**PROGRAM REPORT :**

# EMISSION IMPACTS OF FUELS TO ACCOMMODATE THE NEW YORK STATE OXY-WAIVER REQUEST AND MTBE BAN

**New York State Department of Environmental Conservation**
**Division of Air Resources : Bureau of Mobile Sources**
**Automotive Emissions Laboratory**

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## EXECUTIVE SUMMARY

In view of an upcoming ban on the use of methyl tertiary butyl ether (MTBE) in gasoline in New York State and extensive debate in Congress over the introduction of renewable fuels and the future of the oxygenate requirement in reformulated gasoline (RFG), the New York State Department of Environmental Conservation (DEC) conducted a study of tailpipe emissions from in-use vehicles. This study suggests that oxygenates added to gasoline produce no air quality benefits; thus, there is no need to continue requiring oxygenate in gasoline.

New York State law bans the use of MTBE in gasoline beginning January 1, 2004, due to concerns of the impacts of MTBE in gasoline spills. MTBE has been used in the New York City Metropolitan Area (NYCMA) to satisfy the requirement of the 1990 Clean Air Act Amendments that severe non-attainment areas must use reformulated gasoline that is at least 2 percent oxygen by weight. However, that oxygenate requirement predates the large-scale introduction of motor vehicles with modern computerized engine control systems. Staff of the DEC Automotive Emissions Laboratory (AEL) hypothesized that the fuel management systems in vehicles in current use would adjust engine function to compensate for the additional oxygen in the fuel, thus negating any previous benefit from the oxygenate.

This study looked at previous studies conducted by other researchers, and a test program conducted at AEL. The emissions date from these studies led DEC to conclude that no significant tailpipe emissions increases could be attributed to fuel changes when MTBE was replaced by ethanol, or when no oxygenate was present in the fuel. AEL also looked at on-board diagnostics (OBD II) data generated during the test program, and concluded that modern computer controls adapt to the residual oxygen content in the exhaust, and adjust fuel delivery to maintain proper catalyst function. The research supports the hypothesis that adding an oxygenate is unnecessary.

DEC has already requested that the United States Environmental Protection Agency (EPA) waive the RFG oxygenate requirement for NYCMA. This study will be submitted as part of the ongoing review of that waiver request. If approved, NYCMA equivalent RFG could be produced without any oxygenate additive. Without this waiver, ethanol will likely be used as an oxygenate, as it is in other RFG areas in the country. In some of these areas EPA has granted a relaxation of the VOC evaporative standards for ethanol blends. DEC estimates a 4.4 ton per day increase in mobile source VOC evaporative emissions if this occurs in New York.

## SCOPE

This paper is limited to a discussion of the vehicle emissions aspects of an MTBE[1] ban in New York State. The distribution of fuels and oxygenates, economic impacts, water quality concerns and other critical issues important to a full assessment of the New York MTBE ban are not discussed here.

## INTRODUCTION

New York State legislation has made the use of MTBE in gasoline illegal after January 1, 2004, due to concerns regarding water quality. The 1990 Clean Air Act Amendments require the New York City metropolitan area (NYCMA) to use a reformulated gasoline (RFG) that is at least 2% by weight (wt.%) oxygen. Currently, almost all RFG sold in the NYCMA contains MTBE as an oxygenate. The pending New York MTBE ban would require a substitute oxygenate to satisfy the federal oxygenate requirement, and to replace octane contributed by MTBE. At present, only ethanol can be produced in sufficient quantity to serve as an oxygenate substitute for MTBE in NYCMA RFG. Ethanol, however, also poses risks to air and water quality that had previously prompted the New York State Department of Environmental Conservation (DEC) to seek alternatives to ethanol use in gasoline.

To avoid the environmental risks posed by ethanol as an MTBE substitute, DEC has requested that EPA waive the NYCMA RFG 2 wt.% oxygen requirement. If EPA approves the waiver request, NYCMA "equivalent" RFG (ERFG)[2] could be produced without an oxygenate additive (or, at least, with less added oxygenate) so long as the non-oxygenated ERFG meets all other RFG performance standards. EPA, however, denied a similar oxygenate waiver request by California.

As part of the DEC effort to assess the air quality impact of an MTBE ban, vehicular exhaust emission testing with MTBE RFG, ethanol RFG, and a non-oxygenated ERFG was conducted at the DEC Automotive Emissions Laboratory (AEL).

