# Potential Massachusetts Air Emission Impacts of Switching From MTBE to Ethanol in the Reformulated Gasoline Program

June 22, 2005

Air Improvement Resource, Inc.
47298 Sunnybrook Lane
Novi, Michigan
48374
248-380-3140
tdarlington@airimprovement.com

# Table of Contents

# 1.0 Summary

The State of Massachusetts is considering legislation that will ban the use of MTBE (methyl tertiary butyl ether) in the gasoline which will essentially mandate the use of ethanol in all of Massachusetts's gasoline in order to meet the oxygen requirement for the federal RFG (Reformulated Gasoline) program. The air emissions analysis in this study estimates the potential change in gasoline related emissions for Massachusetts when replacing the current 10 volume percent MTBE with 10 volume percent of ethanol in the RFG clean fuel program. The results from this study show that using 10% ethanol will "increase" total ozone precursors (VOC + NOx) by as much as 19 tons during an ozone exceedance day. This increase is equivalent to about a 14 percent increase in VOC and NOx emissions from the on-road gasoline motor vehicle fleet. Since Massachusetts continues to experience ozone exceedances under the new tighter federal ozone standards, the increase in air emissions from switching to ethanol will likely need to be offset with additional emissions controls at an increased cost to the air program. Although EPA's RFG complex model projects that switching from MTBE to 10% ethanol would also increase air toxics emissions from the vehicle fleet, the total increase in air toxics for Massachusetts is not estimated in this study which is only focused on ozone precursors.

This analytical comparison study uses the latest known science for estimating the fuel composition effects on gasoline related emissions from both mobile sources (on-road gasoline motor vehicle fleet) and off-road sources (small gasoline engines). These enhancements in estimating emissions are currently not reflected in the EPA emission models used by states for predicting VOC and NOx emissions in Ozone SIPs (state implementation plans). The inclusion of off-road engine sources in this study is important since they represent a larger share of gasoline related emissions in the air basin emissions inventory than those from on-road vehicles. The most significant improvement in estimating emissions is the relatively recent knowledge that using ethanol in gasoline will significantly increase VOC permeation emissions through the vehicle plastics and elastomers in contact with the fuel by about 65 percent or more when compared to an MTBE fuel blend. This increase in permeation emissions affects evaporative emissions from on-road vehicles, off-road equipment and off-road vehicles, and portable gasoline containers. In addition, using 10% ethanol will increase the oxygen content by about 60 percent in the gasoline which then contributes to about a 4.5 percent increase in NOx emission from on-road vehicles. Because of these recent improvements in estimating emissions, this analysis shows that switching from MTBE to 10% ethanol to meet the oxygen requirement in RFG will result in a significant increase in ozone precursors into Massachusetts's air basin during a potential ozone episode day.

## 2.0 Introduction

Massachusetts is required to use federal Reformulated Gasoline, or RFG, which is a cleaner burning gasoline formulation that reduces pollutants from vehicles which form ozone. These ozone "precursors" include volatile organic compounds, or VOC, exhaust oxides of nitrogen, or NOx, and also exhaust carbon monoxide, or CO - a weak ozone precursor. Relative to a 1990 baseline, RFG reduces total vehicle VOCs by about 29%, NOx by about 7% and air toxics by about 32%. By law this federal RFG must contain an oxygen containing compound like MTBE or ethanol that adds at least 2 weight percent oxygen up to 3.5 weight percent. Besides reducing emission from vehicles, the addition of oxygen in RFG is the only fuel property change that also reduces the exhaust VOC and CO emissions from the less sophisticated off-road gasoline engines. The inclusion of emission effects on off-road engine sources in this study is important since they can now represent a larger share of the gasoline related emission inventory than emissions from on-road vehicles. The current RFG contains about 10 volume percent MTBE (2 % oxygen), which is a very clean burning, high octane, and easy-to-use oxygenate that has been blended in gasoline since 1979. However, the state is considering banning MTBE and instead switching to 10 volume percent ethanol (3.4% oxygen).

