eqn 7}$$

So, (6) and (7) are used to find the actual ethanol and non-ethanol HC masses. These are added to find the actual total organic result.

## Appendix C
Technology Phase-In Schedules

| Federal Areas | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Cars, all LDTs** | | | | | | | | |
| | Older | Mid 1990s | Enhanced | Near Zero | PZEV | ZEV | Total | /td. EF g/day |
| Ethanol EF> g/day | 2.033 | 0.859 | 0.804 | 0.43 | 0.12 | 0 | 0.12 | |
| MYR Group | | | | | | | | |
| pre-1991 | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 2.033 |
| 1991-1995 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0.859 |
| 1996 | 0 | 80 | 20 | 0 | 0 | 0 | 100 | 0.848 |
| 1997 | 0 | 60 | 40 | 0 | 0 | 0 | 100 | 0.837 |
| 1998 | 0 | 10 | 90 | 0 | 0 | 0 | 100 | 0.8095 |
| 1999 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2000 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2001 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2002 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2003 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2004 | 0 | 0 | 75 | 25 | 0 | 0 | 100 | 0.7105 |
| 2005 | 0 | 0 | 50 | 50 | 0 | 0 | 100 | 0.617 |
| 2006 | 0 | 0 | 25 | 75 | 0 | 0 | 100 | 0.5235 |
| 2007 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.43 |

| HDGVs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Older | Mid 1990s | Enhanced | Near Zero | PZEV | ZEV | Total | /td. EF g/day |
| Ethanol EF> g/day | 2.033 | 0.859 | 0.804 | 0.43 | 0.12 | 0 | 0.12 | |
| pre-1991 | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 2.033 |
| 1991-1995 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0.859 |
| 1996 | 0 | 80 | 20 | 0 | 0 | 0 | 100 | 0.848 |
| 1997 | 0 | 60 | 40 | 0 | 0 | 0 | 100 | 0.837 |
| 1998 | 0 | 10 | 90 | 0 | 0 | 0 | 100 | 0.8095 |
| 1999 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2000 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2001 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2002 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2003 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2004 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2005 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2006 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2007 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2008 | 0 | 0 | 50 | 50 | 0 | 0 | 100 | 0.617 |
| 2009 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.43 |

| California | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Cars & LDT1** | | | | | | | | |
| | Older | Mid 1990s | Enhanced | Near Zero | PZEV | ZEV | Total | Wtd. EF (g/day) |
| Ethanol EF> g/day | 2.033 | 0.859 | 0.804 | 0.43 | 0.12 | 0 | 100 | |
| MYR Group | | | | | | | | |
| pre-1991 | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 2.033 |
| 1991-1994 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0.859 |
| 1995 | 0 | 90 | 10 | 0 | 0 | 0 | 100 | 0.854 |
| 1996 | 0 | 70 | 30 | 0 | 0 | 0 | 100 | 0.843 |
| 1997 | 0 | 50 | 50 | 0 | 0 | 0 | 100 | 0.832 |
| 1998-2002 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2003 | 0 | 0 | 90.31 | 0 | 9.29 | 0.4 | 100 | 0.737 |
| 2004 | 0 | 0 | 59.6 | 21.5 | 18.5 | 0.4 | 100 | 0.594 |
| 2005 | 0 | 0 | 19.6 | 52.7 | 27.3 | 0.4 | 100 | 0.417 |
| 2006 | 0 | 0 | 0 | 63.5 | 36 | 0.5 | 100 | 0.316 |
| 2007 | 0 | 0 | 0 | 59.1 | 40.3 | 0.6 | 100 | 0.302 |
| 2008 | 0 | 0 | 0 | 54.6 | 44.8 | 0.6 | 100 | 0.289 |
| 2009 | 0 | 0 | 0 | 49 | 50.1 | 0.9 | 100 | 0.271 |
| 2010 | 0 | 0 | 0 | 44.4 | 54.6 | 1 | 100 | 0.256 |
| 2011 | 0 | 0 | 0 | 39.4 | 59.2 | 1.4 | 100 | 0.240 |
| 2012-2014 | 0 | 0 | 0 | 34.2 | 64.4 | 1.4 | 100 | 0.224 |
| 2015-2017 | 0 | 0 | 0 | 31.1 | 67 | 1.9 | 100 | 0.214 |
| 2018+ | 0 | 0 | 0 | 28 | 69.6 | 2.4 | 100 | 0.204 |
| | | | | | | | | |
| **All other LDTs, MDVs, and HDGVs** | | | | | | | | |
| Year | Older | Mid 1990s | Enhanced | Near Zero | PZEV | ZEV | Total | Wtd. EF (g/day) |
| Ethanol EF> g/day | 2.033 | 0.859 | 0.804 | 0.43 | 0.12 | 0 | | |
| MYR Group | | | | | | | | |
| pre-1991 | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 2.033 |
| 1991-1994 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0.859 |
| 1995 | 0 | 90 | 10 | 0 | 0 | 0 | 100 | 0.854 |
| 1996 | 0 | 70 | 30 | 0 | 0 | 0 | 100 | 0.843 |
| 1997 | 0 | 50 | 50 | 0 | 0 | 0 | 100 | 0.832 |
| 1998-2002 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2003 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 0.804 |
| 2004 | 0 | 0 | 60 | 40 | 0 | 0 | 100 | 0.654 |
| 2005 | 0 | 0 | 20 | 80 | 0 | 0 | 100 | 0.505 |
| 2006 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2007 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2008 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2009 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2010 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2011 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2012-2014 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2015-2017 | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |
| 2018+ | 0 | 0 | 0 | 100 | 0 | 0 | 100 | 0.430 |