## INDUSTRY FUEL STUDIES

### Auto/Oil Study and the Complex Model

Much of the research on oxygenated gasoline emissions effects occurred during the development and implementation of federal RFG rules in the 1990 Clean Air Act Amendments. During the early 1990s, the automotive and oil industries conducted a multimillion dollar research effort known as the Auto/Oil Air Quality Improvement Research Program (Auto/Oil). At about the same time, EPA also conducted a series of large scale research projects.

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1 See Table of Acronyms at end of text.

2 The term "RFG" has become synonymous with "federal RFG", which is an RFG formulation with a minimum 2 wt.% oxygen as prescribed by the 1990 Clean Air Act Amendments for ozone nonattainment areas. Consequently, "non-oxygenated RFG" may be inappropriate terminology and we therefore introduce the term "equivalent" RFG (ERFG) to describe the non-oxygenated fuel used in this study.

Studies regarding the choice of oxygenate and the effect and oxygen content on emissions were but small portions of these research projects, yet generated most of the data for development of the EPA Complex Model that is used to demonstrate fuel compliance with RFG rules. Consistent with Clean Air Act requirements, these studies were limited primarily to 1990 and earlier technology vehicles.

### Alliance of Automobile Manufacturers Study

One of the few recent oxygenated fuel studies was conducted by the Alliance of Automobile Manufacturers (AAM) in response to California regulatory initiatives, including the California MTBE ban. The AAM research encompassed both oxygenates and fuel sulfur content. The AAM study attempts to identify the effects of the chemicals (MTBE and ethanol). This is common for fuel effects studies. Although more cars were tested by AAM, only 5 were tested on all 3 fuels.

AAM research employed three test gasolines: (1) a non-oxygenated gasoline used as a base fuel; (2) a 2 wt.% oxygen MTBE gasoline produced by blending 11% by volume MTBE to the base non-oxygenated fuel; (3) a 4 wt.% gasoline produced by blending 11% by volume ethanol to the base non-oxygenated fuel. Except for the added oxygenate, the gasoline composition was identical for each test fuel, thus differences in emissions among the test fuels should have been due to differences in the oxygenates and resultant oxygen content.

Because AAM was attempting to identify chemical specific emissions effects, none of the test gasolines in this study would have met the Complex Model VOC and toxics reduction properties of RFG currently sold in the NYCMA. DEC reanalyzed this data to treat each vehicle as an individual, similar to the treatment of the vehicles in the DEC study described below.

DEC analysis of these 5 cars data shows both oxygenated AAM fuels reduced CO emissions compared to the base AAM fuel. Neither MTBE nor ethanol as an oxygenate was consistently superior to the other. Comparison of engine out emissions (before the catalytic converter) to tailpipe emissions suggested that catalytic converter CO removal efficiency increased with oxygenated fuels relative to the base fuel.

## DEC AEL TEST PROGRAM

### *Overview of the DEC AEL Test Study*

To evaluate potential vehicular emission impacts associated with an MTBE ban, AEL conducted an emission testing study in late 2002. The study employed two high mileage (120,000 and 155,000 miles) DEC light-duty fleet vehicles: a 1998 Plymouth Breeze and a 1997 Oldsmobile Achieva. Three RFG test fuels were formulated for and used in this study : an MTBE RFG; an ethanol RFG; and a non-oxygenated ERFG. Federal certification fuel (cert fuel) was also used in this study as a reference fuel, with cert fuel testing preceding the first RFG fuel test and following the last RFG fuel test for each vehicle. On each day of testing, six emissions tests, using six different emission test cycles, were performed on one test vehicle. A total of 245 valid emission tests were conducted over the course of this study. One cycle was rejected due to a miss-start at the beginning of FTP Bag 1 on the Plymouth Breeze.

## Test Fuels

All study test fuels were supplied by Chevron Phillips. Test fuel analyses are provided in Appendix A. All study fuels met the federal 30 ppm sulfur requirement to be implemented in 2004. The MTBE RFG was specified to otherwise represent typical year 2000 NYCMA RFG. The ethanol RFG and non-oxygenated ERFG test fuels were specified to have Complex Model performance similar to the study MTBE RFG. No other restrictions or specifications were imposed on the fuel supplier. AEL believes the study fuel specifications approximate the fuel blending situation that refiners will face upon implementation of the NY MTBE ban.