Many policy makers are under the false impression that all oxygen-containing compounds used in gasoline have about the same overall emissions impact. Except for air toxics, even the EPA emission models for both on-road and off-road vehicles do not differentiate between using ethanol or MTBE in RFG for the source of oxygen. These EPA models had been developed with an oxygenate-neutral policy where all oxygen in the fuel is assumed to have the same effectiveness in reducing exhaust emissions, and that emissions are assumed to change only linearly (or proportional) with oxygen concentration. Recent data and analysis from testing programs conducted for California, however, show that there is significantly higher emission differences associated with the use of ethanol. Ethanol can increase NOx emissions from on-road vehicles at the higher oxygen levels, and ethanol also increases "permeation" VOC emissions from fuel system components (plastics and elastomers) in on-road vehicles, off-road vehicles, and portable gasoline containers. MTBE, however, does not increase NOx or VOC permeation emissions relative to a non-oxygenated gasoline. The oxygen in both compounds reduces exhaust carbon monoxide (CO) emissions which is a weak ozone precursor. Although not addressed in this study, ethanol also increases the amount of air toxics from vehicles compared to MTBE blends as predicted in EPA's RFG models.

This study evaluates the overall air emissions impact of a switch from 10 % MTBE to 10 % ethanol in Massachusetts. The study uses recent testing data on ethanol permeation effects conducted by the Coordinating Research Council, a research group funded by the automobile and oil companies. It also uses test data and analyses of the effects of ethanol on NOx emissions developed by the California Air Resources Board.

This report is organized into the following sections:

- Background
- Methodology Used in the Study
- Massachusetts Gasoline Characteristics
- Permeation VOC Emissions
- Results
- Discussion

There are two additional sections:

- References
- Appendix: Background on Air Improvement Resource, Inc.

## 3.0 Background

Gasoline related emission inventories are made up of a combination of exhaust emissions and evaporative emissions. While exhaust emissions are made up of unburned hydrocarbon emissions (VOCs), NOx, CO, and air toxics, the evaporative emissions are made up only of VOCs since they represent those gasoline vapors that escape from all parts of the vehicles other than that from the exhaust pipe. Permeation VOC emissions are the portion of evaporative VOC emissions that permeate through the plastic and elastomer materials in the vehicles fuel system and fuel containers that are in contact with the fuel. Gasoline related emissions are also grouped into two general sources of gasoline users which are the on-road vehicles and the off-road engine sources that are generally the smaller engines such as lawnmowers, chainsaws, power generators, etc. Even though these off-road sources consume only about 5% of the gasoline, they represent a significant share of the gasoline related VOC inventory (50+%).

The impacts of RFG on state emissions inventories can be estimated using a number of emission prediction models developed by EPA and CARB (California Air Resource Board). The vehicle fleet emissions can be estimated with EPA's MOBILE6.2 emissions model, and all states except California that have implemented RFG programs use the MOBILE model to estimate the benefits of RFG.[1] The EPA's MOBILE model which estimates on-road vehicle emissions, however, does not differentiate between RFG using MTBE and RFG using 10% ethanol. One reason for showing no difference is because data on the permeation characteristics of ethanol have only recently become available, and neither the MOBILE model nor EPA's model for estimating emissions from off-road equipment and vehicles (NONROAD) have been updated for these ethanol permeation effects. Another reason is that EPA emission models do not reflect the non-linear increase in NOx emissions associated with the higher oxygen levels in the 10% ethanol blends. Lastly, the EPA emission models do not include a model for small portable gasoline containers used for storing fuel for the off-road engines.

The following sections review five studies which have presented the results of ethanol's impact on permeation VOC emissions. The five studies are:

- The Coordinating Research Council (CRC) Study
- The AIR, Inc. Permeation Study for the API
- The AIR, Inc. Fuels Study for Southeast Michigan Council of Governments
- California Air Resources Board Draft Study of Ethanol Effects
- California Air Resources Board Test Program for Permeation from Portable Containers

[1] California uses its own emissions models. EMFAC is used for on-road vehicles, and OFFROAD is used for off-road equipment and vehicles, and portable gasoline containers.