## Emissions Testing Protocol and Instrumentation

The emissions testing protocol required the following vehicle preparation steps before testing: fuel tank draining; fuel changeover; evaporative canister substitution; and catalyst desulfurization. Fuel drains were installed either through the fuel vent lines or by replacing the drain plug with a connection to AEL fuel drain equipment. The evaporative canisters were disconnected from the air inlet at the purge valve connection and were then sealed. A new, unused canister was connected to the purge valve to ensure the correct pressure/vacuum signal was present for the OBD-II system to read.

After completing the initial fuel tank draining and canister substitution, vehicles were fueled with certification fuel and driven on the AEL chassis dynamometer for system/vehicle checks and catalyst desulfurization. Catalyst desulfurization was accomplished by driving to fully warm the engine and exhaust system and next running multiple repeats of the FTP Bag 1, followed immediately by at least six wide open throttle accelerations up to 80 mph.

Following catalyst desulfurization, study vehicles were emission tested on the AEL light-duty chassis dynamometer. Each vehicle was tested on all four fuels in the following order: (1) cert fuel; (2) MTBE RFG; (3) non-oxygenated ERFG; (4) ethanol RFG; (5) cert fuel. Four days testing was conducted on each vehicle with each fuel (5 days testing on ethanol for the Achieva). Each day of testing included six emission test driving cycles: FTP Bag1, FTP Bag2, FTP Bag3, the Highway Fuel Economy Test (HFET), the New York City Cycle (NYCC), and the Supplemental FTP (SFTP) US06.

Gaseous exhaust emissions were measured by both bag sample and realtime sample emission instrumentation systems. OBD-II scan hardware and software was used to monitor engine and engine/emission control systems in real time during emission testing. The OBD-II scanner recorded numerous parameters, including: throttle position; spark advance; lambda sensor voltage; short term fuel trim; and long term fuel trim.

## Results and Discussion

Data from over 200 emission tests on the two vehicles in this study do not indicate any consistent (*i.e.*, across both vehicles) increase in any of the regulated emission species (HC, CO, NOx) or in $CO_2$ emissions for either the ethanol oxygenated RFG or the non-oxygenated ERFG relative to the MTBE oxygenated RFG. The possibility exists, however, that such emission increases may have been masked by confounding factors in this study and that such emission increases may occur in other real-world vehicles.

Inasmuch as the three study RFGs were specified to meet the same EPA Complex Model RFG emission targets, extreme differences in exhaust emissions among the study RFGs would not be expected, and differences may not be due to the different oxygenate or lack of oxygen in the fuel.

Both test vehicles were tested on certification fuel at the start and end of each vehicle testing period. Significant variations in initial and final cert fuel emissions were often observed, thus complicating assessment of fuel composition effects on emissions. Appendix B provides a qualitative and quantitative summary of specific fuel comparison emission difference observations. DEC cautions that the emissions data from these two vehicles can not **and** should not be extrapolated to an entire fleet.

### Engine Control System Monitoring

A key aspect of the AEL study was the evaluation of engine control system response to changes in fuel properties. To this end, realtime OBD-II data were collected, analyzed, and evaluated. Appendix C presents typical results for both vehicles.

Study OBD-II data indicate that engine control systems in both vehicles always attempted to maintain closed-loop operation, with the air/fuel ratio (AFR) constantly oscillating slightly above and below the stoichiometric AFR (dithering) to optimize and maintain catalyst function. Differences in test fuel oxygen content effected changes in engine control system signals, especially the long term fuel trim and AFR dithering.

Analysis of the OBD II data showed that both vehicles control systems operated to maintain proper 3-way catalyst operation regardless of fuel oxygen content. The control systems achieve residual oxygen levels that are independent of the oxygen content of the fuel. See Appendix C for an expanded discussion of the OBD II data analysis.