## 3.1 CRC Study

When California implemented its Phase 3 RFG requirements calling for the phase-out of MTBE and replacement with ethanol, one of the issues raised during the Board Hearing was whether ethanol increased permeation emissions of VOC components through plastic and rubber parts in the fuel system of vehicles. The Air Resources Board directed their staff to study this issue. The CARB and the Coordinating Research Council (CRC) initiated a 2-year, 10-vehicle testing program to evaluate this issue. On September 20, 2004, CRC issued a detailed report summarizing the results of the testing. [1]

The testing program revealed that ethanol increases permeation emissions from on-road passenger cars and light duty trucks an average of 1.4 grams per day (g/day) per vehicle as compared to an MTBE fuel, under the test conditions of a diurnal temperature of 65º F to 105º F. The testing also found that this increase in permeation VOC emissions is sensitive to ambient temperature. At lower ambient temperatures, the increase in emissions due to ethanol is lower, so this indicated a need to correct for any differences in the ambient and test temperatures when estimating the increase in emissions.

## 3.2 AIR Permeation Study for API

Recognizing that the CRC data and report would be released, and desiring to determine the inventory impacts of expanding ethanol use, the American Petroleum Institute (API) contracted with AIR, Inc. to determine, based on the CRC on-road data, and other data that is available, the impact of ethanol on permeation emissions for on-road vehicles, off-road equipment, and portable containers. The study was conducted for several different areas of the country, including California, Atlanta, Houston, and the New York/New Jersey/Connecticut area. [2]

The study used the available data, developed temperature correction factors, and estimated the permeation VOC increases in the above geographical areas. For example, in California, the study estimated that ethanol increases permeation emissions from on-road vehicles, off-road sources, and portable containers by 25 tons per day (tpd) in 2003. The study further estimated that ethanol would increase VOC permeation by 24 tons per day in the New York/New Jersey/Connecticut area. These VOC increases are on the order of 5-6% of on-highway State Implementation Plan (SIP) VOC for New York and New Jersey areas.

## 3.3 AIR Study for SEMCOG

AIR also studied various gasoline and diesel fuel options for the Southeast Michigan Council of Governments. [3] SEMCOG evaluated a number of fuel options, including RFG with ethanol, RFG without ethanol, 100% RFG in conventional gasoline, and other options. The methods used to estimate permeation emissions were consistent with the API report, and the NOx effects of ethanol were estimated with the California Predictive Model. This study found that RFG without ethanol would have larger VOC benefits than RFG with ethanol, due to lower permeation VOC emissions. The study also found that RFG with ethanol would increase NOx over Michigan baseline fuel, and that using ethanol fuel blends in 100% of Michigan's gasoline would increase both NOx and VOC. The state of Michigan is currently considering using lower RVP fuels as a more cost-effective means to further reduce VOC emissions versus using ethanol blends.

### 3.4 California ARB Draft Study on Ethanol

The California Air Resources Board recently released a draft study of the effects of ethanol in California. [4] Similar to the AIR study for SEMCOG, ARB estimated the permeation effects for on-road vehicles, off-road equipment, and portable containers. ARB also estimated NOx impacts for on-road vehicles. This draft study concluded that ethanol increases VOC by 45-75 tpd, and that NOx increases by 21 tpd in California with ethanol blends as compared to using MTBE blends.

### 3.5 California Air Resources Board Test Programs on Portable Containers

There is no specific ARB report on permeation of portable plastic fuel containers with and without ethanol, however, ARB has performed a number of tests with its certification fuel, which contains MTBE, and fuel containing 6 % ethanol. The data, which was obtained by AIR, Inc, is shown in Table 12 of the API study referenced earlier. [2] Basically, a number of different portable containers were tested, and the average size was about 3.3 gallons. The average emission rate on MTBE fuel was 4.7 g/day, and on fuel containing ethanol was 6.6 g/day, for an increase in VOC emissions of about 39%.

# 4.0 Methods

This section discusses the methods used to estimate emission impacts of converting to ethanol use in Massachusetts's RFG program.

## 4.1 Fuel Cases

Two fuel cases are being evaluated in this study, as follows:

#1: Baseline RFG with 10% MTBE
#2: RFG with 10% ethanol

Detailed fuel properties for both of these fuel cases are developed in Section 5. In this study, the gasoline sales in the state of Massachusetts are assumed to be fully switched from MTBE to ethanol in calendar year 2007.

## 4.2 Pollutants and Evaluation Years

This study evaluates VOC, CO, and NOx emissions from on-road gasoline vehicles, off-road gasoline equipment, and portable gasoline containers. There are not expected to be any particulate matter (PM) differences between the two fuels. The evaluation year is 2007.

## 4.3 Models Used

This analysis uses the EPA MOBILE6.2 model for MTBE emissions for on-road sources, and the California ARB Predictive Model to adjust the exhaust emissions from gasoline vehicles for 10% ethanol effects. Non-ethanol permeation evaporative emissions from on-road sources are estimated with MOBILE , but do not change between MTBE and ethanol RFG because the fuel RVP is assumed to be the same in both cases (this is discussed in Section 5.0).

For off-road equipment and off-road vehicles, this analysis uses the EPA NONROAD model for both the MTBE and ethanol related emissions for off-road equipment and off-road vehicles. Unlike the MOBILE model, the NONROAD model can be used for both cases, because the exhaust emissions of off-road equipment and vehicles are generally not equipped with catalytic converters, oxygen sensors and other equipment that is sensitive to differences in oxygenates. These exhaust emissions of these sources generally only respond to changes in oxygen concentration, not the type of oxygen.

Since neither the MOBILE nor NONROAD models include the effects of ethanol permeation, these effects had to be developed outside the models. These emission impacts were developed in a manner consistent with AIR's analysis for both API and SEMCOG, discussed earlier. The ethanol permeation impacts are discussed in more detail in Section 6.

4.4 Vehicle Miles Traveled for On-road Vehicles

Vehicle miles traveled for 2007 was determined from EPA's NMIM model, and are shown in Table 1 below. [5]

| Table 1. Vehicle Miles Traveled (million miles per year) in 2007 | | | |
|---|---|---|---|
| LDGV | LDGT12 | LDGT34 | HDGV |
| 32.328 | 12,184 | 4,580 | 1,371 |

4.5 On-road Vehicle, Off-road equipment, and Container Populations

On-road vehicle, off-road equipment, and container populations for Massachusetts for calendar year 2007 are needed to estimate permeation impacts from each of these sources.

On-road vehicle populations for estimating permeation impacts were determined primarily from data obtained from the Massachusetts SIPs. Data from FHWA state motor vehicle registrations for automobiles, and the ratio of other gasoline on-road vehicles to automobiles in the MOBILE6.2 emissions model. [6,7] were also used. Off-road equipment and vehicle populations were determined directly from EPA's NONROAD model. The NONOAD model does not include portable container populations, but ARB's OFFROAD model includes both off-road equipment and portable container populations, and the percent of portable containers to gasoline equipment for the state is 47.3%**.** For this analysis, portable container populations in Massachusetts were determined by estimating the off-road gasoline equipment populations from the NONROAD model, and applying the ratio of portable containers to off-road gasoline equipment in OFFROAD to the NONROAD populations.

All of the populations for 2007 are shown in Table 2 below.

| Table 2. Source Populations in Massachusetts | |
|---|---|
| Source | Estimated 2007 Population |
| On-road gasoline vehicles (LDGVs, LDGTs, HDGVs) | 4,555,774 |
| Off-road gasoline equipment* | 3,236,052 |
| Portable gasoline containers (plastic only) | 1,531,875 |

*2 stroke and 4-stroke engines

4.6 Other Inputs

AIR assumed a diurnal temperature of 71º F to 96º F. This estimate is commonly used by EPA in estimating emissions on high ozone days. While Massachusetts episodic temperatures may be slightly different, the relative impacts of the switch from MTBE to ethanol would not be significantly different at a somewhat different temperature.