## NON-EXHAUST EMISSIONS[3]

### Complex Model Treatment of the Non-Exhaust Emissions

The Complex Model is used to determine fuel compliance with RFG regulations re tailpipe emissions, but also contains a non-exhaust component that models evaporative emissions, running losses, and refueling losses. The Complex Model, however, does not model resting losses, fuel leakage, permeation, and commingling effects. Nor does the Complex Model provide projections for Tier 1, Tier 2, California LEV, or NLEV vehicles or consider on-board vapor recovery systems. Enhanced I/M with purge and pressure checks and gasoline station Stage 2 pump controls, however, are all assumed to be in use in Complex Model projections. Complex Model non-exhaust VOC is influenced only by fuel RVP; consequently, the fuel oxygenate does not directly influence Complex Model projections of evaporative emissions.

The Auto/Oil study and other studies have found that the addition of ethanol to non-oxygenated gasoline increases RVP. Ethanol concentrations typical of RFG increase RVP about 1 psi relative to the base non-oxygenated gasoline. Decreasing the RVP of the base non-oxygenated gasoline can compensate for the RVP increase due to addition of ethanol.
So long as Complex Model generated regulatory emission targets remain constant, RVP driven non-

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[3] AEL is not equipped to perform evaporative emissions testing.

exhaust emission increases are unlikely. However, EPA has relaxed the Complex Model performance targets for 10% ethanol blended RFG in the Chicago/Milwaukee RFG area. If a similar concession were to be made in the NYCMA, a 4.4 ton/day (1% to 2%) increase in mobile source related hydrocarbon emissions is predicted by DEC.

Two additional sources of potential increases in non-exhaust emissions must be addressed: commingling and permeation. Commingling is the mixing of an ethanol blended gasoline with a non-ethanol blended gasoline. As noted above, adding ethanol to gasoline, even in small quantities, increases evaporative emissions. If consumers purchase both ethanol and non-ethanol gasolines, the resultant blending in vehicle fuel tanks would increase evaporative emissions relative to both the ethanol gasoline and the non-ethanol gasoline.

Commingling is most likely if some RFGs contain ethanol and other RFGs do not. If all RFG contains ethanol, commingling will be limited to cases where vehicle owners purchase fuel from conventional, non-RFG, gasoline stations. The magnitude of commingling induced evaporative emission increases cannot be predicted.

Permeation is the physical movement of hydrocarbon molecules through plastic and rubber fuel system components. Permeation ultimately leads to evaporation of hydrocarbons into the ambient atmosphere. The limited published research on permeation suggests that ethanol may increase permeation emissions by a factor of six, which, if true, would translate to 6.1 tons/day of additional evaporative hydrocarbon emissions in the NYCMA ozone nonattainment area as a result of conversion to ethanol RFG in the area.

These concerns were significant factors that led DEC to request an EPA waiver of the NYCMA RFG oxygen content requirement.

## SUMMATION

Within the limitations and caveats cited herein, this study suggests the following:

- Fuel oxygenates are not necessary to achieve the benefits of RFG.
- MTBE and ethanol blended RFGs have very similar exhaust emissions.
- Current technology vehicles use technologically advanced sensors and computers to effectively compensate for most fuel property differences.
- Literature data indicate that ethanol increases non-exhaust emissions by increasing the volatility (RVP) of gasoline, by increasing permeation losses, and through commingling effects.

## TABLE OF ACRONYMS

| | |
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| MTBE | methyl tertiary butyl ether |
| NYCMA | New York City metropolitan area |
| RFG | reformulated gasoline |
| DEC | Department of Environmental Conservation |
| ERFG | equivalent RFG |
| AEL | Automotive Emissions Laboratory |
| Auto/Oil | Auto/Oil Air Quality Improvement Research Program |
| AAM | Alliance of Automobile Manufacturers |
| VOC | volatile organic compounds |
| Cert | certification fuel or gasoline |
| Chevron Phillips | Chevron Phillips Chemical Company |
| ppm | parts per million |
| OBD-II | on-board diagnostics second generation |
| FTP | Federal Test Procedure |
| HFET | Highway Fuel Economy Test |
| NYCC | New York City Cycle |
| SFTP | Supplemental Federal Test Procedure or USO6 |
| AFR | air/fuel ratio |
| LEV | low emission vehicle |
| NLEV | national low emission vehicle |
| RVP | Reid vapor pressure |
| gpm | grams per mile |
| CVS | constant volume sampler |
| RT | realtime |
| CL | confidence Level |
| UCL | upper confidence limit |
| LCL | lower confidence limit |