## 4.7 Method of Combining Model Results

As noted above, the fuel options affect 3 major sources: on-road vehicles, off-road equipment and vehicles, and portable containers. This study examines the effects from all three sources. The general equation used to estimate these effects is the following:

Total effect = On-road effect + off-road effect + portable container effect

Where:

Onroad effect = Exhaust effect + Evaporative effect + permeation effect
Off-road effect = Same as on-road, but for off-road sources
Portable container effect = Permeation effect

And where:

Exhaust effect from onroad vehicles = MOBILE6.2 exhaust baseline * % Change from Predictive Model
Evaporative effect from onroad vehicles = change in evaporative emissions as estimated by MOBILE6.2 directly
Permeation effect from onroad vehicles = method used by AIR in API permeation study

Exhaust effect from off-road vehicles = estimated by EPA NONROAD model
Evaporative effect from off-road vehicles = estimated by EPA NONROAD model
Permeation effect from off-road vehicles = method used by AIR in API permeation study

Permeation effect from portable containers = method used by AIR in API permeation study

## 5.0 Massachusetts Fuel Characteristics - 2007

Detailed fuel property estimates for the two fuels are shown in Table 3. The information for the baseline MTBE was based on survey data published by the EPA. [8] Ethanol RFG properties were derived from the MTBE fuel property data for Springfield and Boston-Worcester, with the exception of the T50 level (temperature as which 50% of fuel is distilled), which was derived from the value for Connecticut, which has ethanol. Most of the other properties are not expected to change from the levels found in current gasoline containing MTBE in Massachusetts (properties that are expected to change are shown in **bold** type).

**Table 3. Fuel Properties for Baseline and Ethanol Gasoline in Massachusetts**

| Property | MTBE RFG | Ethanol RFG |
|---|---|---|
| **Oxygen (wt %)** | **2.10** | **3.4** |
| Benzene (vol %) | 0.64 | 0.64 |
| RVP (psi) | 6.86 | 6.86 |
| Aromatics (vol %) | 22.0 | 22.0 |
| Sulfur (ppm) | 30 | 30 |
| Olefins (vol %) | 11.90 | 11.90 |
| **T50 (ºF)** | **204** | **210** |
| T90 (ºF) | 321 | 321 |
| **MTBE (vol %)** | **9.8** | **0.0** |
| **Ethanol (vol %)** | **0** | **10.2** |
| **TAME (vol %)** | **1.79** | **0.0** |

The above fuel property data was inputted into the ARB Predictive Model. As indicated in the SEMCOG report, the Predictive Model estimates the change in emissions of any gasoline versus a reference gasoline, so procedures developed in the SEMCOG analysis were used to compare the two fuels in Table 3 to each other. The changes in exhaust VOC and NOx emissions are shown in Table 4.

**Table 4. Predictive Model Results (% change from MTBE to Ethanol)**

| Pollutant | % Change |
|---|---|
| Exhaust VOC | +0.7% |
| Exhaust NOx | +5.0% |

As noted in Table 4, the switch from MTBE to ethanol is expected to increase VOC by 0.7% and NOx by 5.0% in on-road gasoline vehicles.

# 6.0 Permeation VOC Emissions

A recent extensive testing program conducted by the Coordinating Research Council shows that ethanol blends increase permeation VOC emissions from on-road vehicles by about 65% as compared to a MTBE blended fuel. Also, data from the California Air Resources Board shows that permeation VOC emissions also increase for off-road equipment, and portable containers used to store gasoline for off-road equipment and off-road vehicles. Based on the studies to date, the increase in permeation VOC's is a phenomena that is unique to ethanol blends and not other oxygenates such as ethers or MTBE. In fact, of the three fuels tested in the CRC study, MTBE blends had the lowest permeation emissions and were about 15% lower that the straight hydrocarbon blend, but this difference between MTBE blends and straight hydrocarbon is not conclusive since it fell within the statistical accuracy of the study data. Based on these results, using ethanol in the gasoline apparently increases the gasoline's solvency action on the non-metallic materials in contact with the fuel, which then contributes to higher permeation of the gasoline components through these materials as more VOC emissions into the atmosphere.

The permeation effects of ethanol in this report are based on the results from the CRC study, and utilize the estimation methods developed in the study by AIR for the American Petroleum Institute (API). [2] Generally, the ethanol permeation impacts are a function of the population of the various sources (on-road vehicles, off-road equipment and vehicles, and portable containers), the ethanol permeation increase for each type of source, and the temperature correction factors for this permeation increase. The AIR study developed all these inputs for California, Atlanta, Houston, and the New York/New Jersey/Connecticut areas, but the same techniques have been applied in Massachusetts.

Permeation increases due to ethanol for various sources are shown as grams per day per unit of source (g/day/unit) in Table 5. These emission increases are for a 65-105º F test procedure with an average temperature of 85º F, and are corrected to 83.5º F, which is the midpoint temperature of 71º to 96º F.

| Table 5. Permeation VOC Increases for Various Sources due to Ethanol | | |
|---|---|---|
| Source | Model Year Group | VOC Permeation Increase (g/day/unit) |
| On-road gasoline vehicles | Pre-1991 | 2.03 |
| | 1991-1995 | 0.86 |
| | Enhanced evap (phase-in schedule varies by vehicle class) | 0.80 |
| | Tier II evap (phase-in schedule varies by vehicle class) | 0.43 |
| Off-road gasoline equipment | All | 0.40 |
| Recreational vehicles and recreational marine | Pre-2008 | 0.40 |
| | 2008+ | 0.123 |
| Plastic portable fuel containers | All | 1.86 |

The values in Table 5 were developed on CRC tests that used E6 (6 volume % ethanol blend), instead of E10 (10 volume % ethanol blend), which will be used in Massachusetts. Assuming that permeation is a function of the ethanol content in the fuel, it is possible that this assumption could understate the ethanol permeation impact. While further testing of E10 is planned by the Coordinating Research Council, this analysis also estimated the emission impact as if the permeation impact is proportional to ethanol concentration in the gasoline. For the sensitivity case, permeation emissions were assumed to be 66% higher (10% / 6%) because of the use of E10, instead of E6 in Massachusetts.

# 7.0 Results

## 7.1 Baseline Inventories

Baseline air pollutant inventories for on-road and off-road VOC, CO, and NOx emission are shown in Table 6. This inventory summary does not include the portable container VOC inventory in the baseline, because this analysis is only estimating the increase in VOC emissions by adding the increase in permeation emissions from containers and vehicle fuel systems due to ethanol being added to the fuel.

**Table 6. 2007 Massachusetts Gasoline Vehicle and Gasoline Fueled Equipment Inventories (tpd - tons per day)**

| Source | Exhaust VOC | Evaporative VOC | CO | NOx |
|---|---|---|---|---|
| On-road gasoline vehicles | 37.0 | 58.4 | 1015.6 | 100.1 |
| Off-road gasoline equipment and off-road gasoline vehicles | 36.3 | 5.5 | 561.0 | 5.4 |
| Total mobile, gasoline | 73.3 | 63.9 | 1576.6 | 105.5 |

The baseline inventory is 137.2 tpd of VOC, 1576.6 tpd of CO and 105.5 tpd of NOx. These inventories may be somewhat different than the SIP inventories estimated by the state, because the state follows a much more detailed EPA approved procedure for estimating local inventories. However, the estimates developed in this study are sufficiently accurate since the focus of this analysis is on the "relative difference" in inventories due to a switch from MTBE to ethanol in the gasoline.

## 7.2 Emission Changes Due to Ethanol

### 7.2.1 On-Road Vehicles

On road VOC, CO, and NOx gasoline vehicle inventories in 2007 with MTBE and ethanol are shown in Table 7.

**Table 7. On-Road Gasoline Vehicle Inventories in Massachusetts (tons per ozone episode day)**

| Pollutant | MTBE | Ethanol | Difference |
|---|---|---|---|
| Exhaust VOC | 37.0 | 37.3 | +0.3 |
| CO | 1015.6 | 1015.6 | 0.0 |
| NOx | 100.1 | 105.1 | +5.0 |

The exhaust VOC and NOx inventory increases are estimated by applying the percent increases in Table 4 by the MTBE inventories above. The CO inventory does not change, because the MOBILE model does not differentiate between RFG with MTBE and RFG with ethanol. The non-permeation related evaporative emissions also do not change because the RVPs are assumed to be the same in either case.

### 7.2.2 Off-road Vehicles

Off-road vehicle and equipment inventories in 2007 in Massachusetts on MTBE and ethanol fuels are shown in Table 8. The results show that ethanol will reduce VOC by 1.0 tpd and CO by 57.7 tpd, but that NOx will increase by 0.7 tpd. The reductions in HC and CO are due to the greater wt % of oxygen with ethanol at 10 volume % than with MTBE (3.4% as opposed to about 2.1%).

**Table 8. 2007 Massachusetts Inventories for Off-road Vehicles and Off-Road Equipment (gasoline-fueled only, tons per day)**

| Pollutant | MTBE | Ethanol | Difference |
|---|---|---|---|
| VOC | 41.8 | 40.8 | -1.0 |
| CO | 561.0 | 503.3 | -57.7 |
| NOx | 5.4 | 6.1 | 0.7 |

### 7.2.3 Permeation VOC Impacts

The permeation VOC impacts from using ethanol are shown in Table 9. The first estimate assumes that the permeation impacts in Massachusetts with 10% ethanol are the same as with 6% ethanol. The other assumption is that the permeation impact is proportional to ethanol concentration. Overall, VOC emissions in Massachusetts will increase by 8.4-14.0 tpd due to the permeation effects of ethanol.

**Table 9. Massachusetts Ethanol Permeation VOC Impacts (tons per day)**

| Source | Based on 6% testing | Proportional to concentration @ 10% |
|---|---|---|
| On-road gasoline vehicles | 3.86 | 6.43 |
| Off-road gasoline vehicles and off-road gasoline equipment | 1.43 | 2.38 |
| Portable gasoline containers | 3.14 | 5.23 |
| Total | 8.43 | 14.04 |

### 7.2.4 Summary of Impacts

The summary of ethanol impacts is shown in Table 10.

**Table 10. Overall Impacts of Ethanol RFG in 2007**

| Pollutant | Baseline Inventory – Gasoline (tons per day) | Net Ethanol Impact (tons per day) | % Change |
|---|---|---|---|
| VOC | 137.2 | +7.7 to +13.3 | +5.6% to 9.7% |
| NOx | 105.5 | +5.7 | +5.4% |
| CO | 1576.6 | -57.7 | -3.7% |

If Massachusetts switches from a 10% MTBE RFG blend to a 10% ethanol RFG blend, mobile source VOC will increase by 5.6% to 9.7% and NOx will increase by 5.4%. CO will be reduced by 3.7%, but the CO reductions cannot be used to mitigate the VOC and NOx increases.

# 8.0 Discussion

This study shows that switching from RFG with MTBE to RFG with ethanol in Massachusetts will increase mobile source VOC emissions by 6 to 10% and NOx emissions by 5.4%. Since the state has been experiencing ozone exceedences with the new more stringent 8-hour ozone standard, these increases in emissions will likely need to be offset by emission reductions from other sources for the state to attain and then maintain the 8-hour ozone standards.

The following discussion expands on some of the uncertainties in this analysis.

## 8.1 VOC Emissions Impact

The range in VOC impacts of 6% to 10% increases comes from the uncertainty in the impact of 10% ethanol blends on permeation emission increases. The 6% figure assumes that the permeation increases are the same at 10 vol % ethanol as at 6 vol % ethanol which is the ethanol concentration used in the CRC permeation study. The 10% increase assumes the permeation increase is proportional to ethanol concentration in the gasoline. The Coordinating Research Council is conducting further testing of 10% vol ethanol blends, and the results of this study should be available later this year.

This analysis also assumes that all vehicles traveling in Massachusetts are filled with RFG blends using ethanol that is sold in Massachusetts. In fact, some vehicles from Massachusetts will regularly travel to surrounding states, and then sometimes fill up with non-ethanol containing gasoline, before returning to Massachusetts. Similarly, non-Massachusetts vehicles will travel into Massachusetts from outside the state, and these vehicles will also perhaps have non-ethanol containing fuel in their tanks. If these vehicles never fill up with gasoline sold in Massachusetts, then these vehicles with non-ethanol containing gasoline will not have an ethanol related permeation increase. However, vehicles which travel back and forth in and out of Massachusetts and then sometimes fill up with Massachusetts gasoline containing ethanol and at other times fill up with non-ethanol containing gasoline, will suffer increased emissions due to "commingling." Commingling of ethanol and non-ethanol fuels with the same RVP results in a fuel mixture that has a higher RVP, which thereby increases evaporative emissions. Commingling has been assumed to be zero in this analysis.

The permeation VOC emission increases from off-road equipment in this analysis are based on lawnmowers. Lawnmowers have relatively small fuel tanks compared to other off-road equipment and vehicles. It is likely that the permeation impacts for off-road equipment are actually higher than estimated in this analysis; in fact, California ARB estimates a higher permeation VOC impact for off-road equipment.

## 8.2 NOx Emissions Impacts

The on-road NOx impacts of ethanol are based on the current ARB Predictive Model. The Coordinating Research Council has completed additional testing of the effects of ethanol on NOx emissions, and ARB plans to update its Predictive Model based on this testing later this year. The off-road NOx impacts are based on EPA's NONROAD model; no updates to this model for the NOx impacts are expected.

## 9.0 References


1. “Fuel Permeation from Automotive Systems, Final Report,” Harold Haskew and Associates, and ATL, CRC Project E-65, September 2004.

2. “Effects of Gasoline Ethanol Blends on Permeation Emissions Contribution to VOC Inventory From On-Road and Off-Road Sources”, AIR, Inc. for API, March 3, 2005.

3. “Emission Reductions from Changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area”, AIR, Inc. for Southeast Michigan Council of Governments, Alliance of Automobile Manufacturers, and the American Petroleum Institute, February 23, 2005.

4. “A Summary of the Staff’s Assessment Regarding the Effect of Ethanol in California Gasoline on Emissions”, Draft Report, February 2005, California Air Resources Board.

5. “EPA’s National Mobile Inventory Model (NMIM), A Consolidated Emissions Modeling System for MOBILE6 and NONOROAD”, EPA420-R-05-003, March 2005.

6. “State Motor Vehicle Registrations – 2003”, FHWA, October, 2004.

7. “Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates, and Projected Vehicle Counts for Use in MOBILE6”, EPA420-R-01-047, September 2001.

8. “RFG Property and Performance Averages for Springfield County and Boston-Worcester, Massachusetts”, U.S. EPA, www.epa.gov/otaq/fuels/rfg/properf/srpingma.htm.

## Background on Air Improvement Resource, Inc.

Air Improvement Resource was founded in 1994, and conducts emissions, ambient air quality, and meteorological related research for a variety of industrial and governmental concerns. AIR has four employees, and is located near Detroit, Michigan. AIR is most widely known for its work on many projects with the two Federal and two California on-road and off-road emissions models. Recent projects include:

- Analyzing carbon monoxide emissions data on certification vehicles to determine impacts of cold temperatures (Coordinating Research Council)
- Estimating the emission changes associated with different fuels in the Southeast Michigan Area (SEMCOG, Alliance of Automobile Manufacturers, and American Petroleum Institute)
- Analysis of the emission inventory impacts of ethanol permeation (American Petroleum Institute)
- Analysis of the impact of MMT in gasoline in emissions in the U.S. and Canada (Alliance of Automobile Manufacturers and Canadian Vehicle Manufacturers Association)
- Revisions to the ARB OFFROAD Emissions Model (California Air Resources Board)
- Revisions to the EPA NONROAD Emissions Model (Environmental Protection Agency)
- Evaluation of options for meeting California's Phase 3 Exhaust and Evaporative Emission Standards for Small Gasoline Off-road Engines (Briggs and Stratton Corporation, and Engine Manufacturers Association)
- Ongoing evaluation of the EPA MOVES Model (Alliance Of Automobile Manufacturers)
- Evaluation of New ARB On-road EMFAC Model (Alliance of Automobile Manufacturers, and Engine Manufacturers Association)

The three technical employees of AIR are Tom Darlington, Dennis Kahlbaum, and Jon Heuss. Tom Darlington is an engineer with 25 years developing emission models, with experience at the EPA, Detroit Diesel Corporation, General Motors, and as a consultant. Dennis Kahlbaum is a meteorologist/ computer programmer with 25 years experience programming emission models, analyzing meteorological and emission data, and forecasting weather trends, with experience at Computer Sciences Corporation (for EPA), Consumers Energy Corporation, and AIR. Jon Heuss is a Principal Scientist with 40 years experience at General Motors who has played a major role in the review of the national and state ambient air quality standards. More information on the company can be found at "airimprovement.com."